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MEMS 411: Heavy Cart Ramp Assistant

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Washington University in St. Louis
JAMES MCKELVEY SCHOOL OF ENGINEERING

Mechanical Engineering Design Project
MEMS 411 Group H, Fall 2023

Heavy Cart Ramp Assistant

The goal of this project was to design and build a device or system with the capability of lifting a heavy argon gas tank onto a scale with a short but steep ramp on either end. Dr. Kathy Flores, a research professor in the MEMS department at Washington University in St. Louis, was the customer for the project, and requested that the device meet these criteria: 1) be safe for users; 2) not be permanently affixed to the scale; 3) minimize the number of people required to complete the task, and 4) be portable and easily stored in the lab. From these needs, three performance goals were established. First, the device should decrease the time required to get the tank onto the scale; second, the device should occupy $\leq 9ft^2$ of floor space; and finally, the device should require the user to only exert $\frac{1}{5}$ of the force neccesary without the device.
The general idea was to be able to lift the tank vertically and bypass the ramp completely. With the time, skills, and budget available for this project, it was decided that the most effective device would use an existing car jack as a base to lift the tank, after which additions would be made to transfer the tank from the device to the scale. These additions consisted of carbon steel beams and wedge-shaped blocks made of whitewood.
The device system met all three performance goals. The time to get onto the scale was decreased from 6 minutes to 3 minutes and 3 seconds. In total, the bridge pieces and car jack occupy $5.11ft^2$ of floor space, which fits well within the $9ft^2$ goal. The force required without the device was also decreased by 80%, from ∼100lb to ∼15lb. All in all, this project was successful in helping Dr. Flores find an easier way to get heavy argon tanks onto the weighing scale platform.

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1 Introduction

Dr. Kathy Flores is a lecturer and research professor in the McKelvey School of Engineering's Mechanical Engineering and Materials Science department at Washington University. In her lab, she and her students regularly use argon to create a controlled environment for their experiments. The argon is delivered in large, silver tanks, averaging about five feet tall and two feet in diameter. The tanks are welded onto rectangular carts with wheels to aid in transitioning them from place to place.

Dr. Flores needs to know how much argon is left in a tank at any given time, so new tanks get wheeled onto a short grey scale with a ramp on the front and back ends. However, with the size of the tank and the density of liquid argon, the tanks usually surpass the capacity of the scale, which has a maximum reading of 1000 pounds.

The tanks are estimated to weigh anywhere between 1000-1500 pounds. The researchers in the lab have to exert a great amount of force to roll the tank up the ramp and onto the scale. Dr. Flores has asked us to develop an easier way to achieve this goal. We were tasked with creating a device that a) helps the operator get the tank onto the scale with less effort and b) minimizes the tank's momentum to keep it from crashing into the wall behind the scale.

2 Problem Understanding

2.1 Existing Devices

Exploring existing products in the world serves as a powerful source of inspiration and innovation. When we discover designs that closely align with our project's objectives, these existing solutions become our design's closest competitors, serving as invaluable benchmarks against which we compare our own ideas. This process not only fuels our brainstorming but also challenges us to continually enhance our design. Therefore, learning from what already sells in the market can help us fulfill the needs and expectations of our customer.

2.1.1 Existing Device #1: Manual Pallet Jack by Wesco Industrial Products

Figure 1: Wesco Industrial Products 272744 Standard Manual Pallet Jack

Link: https://www.digitalbuyer.com/wesco-deluxe-adjustable-pallet-truck-272744.html
Description: The Wesco Industrial Products 272744 Standard Manual Pallet Jack is a robust material handling solution designed for industrial and warehouse use, boasting a substantial load capacity of approximately 5500 pounds. This pallet jack accommodates standard pallet sizes, typically 27 inches in width and 48 inches in length, offering versatility for various industry-standard dimensions. Users benefit from its user-friendly controls, comfortable handle, and efficient hydraulic pump mechanism operated via a hand lever for easy lifting and lowering of heavy loads, minimizing physical strain. Safety is a top priority, evident in the inclusion of features like a foot-operated brake for secure parking and load retention mechanisms to prevent unintended lowering of the forks. These safety measures enhance the overall efficiency and safety of material handling operations. Manual pallet jacks, such as the Wesco 272744, play pivotal roles across industries like manufacturing, warehousing, and distribution, aiding in inventory movement, truck loading and unloading, and storage organization.

2.1.2 Existing Device #2: Manual Straddle Stacker from Apollo-Lifts

Figure 2: 2200 lbs Capacity Manual Straddle Stacker

Link: https://handtrucks2go.com/2200-lbs-Capacity-Manual-Straddle-Stacker-63-Lift.html

The Manual Straddle Stacker from Apollo-Lifts is a versatile material handling tool, boasting a typical load capacity ranging from 1000 to 1500 pounds, making it suitable for a wide range of industrial applications. Featuring fork lengths of approximately 42 to 48 inches and widths of around 6 inches, with an overall width between 27 to 30 inches and an overall length spanning 60 to 70 inches, this stacker offers adaptability to handle various load sizes. Its innovative straddle leg design allows it to lift pallets without requiring outriggers, enhancing stability and versatility. Operated manually, the stacker utilizes a hydraulic pump mechanism assisted by a large spring to facilitate lifting. The spring stores potential energy when the operator engages the hydraulic pump, ensuring precise control during lifting and positioning tasks without relying on electrical power. Adjustable forks cater to different load dimensions, promoting efficient handling, while safety features such as brakes, load retention mechanisms, and safety handles prioritize operator well-being. This Manual Straddle Stacker combines robustness, adaptability, and safety, making it a valuable asset for industrial material handling needs.

2.1.3 Existing Device #3: Hand Winch Lifting Crane by Strongway

Figure 3: Strongway Hydraulic Engine Hoist with Load Leveler

Link: https://www.amazon.com/Strongway-Hydraulic-Engine-Hoist-Leveler/dp/B00TIN4W7W

The Strongway Hydraulic Engine Hoist with Load Leveler is a versatile lifting tool, featuring a 2-ton (4000-pound) capacity and an impressive lift range from 1 inch to 82 5/8 inches. Its hydraulic lifting mechanism enables smooth and precise load handling, making it ideal for engine removal, machinery positioning, and various heavy-duty tasks. The hoist is user-friendly, incorporating a load leveler for precise load balancing, ensuring stability and safety during lifting operations. With a sturdy steel frame, telescoping boom, and adjustable legs, it provides stability and support. Users can easily raise and lower loads using the manual winch, making it a valuable asset for professionals and DIY enthusiasts alike, streamlining heavy lifting tasks with efficiency and safety.

2.2 Patents

2.2.1 Portable Engine Hoist (US5261640A)

This patent describes a portable engine hoist that can be folded into a compact storage configuration for convenience. The hoist has a base with caster wheels and elongated feet that extend from it, each equipped with wheels. An upright post extends from the base and supports a lifting beam that can pivot up and down using a mechanical jack. An inclined brace attached to the post carries a cross arm that can be bolted to the feet, providing a sturdy support structure. When needed, the cross arm can be unbolted and pivoted away from the feet, allowing the hoist to be folded up and securely latched for storage.

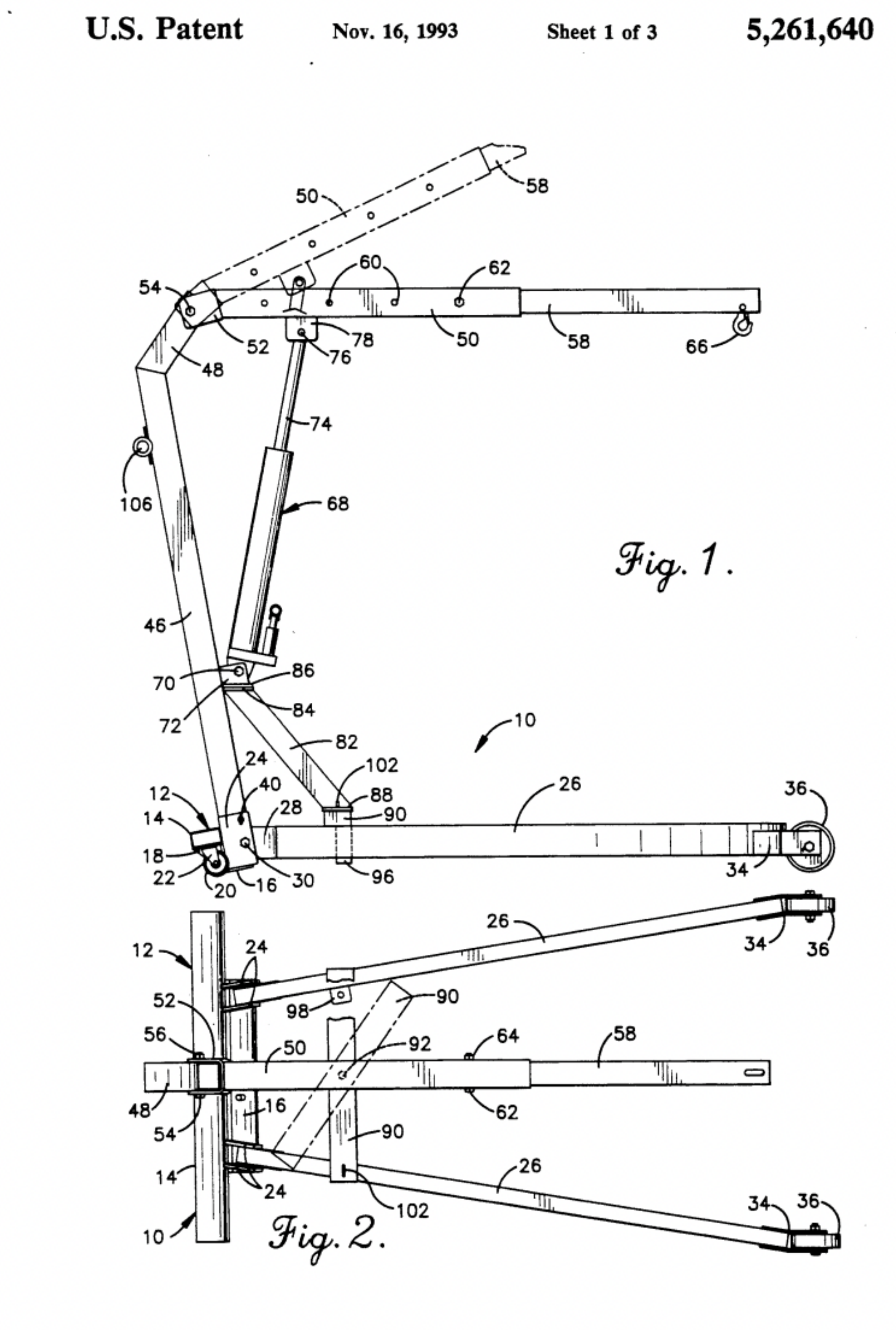


Figure 4: Patent Images for Portable Engine Hoist

2.2.2 Hydraulic Pump (US2851952A)

This patent describes a variable delivery hydraulic pump featuring multiple pairs of interconnected cylinders with pistons. These pistons are driven by a common shaft through eccentric sheaves, and adjusting the shaft's position alters the eccentric sheaves' relative rotation, controlling the pump's volumetric output. The invention incorporates damping mechanisms, including a dashpot, to stabilize and precisely control axial shaft movement. This hydraulic pump design offers high-pressure operation, excellent volumetric efficiency, and the ability to finely adjust liquid delivery rates from zero to maximum capacity.

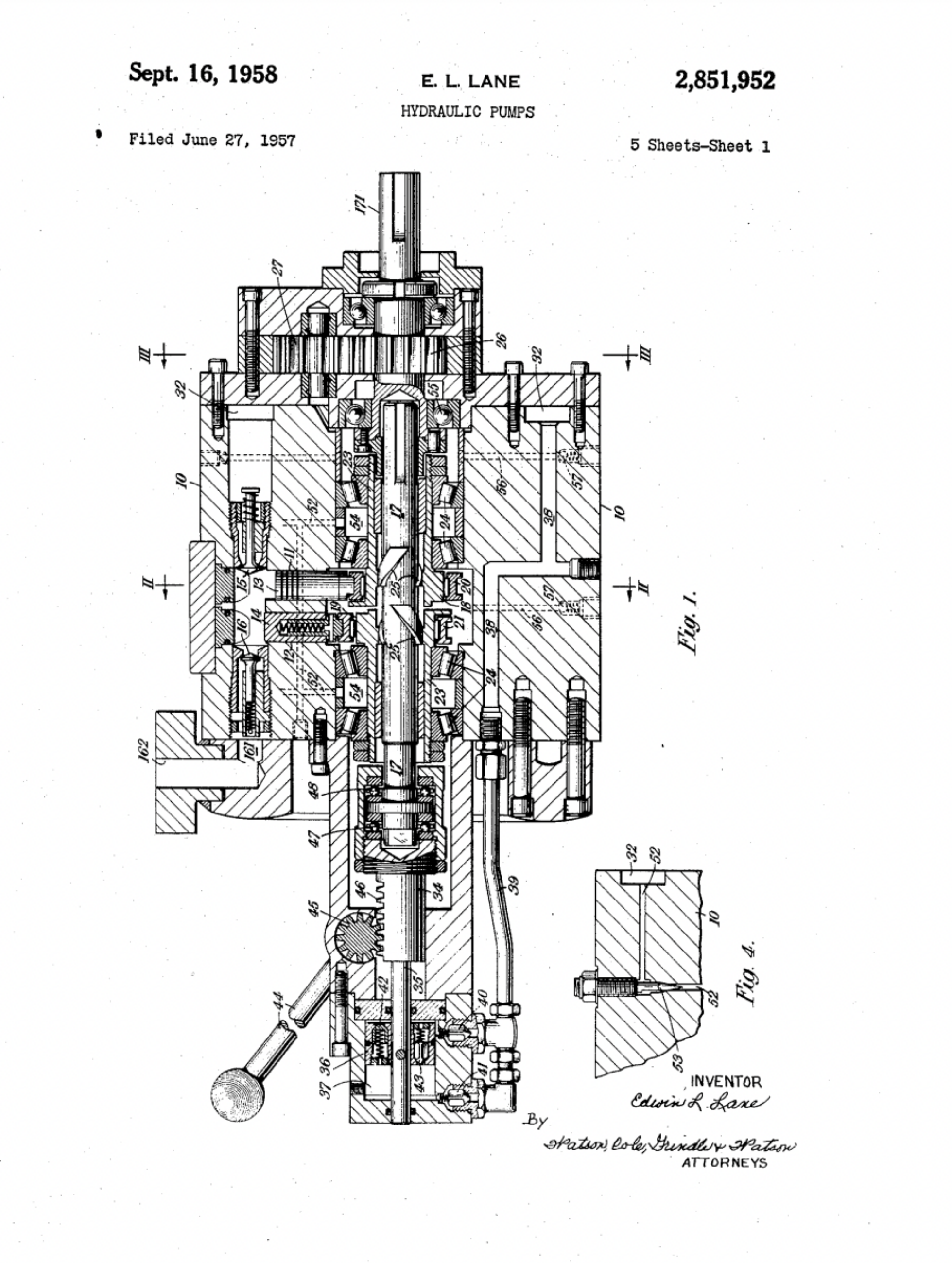


Figure 5: Patent Images for Hydraulic Pump

2.3 Codes & Standards

2.3.1 Safety Code for Elevators and Escalators (ASME A17.1)

This standard is the accepted guide for elevator and escalator-related design, construction, installation, operation, inspection, testing, maintenance, alteration, and repair throughout North America. Although it is primarily intended for elevators and escalators, we are mostly interested in its design, construction, and safety aspects. This is because the concept we are currently brainstorming for our device focuses on the vertical lifting of heavy loads. Specifically, we are considering the possibility of offsetting/ignoring the ramp, raising the gas tank off the ground, and placing it directly on the flat platform of the scale. This would involve a vertical movement that resembles a short elevator ride for the gas tank. If we were to go forward with this design, ASME A17.1's safety precautions would become very important as it covers topics such as structural integrity, emergency procedures, and load handling. The safety of both our team and the device's users is the top priority. Although intended for elevators, this standard can be adapted to enhance the safety and reliability of our design.

2.3.2 Standard Specification for Carbon Structural Steel (ASTM A36/A36M)

This is a standard for carbon structural steel. It covers carbon steel shapes, plates, and bars used in the construction of bridges, buildings, and various structural frameworks through riveting, bolting, or welding. These structural products must meet the general requirements outlined. When welding ASTM A36 steel appropriate procedures must be followed. These steel plates encompass a wide range of shapes, including beams, channels, angles, tees, and bars, and are suitable for bearing plates in various structures. It outlines material requirements and properties for structural components, such as frames or supports of our design. By adhering to ASTM A36/A36M, we can select suitable materials that meet the necessary strength and durability criteria for handling heavy loads safely.

2.4 User Needs

Considering customer needs during the early phases of product design is crucial. Gathering insights directly from the customer helps us understand why and what we're building. This approach minimizes risks, ensures precision, and leads to the brainstorming of ideas. In hopes of coming up with potential designs, we aim to be thorough with this step of the process.

2.4.1 Customer Interview

Interviewee: Dr. Flores
Location: Jubel 020, Washington University in St. Louis, located near the intersection of Brookings Drive and Hoyt Drive.
Date: September 8^{th}, 2023
Setting: Dr. Flores held an interview session at her lab. She gave an introduction explaining what happens in her lab and why she needed the device. She showed the gas tank to us and we spoke to the TA who is tasked with moving the tank up and down the scale. After they provided us with a general overview of what they were looking for, they answered a series of questions from

students working on this project. The whole interview was conducted in her laboratory, and took ~25 minutes.

Interview Notes:

What will the device be used for?

- According to the customer, this device will facilitate the movement and positioning of a heavy gas tank onto a weighing scale platform for experiments involving argon gas in a laboratory setting. The device should assist in rolling the heavy cart up a ramp onto the scale platform and safely back down, all while avoiding collisions with walls and ensuring precise positioning on the scale. This device aims to streamline and improve the safety of the process, as well as enhance accuracy in measuring the gas.

Besides creating a device that can put the tank onto the scale successfully, do you have any other requirements or preferences?

- Customer requires that the device must only require 1 user to facilitate the process of successfully putting the tank onto the scale. They want the device to prevent the user from continuing to hit the electrical conduit on the other side of the scale. This happens from the tank hitting against the wall. They also don't want the device to interfere with the walk space in front of the scale.

How heavy does the gas tank range from?

- While originally said to range from heavy to very heavy, the customer estimates that the maximum it can weigh is somewhere between 1000 pounds and 1500 pounds. This is only a guess considering that the scale maxes out at 1000 pounds. The minimum the tank weighs is 350 pounds.

Does the device have to be portable?

- Customer says it would be nice if the user could easily store the device next to the scale or if it folds nicely into one of our storage spots in the room. Still, the only thing they ultimately care about is if it works and successfully gets the tank up the ramp.

How have you been doing this in the meantime?

- The process of getting the tank onto the scale involved two people in the summer. One person would hold the handle attached to the tank and push, while the other would pull. The one who was pulling was in charge of trying to prevent the tank from hitting the nearby wall, which poses a safety risk to that individual.

Does the ramp on the scale play a factor in how it performs when measuring the tank at the top of the scale?

- Customer is not sure but assures us that it is something we can test out ourselves to determine.

Can we build something on top of the scale?

- Customer doesn't want anything stuck on there. They want the device to "come and go" after being used.

Can you describe the wheels on the bottom of the gas tank?

- Customer says 2 of the front ones (closer to the handle) are on casters while the other two are not. TA who pushes cart welded to the bottom of the gas tank says they are pretty stable.

Is it okay if using the device requires the user to follow a process with steps?

- That is okay as long as it completes the job.

2.4.2 Interpreted User Needs

To summarize the interview, the device will facilitate the safe movement of heavy gas tanks onto a weighing scale platform for argon gas experiments, streamlining the process and enhancing measurement accuracy. It should be user-friendly for a single operator, preventing collisions with walls and not obstructing walkways. The device must handle a weight range of approximately 350 to 1000-1500 pounds, offer portability, and be removable from the scale. A step-based operation is acceptable as long as the device effectively completes the task.

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	The device is user-friendly and only requires one person	5
2	The device can handle range of ∼350 to 1000-1500 pounds	5
3	The device is safe for users	5
4	The device does not impact the scale reading	5
5	The device does not slam into nearby wall	4
6	The device is not permanently affixed to the scale	3
7	The device is portable and easily stored in the lab	2

Considering our interview insights and customer needs, we are actively brainstorming design ideas that match what our customer wants. Our goal is to formulate a comprehensive plan that effectively addresses all seven customer needs, with a particular focus on those rated with importance levels of 4-5.

2.5 Design Metrics

In the pursuit of designing an efficient and safe device for handling heavy gas tanks in a laboratory setting, several critical specifications have been identified. These target specifications encompass essential metrics ranging from weight capacity and device footprint to mobility within the lab and crucial safety considerations. Each metric is associated with specific numerical values representing acceptable and ideal thresholds.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	1,2	Weight capacity of machine	lb	1350	2000
2	7	Area occupied by machine	ft^2	7	5
3	6,4	Ability for device to move around the lab	DOF	3	2
4	3	Device pinch points or safety hazards	–	4	2
5	5	Device stopping speed	in/s	2	5

2.6 Project Management

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

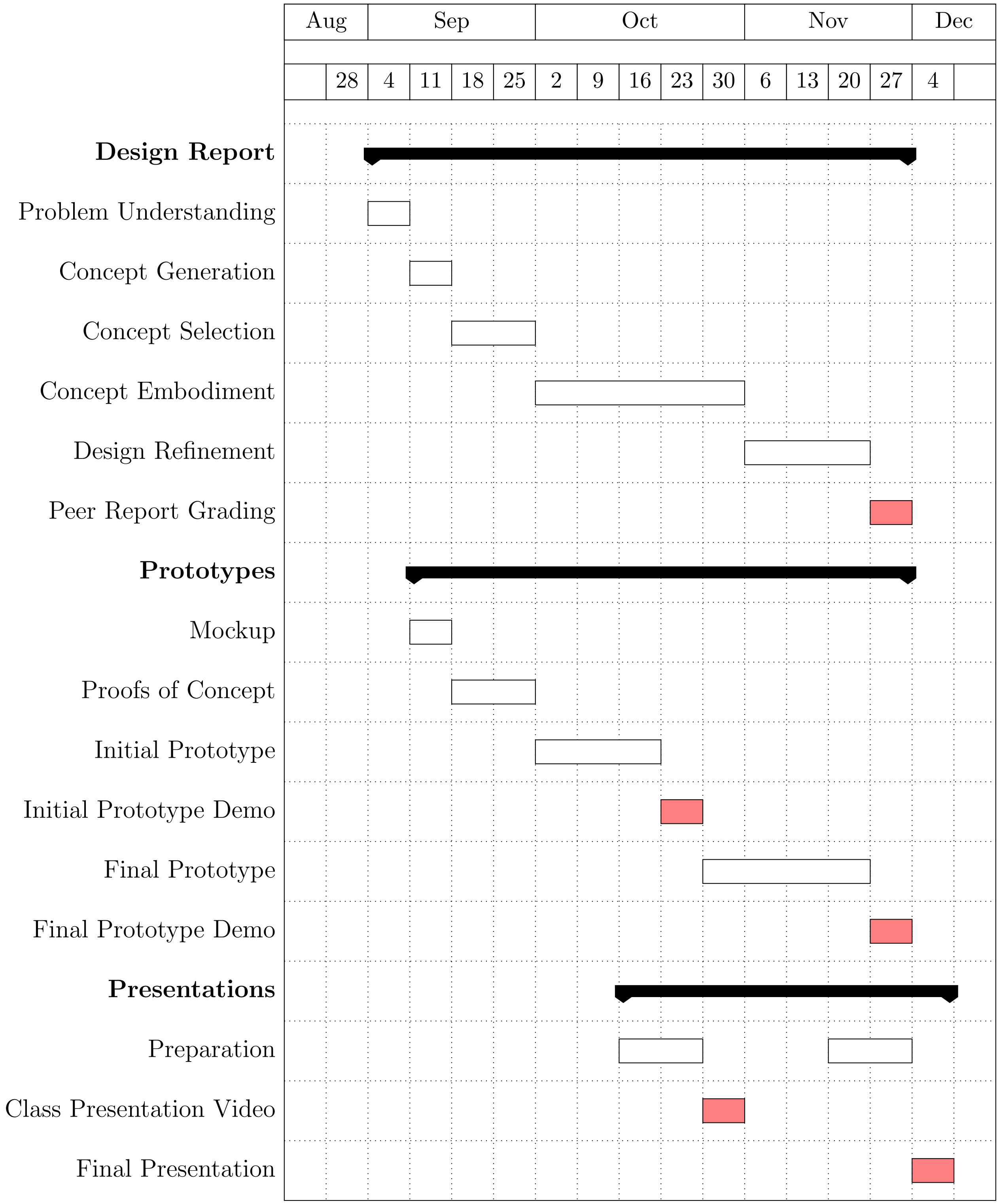


Figure 6: Gantt chart for design project

3 Concept Generation

3.1 Mockup Prototype

The mockup showed us the practical aspects of building our device, along with user needs and the device's functionality. It brought our group together in person to brainstorm and explain why we favored certain ideas over others. Each of us had a chance to explain what they were imagining for our device and how they saw it being used. In addition to helping our group communicate our ideas to each other, the mockup inspired us to make decisions because it showed us what was missing in our design. For example, we realized we need to settle on an activation method, such as a foot pump or hand crank. We also need to decide if we should include arms to secure the tank better. Lastly, physically building the mockup helped us realize the importance of precise measurements from the actual tank and scale, as our initial assumptions were largely speculative.

Figure 7: Photograph of mock up towards the front

Figure 8: Photograph of mock up from behind

Figure 9: Photograph of mock up from the side

3.2 Functional Decomposition

Our function tree is shown in Figure 10, which briefly evaluates different aspects that we need our design to include.

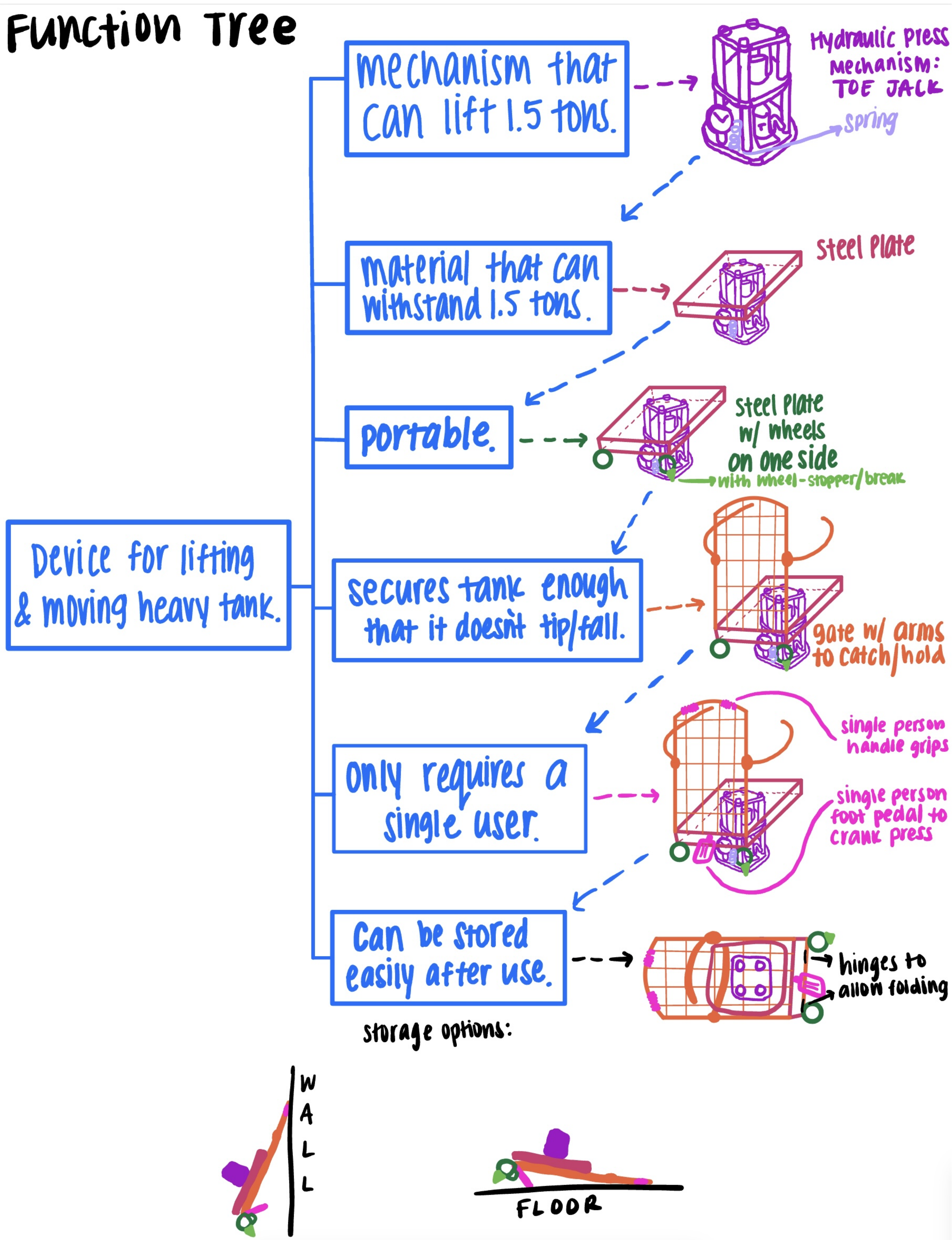


Figure 10: Function tree for Lifting Device, hand-drawn and scanned

3.3 Morphological Chart

Figure 11 shows our morphological chart, which breaks down the different options we have as we tackle each separate design goal.

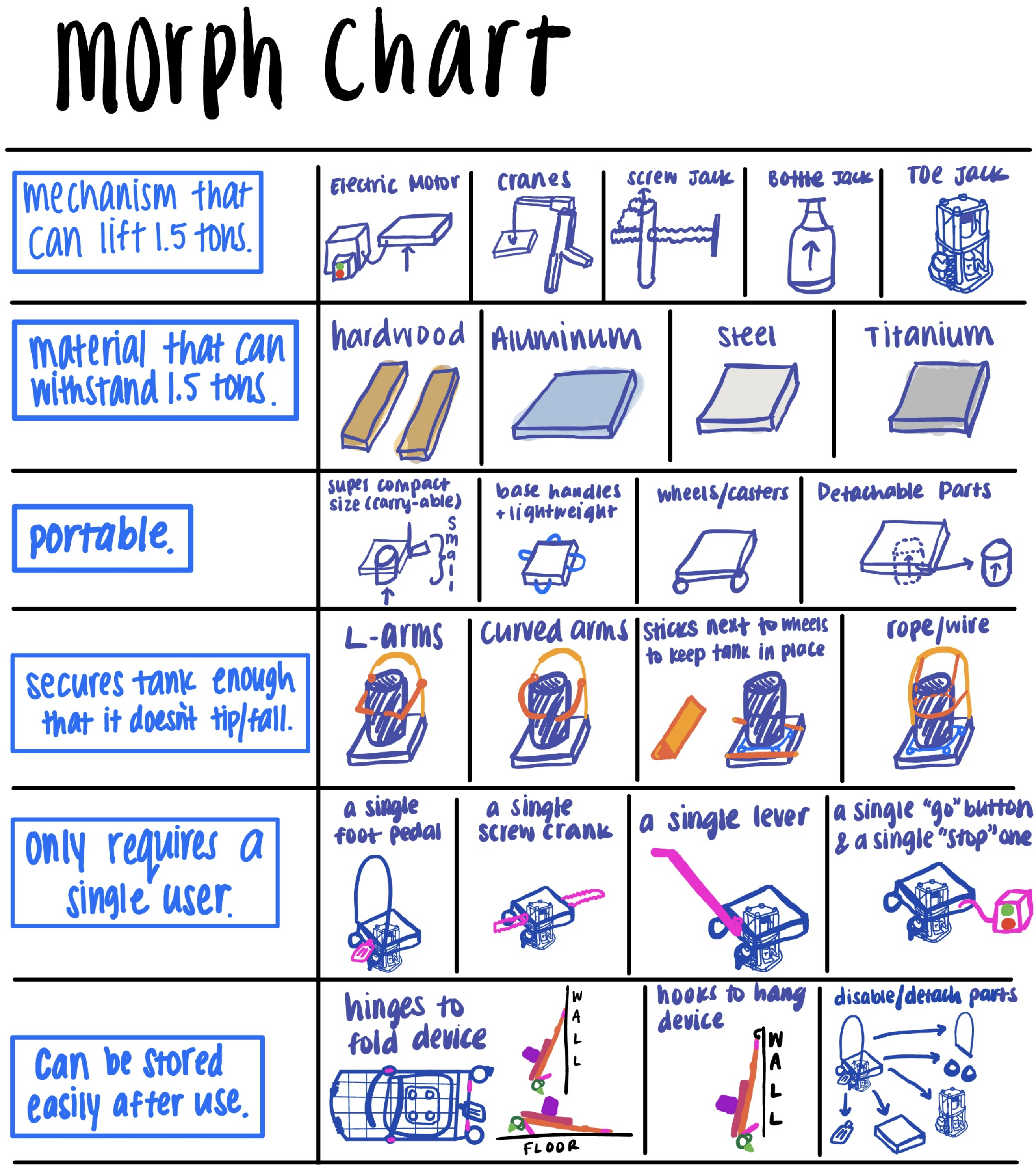


Figure 11: Morphological Chart for Lifting Device

3.4 Alternative Design Concepts

3.4.1 Concept #1: Tank ChairBoost

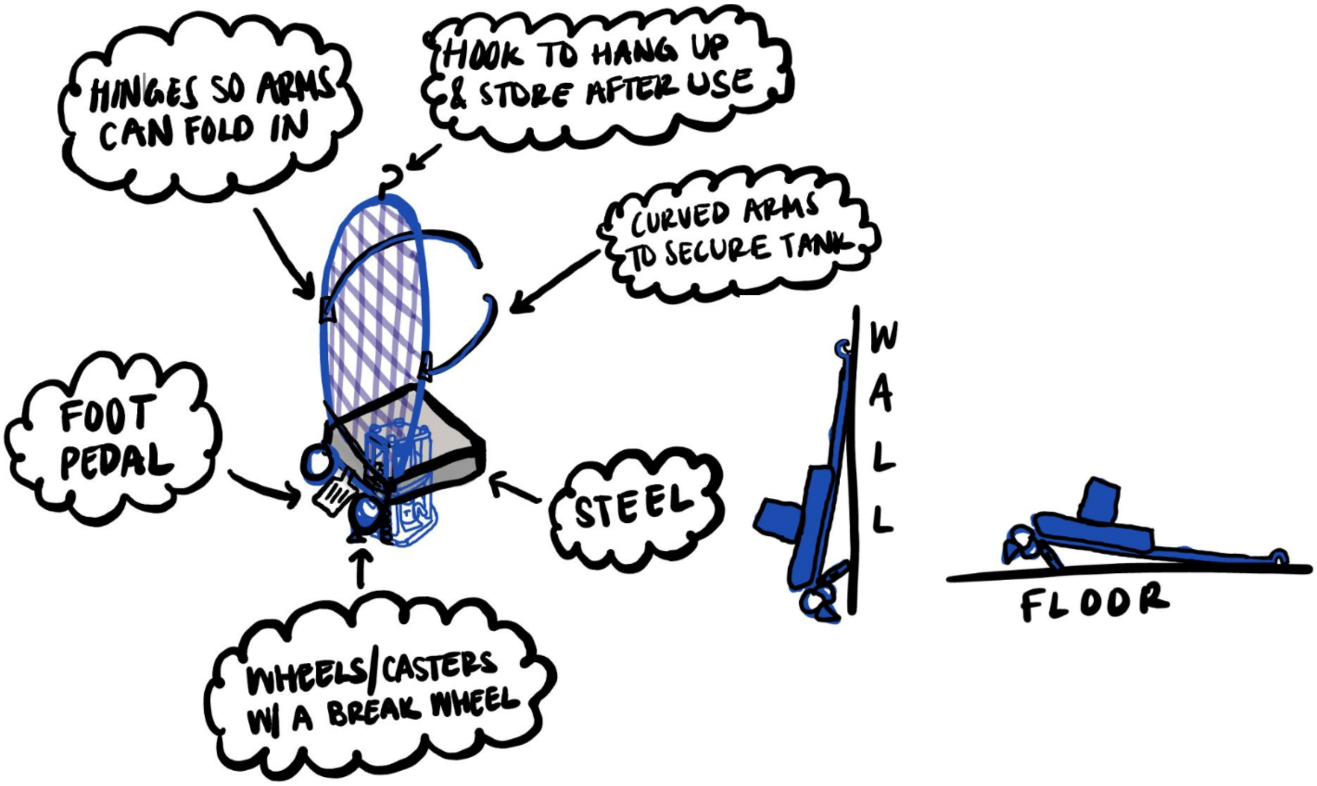


Figure 12: Sketches of Tank ChairBoost concept

Description: The design concept features a portable device using a toe jack, eliminating the need for electrical power. First, the user will roll the portable device with built-in wheels next to the tank, ensuring adequate space near the scale's ramp. The steel base, chosen for its affordability and strength, supports the tank when correctly centered. Retractable arms secure the tank in place. A foot pedal operates the toe jack, raising the steel plate under the tank. The goal of the user is to elevate the tank itself to match the height of the scale's top platform. This way, the user can smoothly roll the tank onto the scale. Designed for single-user operation, the device will reduce the risk of wall collisions because we have offset the need to harshly push up the ramp of the scale. Lastly, the device's hook allows it to be hung, while it's folding arms also allow it to also be stored flat.

3.4.2 Concept #2: Tire Jack Lift

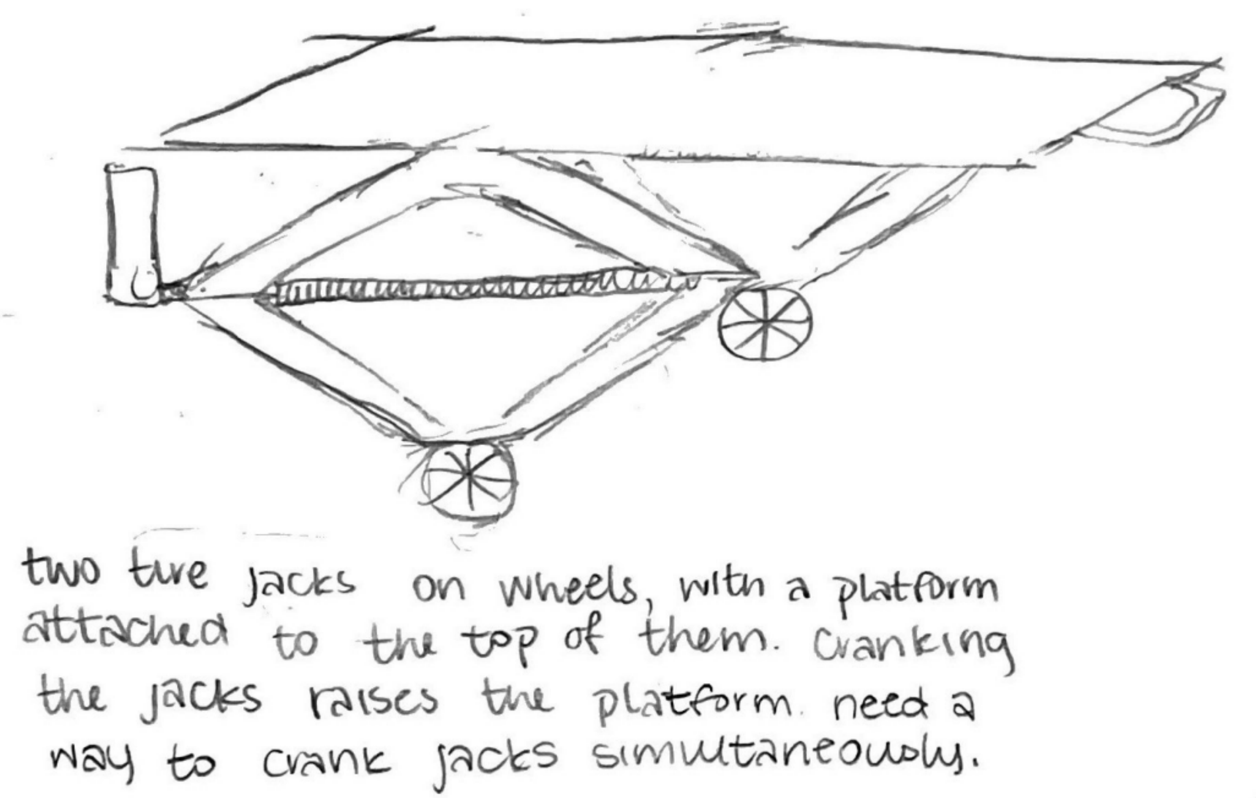


Figure 13: Tire Jack Lifting Mechanism Concept

Description: Two tire jack leadscrews with wheels on the bottom are attached to the arms/platform that will lift the tank. The device is rolled under the tank. The cranks on the leadscrews are attached so that they will turn simultaneously. Cranking the tire jacks raises the platform, which lifts the tank with it. The whole device is rolled forward towards the scale. The platform has arms long enough to reach past the ramp and rest on top of the scale, so that the tank can simply be pushed off the device and onto the scale. The device may be improved by adding hinges between the tire jacks and the platform to allow it to fold up for easy storage.

3.4.3 Concept #3: Lift Table

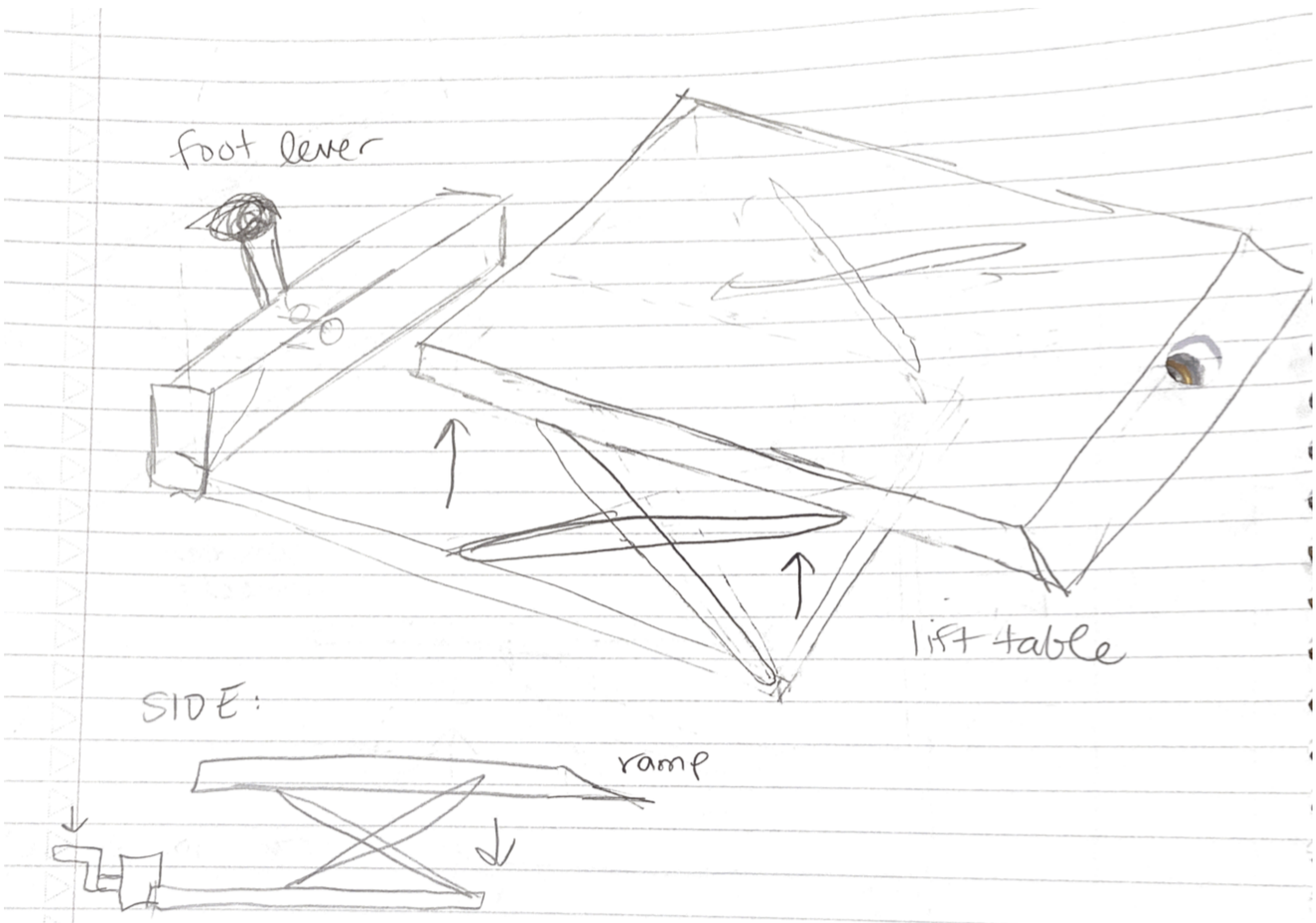


Figure 14: Lift Table

<u>Description</u>: The tank rolls onto the platform via a short, shallow ramp. A foot lever is stepped on, which moves x-bars on either side of the platform to raise the device. This also allows the device to fold away for safe and easy storage. It has an easy-loading feature, allowing tanks to roll onto the platform via a shallow ramp. The tank can then be manually rolled off the ramp by the user onto the scale. It is very simple and easy to use, which contributes to its single-user requirement.

3.4.4 Concept #4: Low Profile Jack

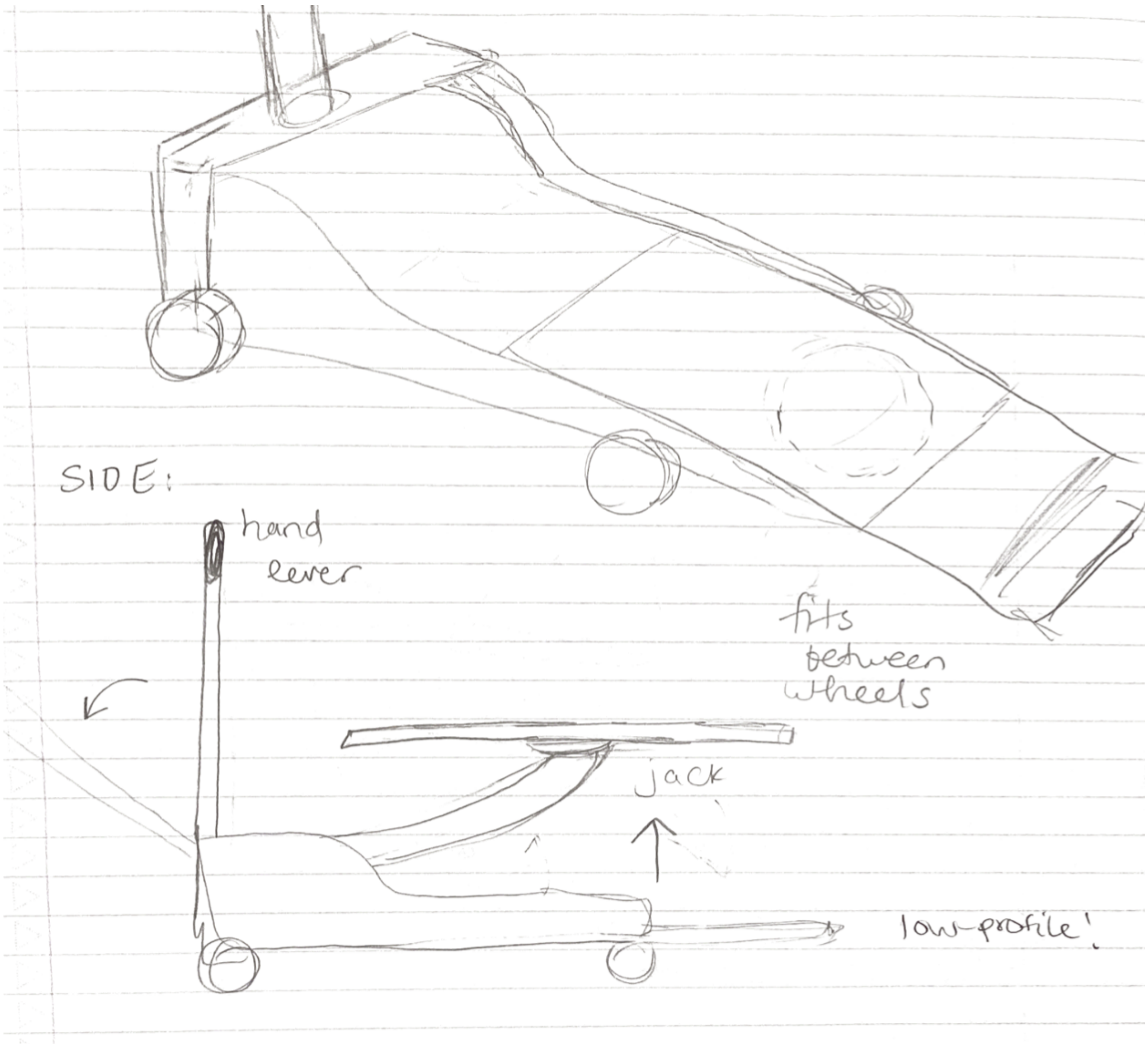


Figure 15: Low Profile Jack

Description: In similar fashion to a pallet jack, this device is narrowed at the nose and sits low enough to be able to fit in between the wheels on the base of the tank. It rolls under, then the hand lever (doubling as a pull handle) is pulled down which causes the jack to raise. The tank is raised with it, and can then be rolled to the scale. The jack is raised high enough that the scale's ramp can be bypassed, but low enough so that the tank can roll smoothly off the jack and onto the scale.

4 Concept Selection

4.1 Selection Criteria

Five main criteria for a successful lifting device were identified and weighted by importance in relation to each other. Figure 16 is the analytical hierarchy process table detailing these comparisons.

	One Operator	1000+ lbs Weight Capacity	Easily Stored	Stop Tank From Hitting Wall	Safe for User		Row Total	Weight Value	Weight (%)
One Operator	**1.00**	0.33	3.00	3.00	0.33		7.67	0.17	16.98
1000+ lbs weight capacity	3.00	**1.00**	7.00	5.00	1.00		17.00	0.38	37.65
Easily Stored	0.33	0.14	**1.00**	0.33	0.14		1.95	0.04	4.32
Stop tank from hitting wall	0.33	0.20	3.00	**1.00**	1.00		5.53	0.12	12.25
Safe for user	3.00	1.00	7.00	1.00	**1.00**		13.00	0.29	28.79
						Column Total:	**45.15**	**1.00**	**100.00**

Figure 16: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

The most important criteria for the device came out to be its capacity to support the weight of a full tank. The least important criteria was the ease of storage of the device.

4.2 Concept Evaluation

The weighted criteria were then applied to each design concept in turn. Each design was given a score according to how well it achieved each criterion, and then given an overall score based on the weighted averages of its scores in each of the five criteria. This weighted scoring matrix is shown in Fig. 17.

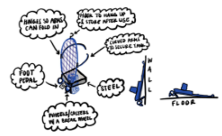
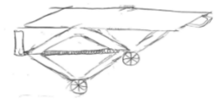
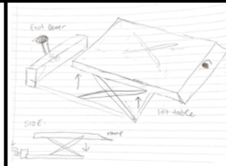
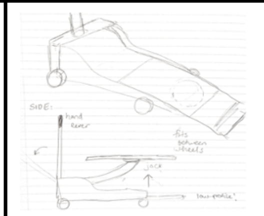
Alternative Design Concepts		**Concept #1**		**Concept #2**		**Concept #3**		**Concept #4**	
									
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
One operator	16.98	5	0.85	3.5	0.59	5	0.85	5	0.85
1000+ lbs weight capacity	37.65	3	1.13	5	1.88	5	1.88	5	1.88
Easily stored	4.32	3	0.13	4	0.17	4	0.17	3	0.13
Prevents tank hitting the wall	12.25	5	0.61	4	0.49	3	0.37	3	0.37
Safe for user	28.79	5	1.44	4.5	1.30	4.5	1.30	5	1.44
	Total score	**4.160**		**4.435**		**4.567**		**4.668**	
	Rank	**4**		**3**		**2**		**1**	

Figure 17: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

4.3 Evaluation Results

The selection chart allowed us to assign scores to each design based on five critical criteria: one operator, 1000+ lbs weight capacity, storability, prevention of collisions with walls, and safety. With weight capacity being a fundamental component of all four designs, our attention shifted to other critical factors such as safety and single-user friendliness to determine the best-suited concept for our project.

The Low-profile Jack emerged as the winner, securing the highest overall score of 4.668. It excelled in handling weight capacity and one operator criteria since a single user can operate the device to lift the entire estimated weight of the tank. For this reason, in both categories, the design earns a perfect score of 5. For the ease of storage criterion, the design earned a 3 because the device is rather tall and cannot fold up to be easily stored away. The device can be easily maneuvered, but it does not have any element to prevent the tank from hitting the wall. This translated to a rating of 3 in preventing a collision; more preventative features, like arms to restrain the tank from rolling too far off the scale, could be employed to prevent the collision. Lastly, the device received a score of 5 for safety because the user's point of interaction is far enough from the mechanism and the tank, preventing any pinching or collision accidents from occurring.

4.4 Engineering Models/Relationships

The first engineering model that may be useful for our design is the Finite Element Analysis (FEA). FEA can be applied to ensure the structural integrity and safety of the device while handling gas tanks weighing 1000+ pounds. FEA can simulate the stress and deformation in the device components, ensuring that it can safely bear the load and avoid failures during operation. It can also help in optimizing the design to prevent collisions with walls during tank movement. FEA will involve modeling the device's components as finite elements and solving equations related to stress, strain, and deformation. Geometries, material properties, estimated weight range of the gas tank, and the ramp's inclination angle would be given variables. By varying these input parameters, FEA can predict how different design choices affect the device's structural performance. As a result, we would be able to determine stress distribution, deformation, safety factors, and any potential failure points in the device.

Another engineering relationship that may be useful for our design is finding moment arms and applied torque. Considering the lifting mechanism for our device, which is likely to raise the tank cart from its center, and assuming that the hinges are centered as well, we can employ a moment arm and applied torque model. In this context, we utilize the following equation:

$$T = FD$$

where T represents the torque required for lifting, F is the weight of the gas tank, and D signifies the distance between the user handle or application point and the lifting part of the device. These are the given parameters. We would be able to solve for different placement options and their impact on the ease of lifting gas tanks. This analysis will allow us to create a design with minimal physical strain. The choice of D can significantly affect the user's experience, making it essential to find the most suitable position for the device.

5 Concept Embodiment

5.1 Initial Embodiment

Figures 18, 19, and 20 show CAD models of the device. These models do not represent our device perfectly; the device is distinctly complicated to model, so these demonstrations are approximations based on models we were able to find online.

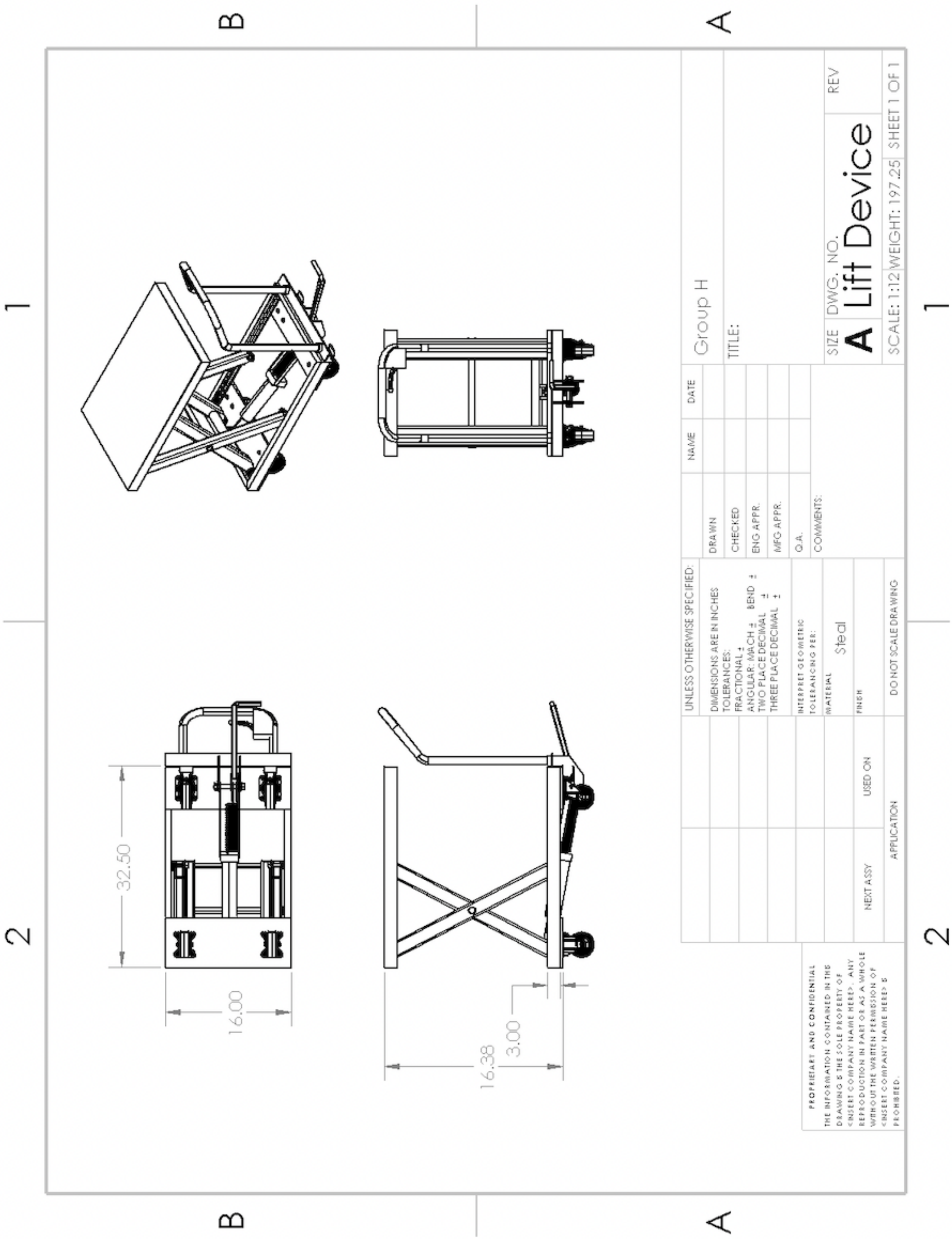


Figure 18: Assembled projected views with overall dimensions

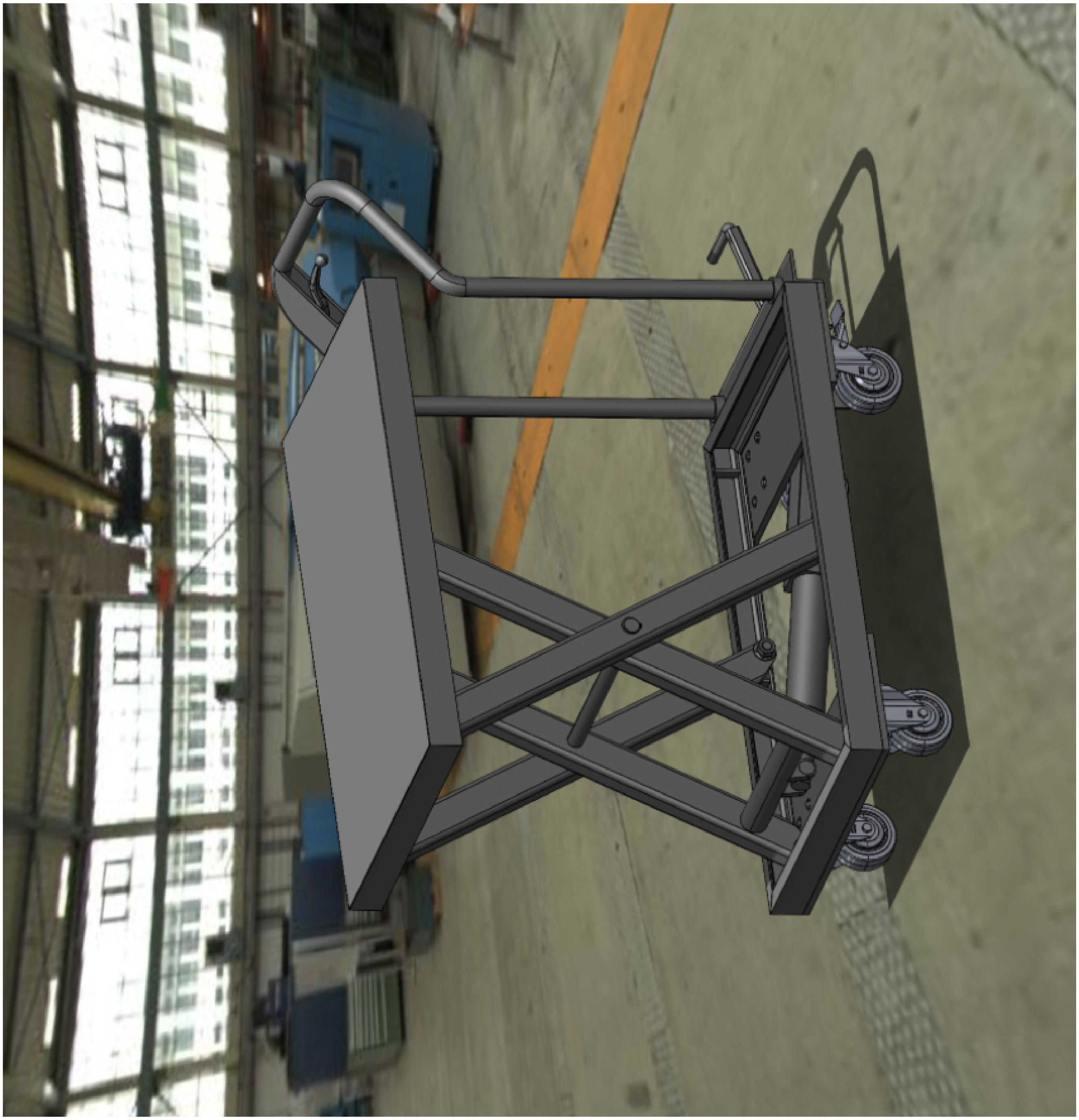
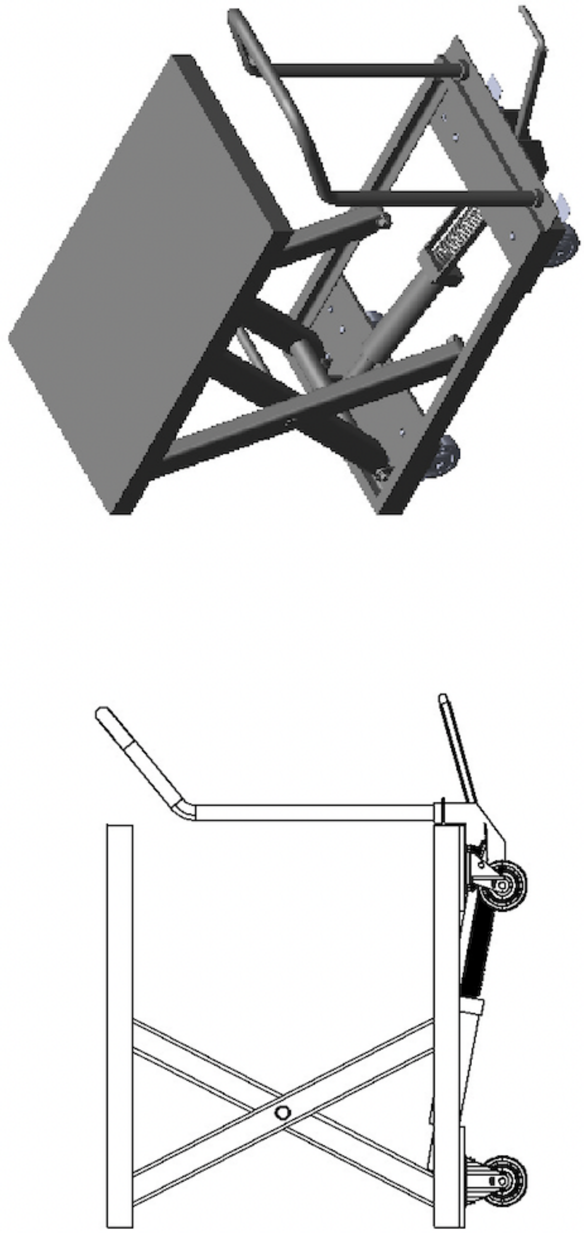


Figure 19: Assembled isometric view



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Pittsburge Automotie ATV/Motorcycle Lift	Lift has foot-activated pump, can be raise up to 16.375 in.	1
2	Bridge (not pictured)	Will sit flush on the ramp, so tank can be rolled onto it	1

Figure 20: Exploded view with BOM

Three prototype performance goals were established for this initial prototype. The prototype had to:

1. Lift 1500 lbs, which was the high-end estimate of the weight of a full tank;
2. Shorten the time it takes a user to get the tank onto the scale by at least $\frac{1}{2}$; and
3. Decrease the amount of force exerted by the user in the process by at least $\frac{1}{5}$.

The first two goals were achieved easily. The base motorcycle lift is rated for 1500 lbs, and the trial run showed that the tank can certainly be lifted and transferred onto the scale in less than half the time it takes without the device. However, for the third performance goal, the device was too tall to test with the real tank, so it was impossible to be able to quantify the amount of force exerted with the lift.

5.2 Proofs-of-Concept

The Proof-of-Concept testing and prototypes influenced our design and its embodiment plan for the Initial Prototype in many ways. First, we learned that we needed to add a separate component to our design that would make it possible to safely transfer the tank over from the motorcycle jack to the top platform of the scale. These bridge pieces will add time to the process because there will an extra step of putting the bridge pieces on the ramp. In addition, this process led us to realize that our current motorcycle lift is too tall for the height clearance of the tank. This was important to know sooner than later because we need to decide whether we will keep our current motorcycle lift or purchase a new one. Lastly, this process helped us to brainstorm how we will safely lift the tank considering the length of the lifting arms and the tank's center of mass. As we move forward, we are considering the ways we will keep the tank balanced on our device.

5.3 Design Changes

One big difference between the Initial Prototype and the selected concept is the method of operation. The Initial Prototype uses a motorcycle jack with a release pedal, providing a convenient and controlled mechanism for raising and lowering the tank. In contrast, the selected concept from Section 4 proposes a manual jack mechanism, which might require more physical effort. The inclusion of a release pedal in the Initial Prototype enhances safety and user control. Additionally, while both designs involve lifting the tank to the desired height and offsetting a ramp for placement on the scale's top platform, the solution for getting the tank over the ramp. The Initial Prototype incorporates a strong plastic piece that can be placed on top of the ramp to align it with the scale's platform, ensuring accurate tank placement. On the other hand, the selected concept from Section 4 has no separate piece because the design displays a long lifting platform that could potentially reach the scale's top platform while ignoring the ramp altogether.

6 Design Refinement

6.1 Model-Based Design Decisions

In our engineering design, we've strategically applied Finite Element Analysis (FEA) and various mathematical models to address key aspects of both our Initial Prototype and Final Prototype, which are the following:

1. Deciding on Lifting Mechanism

The application of moment arms and applied torque models helped us optimize the lifting mechanism of our device. Considering the torque equation (T = F * D), we assessed different placement options to determine the most effective location for lifting the gas tank. Knowing that the lifting arm would have to reach the center of the tank, we found that the distance from the lifting mechanism would be about 14 inches. Therefore, the torque was found to be 21000 in-lbs. In the case of lifting a 1500 lbs tank, a torque of 21000 in-lbs can be considered substantial. The lifting mechanism we use must be designed to handle and provide the necessary torque safely and efficiently. We also wanted to provide an ergonomic design that minimizes physical strain on the user during the lifting process. Soon it became evident that our needs require a more reliable design that is capable of lifting our tank safely and easily for the user, pointing us in the direction of researching car jacks. Still, with an abundance of options, we needed to find one that would be able to fit under the tank at 4.25 inches tall. Also, the lifting arm had to reach the center of the tank (14 inches) so that the heavy tank remains balanced on the car jack throughout the process. The careful consideration of moment arms and torque has significantly contributed to refining the user experience, emphasizing safety, efficiency, and user-friendly operation. Ultimately, we decided on the perfect lifting mechanism; we bought the low profile, long reaching car jack with a lifting capacity of 3 tons as it met all our requirements.

2. Optimal Dimensions for Bridge Pieces

The bridge pieces are essentially two sturdy slabs of hot rolled steel, finely cut to match the dimensions we needed. The metal will have a slick diagonal cut on one side, matching the ramp's angle for a snug connection. While the height had to be 1.75 inches to match the height of the scale, deciding the length and width were up to us. Using our judgement and considering the tank and scale, we calculated the length and width needed for optimal functionality. After raising the tank to the proper height, the tank would be lowered onto these bridge pieces. So, factoring the necessary surface area to accommodate the four wheels while accounting for potential human error in alignment, we decided that they should be 4 inches wide. The length, strategically set at 36 inches, results from adding the tank's length and the ramp's length, which was calculated using the length of the ramp's diagonal. Through more trigonometry, we also found that the angle of the diagonal cut needed to be 167.16 degrees, which is integral to know in order to perfectly fit the ramp's angle. This will allow us to transfer the tank from the car jack onto the scale platform by simply rolling it over. The models and calculations from this decision are shown in the following figure. This application of engineering models greatly enhanced our design decisions, ensuring the bridge pieces are tailored to meet the specific requirements of the prototype.

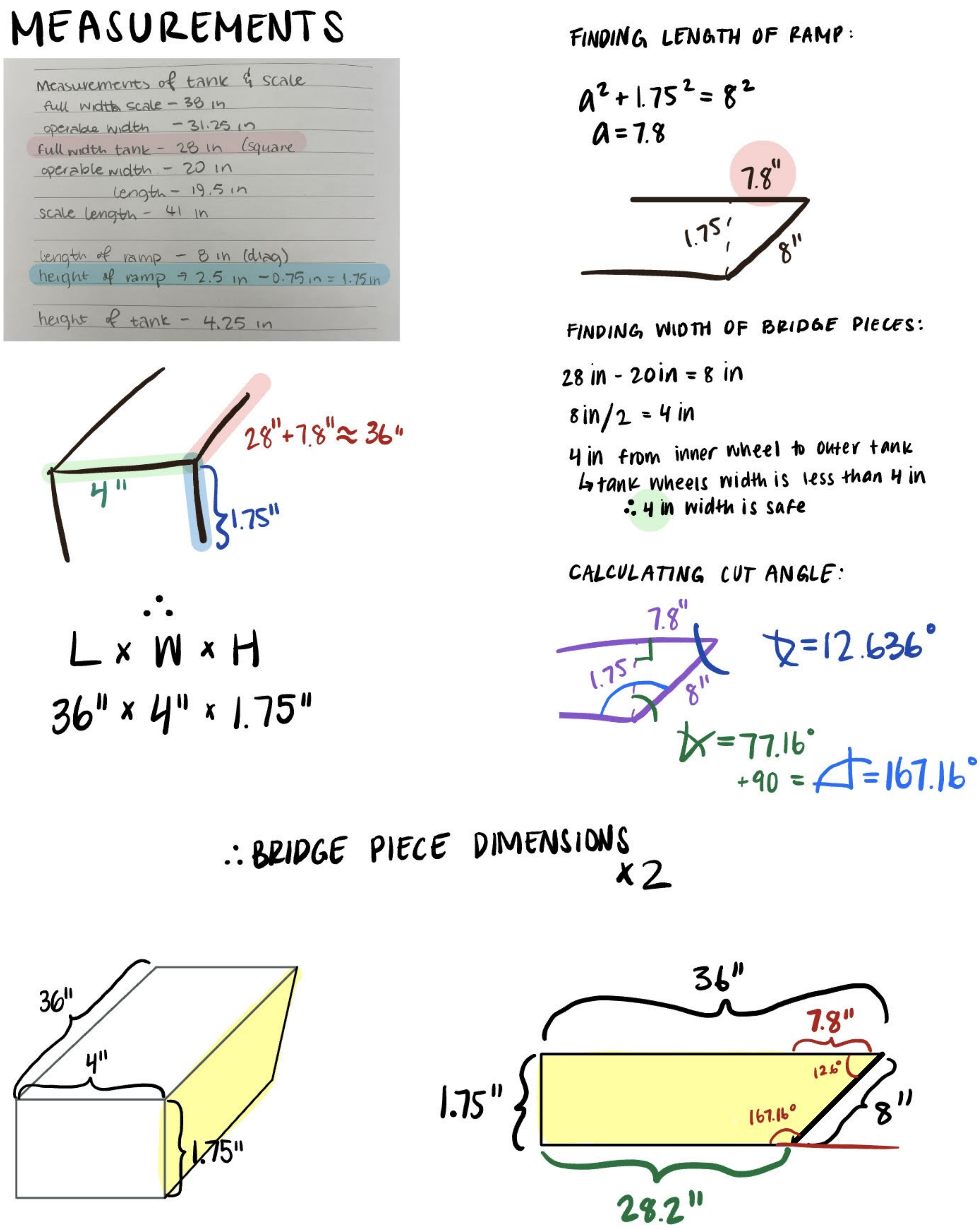


Figure 21: Drawings and calculations to find bridge piece dimensions.

3. **The Choice of Steel for our Bridge Components**

Our use of FEA has been instrumental in ensuring the structural integrity and safety of our device when dealing with a gas tank weighing over 1000 pounds. By simulating stress and deformation within the components, FEA has guided our design choices. For instance, it played a pivotal role in the selection of materials for our bridge pieces. enabled us to subject materials, including aluminum and various steels, to rigorous strength tests, focusing particularly on a 1500 lb load. An example of one of the deformation values we found in Solidworks is shown in the figure below. The simulations consistently revealed minimal deformation, with steel exhibiting slightly superior performance. In light of these findings and considering factors like strength and cost-effectiveness, we made the informed choice to utilize hot-rolled steel for its robustness. This holistic integration of FEA insights and practical testing through SolidWorks has significantly strengthened our confidence in the device's capability to securely withstand the substantial load of the gas tank.

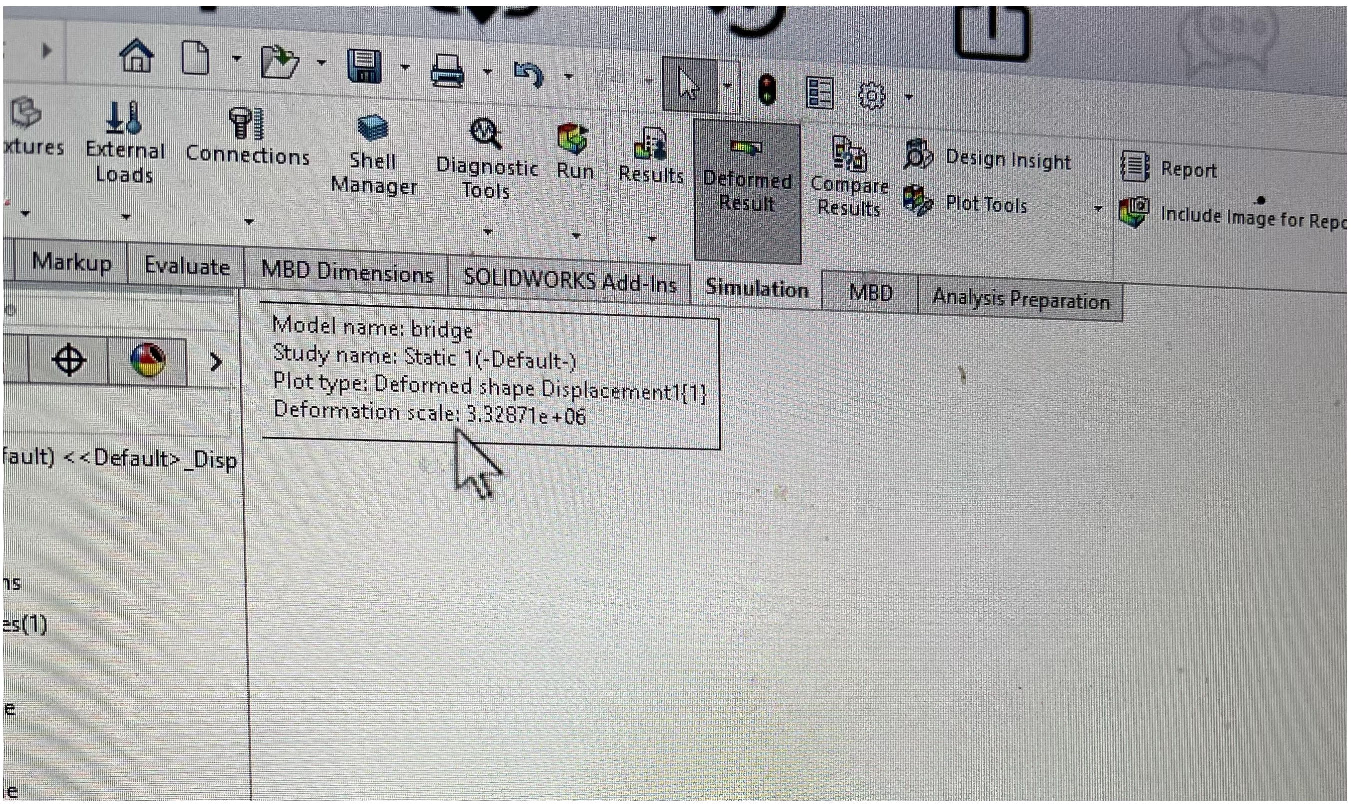


Figure 22: Example of deformation found after bridge piece simulation.

In summary, our strategic use of FEA and different calculations helped us overcome every difficult decision, from material selection to ergonomic considerations. These models have served as powerful tools guiding our engineering process, resulting in a well-rounded and effective gas tank handling device.

6.2 Design for Safety

As part of the design process, five risks were determined for the implementation of the device and bridge pieces. The risks were compared to one another and then ranked in order of importance for consideration the continued development of a functional device system.

6.2.1 Risk #1: Device/Tank Imbalance

Description: If the device is not placed sufficiently near or on the tank cart's center of mass, the system may become unbalanced and the tank is liable to tip over and fall off of the device.

Severity: Catastrophic: if the tank falls, it could become damaged and unusable, or injure someone in the vicinity.

Probability: Seldom: Given a specific set of instructions, users of the device should be able to place the lift in a way that consistently prevents imbalances from occurring, but it cannot be ruled out from happening entirely.

Mitigating Steps: Small straps/stops could be added to the lift to keep the tank upright. They would be large enough to accomplish the task of stabilizing the tank, but do no need to be very hefty because they will not be engaged with the tank for long periods of time.

6.2.2 Risk #2: Collision

Description: The tank could be rolled too fast across the scale, causing it to roll off the back ramp and collide with the wall behind the scale, including the electrical outlet bar and the glass window.

Severity: Critical: The tank crashing into the wall could damage the electrical outlets. This, while undesirable, is not the worst thing, as the electrical bar is seldom used by the lab. However, if the tank is rolling with too much momentum, it could potentially go through the wall or cause significant damage to the glass window, which would present numerous safety hazards and halt proceedings in the lab until the glass could be cleaned and the window replaced.

Probability: Seldom: This risk, while severe, is not likely to occur. Lab personnel are never moving the tank with enough momentum to crash through the wall/window. The tank has collided with the electrical outlet bar in the past, but not generally in any critcal capacity.

Mitigating Steps: The lab has already taken steps to mitigate the damage risk by adding a styrofoam block to cushion the momentum of the tank. The lift was also designed to require less momentum to get the tank up the ramp and onto the scale.

6.2.3 Risk #3: Bridge Piece Failure

Description: Any slight dimensional mistake that misaligns the heights of the bridge pieces and the scale, or makes the bridge pieces too narrow for the tank wheels, could prevent the tank wheels from getting onto the scale platform. It could also fail if the width of the bridge pieces is not wide enough to properly roll the tank wheels across them and onto the scale platform.

Severity: Catastrophic: If the tank cannot transition from the bridge pieces to the scale platform, it will not be able to get weighed. Additionally, a sudden failure of the bridge piece could topple the tank, potentially damaging it and/or rendering it unusable. It can injure someone in the vicinity, especially since the tank is very heavy.

Probability: Unlikely: Since the user will be given detailed instructions, they should be well informed on the ways to align the wheels nicely with the bridge pieces. This will prevent instances where the wheels get rolled off of the bride pieces most of the time. The pieces were designed with the weight of the tank in mind, so they should be able to support the weight of the tank without issue.

Mitigating Steps: The wheels are somewhere between 2-3 inches wide, so as long as the bridge pieces are about an inch wider than that, the tank should successfully transition over the bridge pieces and onto the scale. The pieces are also made of steel, which has a weight capacity large enough to support the tank as it rolls from the device to the scale.

6.2.4 Risk #4: User Injury

Description: The operator of the device could experience a range of injuries resulting from interaction with the tank and device. There could be pinch points at multiple locations on the device. The tank, if improperly loaded onto the device, could fall off and hit the user. It is also possible that the operator could hit another person if their view is obstructed as they navigate the tank around the lab.

Severity: Critical: The importance of user injury is not something to understate; an operator could suffer anything from a minor bruise from getting run into with the cart to a sprained joint or broken bone from getting caught in a possible pinch point or dropping the bridge piece.

Probability: Seldom: Users in the lab should have sufficient experience with heavy machinery to be conscious of dangerous behaviors while operating the device. They will not be driving the heavy tank recklessly, and will likely avoid sticking their fingers in spaces that are likely to close quickly.

Mitigating Steps: The device uses a foot-press lever as the user's primary interaction with the device. This keeps the user's head and hands farther away from the pinch points and hazards of the device. There is also a safety feature on the base lift that prevents the lift from going higher than its max design height. The bridge pieces have felt furniture pads on the bottom to allow them to slide across the floor instead of having to be carried across the lab.

6.2.5 Risk #5: Device Movement Restricted

Description: The wheels could get stuck on debris from the lab floor or the lift or bridge pieces could get impeded by an obstacle in the lab.

Severity: Marginal: While not a desirable occurrence, this risk is easy to fix and easy to avoid. Once the user notices the issue, they would simply remove the obstacle and continue with the process.

Probability: Occasional: This is bound to happen at some point, simply because dirt and debris like small metal fragments get scattered on the floor.

Mitigating Steps: Lab personnel should continue to keep large obstacles and debris out of the middle of the floor. The wheels of the lift and the felt pads on the bridge pieces should be cleaned when used to prevent dirt buildup that might cause future impediments.

Figure 23 shows a color-coded "heat map" of the relative importance of each risk.

		Probability that something will go wrong				
	Category	**Frequent** Likely to occur immediately or in a short period of time; expected to occur frequently	**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**				Balance of tank	Bridge Piece Failure
	Critical	Collision			User Injury	
	Marginal			Device Movement Resrticted		
	Negligible hazard presents a minimal threat to safety, health, and well-being of participants; trivial					

Figure 23: Risk assessment heat map.

According to the heat map, the highest priority in designing this device should be mitigating the collision of the tank with the wall, followed by keeping the tank balanced on the device. The last three are evenly weighted by color, but hold different severities and probabilities. User injury should be the third-highest priority, due to it being more severe than a restriction to the device movement and more likely to occur than a bridge piece failure. The fourth most important risk considered should be the bridge piece failure due to its severity, and finally, the device movement being restricted can be considered.

6.3 Design for Manufacturing

The parts included in the design are the lift platform, the lift mechanism, the base frame, the wheels, and the handle, totaling five individual parts.
Estimated number of threaded fasteners in design: 30
The Theoretically Necessary Components (TNCs) of this design are: wheels, a handle, a base frame, the lift arm, the lift mechanism, and the extender/bridge pieces, totaling seven separate components.

The current design considers the components of the car jack as separate parts, which makes the number of theoretical parts line up closely with the real quantity. The device could also be considered as one part, coupling five of the seven TNCs together into one.

The bridge pieces were counted as two parts, because they are not attached to each other in any way. It may be interesting to consider building a bridge connection so that the two parts become one; while adding more material and weight to the design, this would help keep the bridges parallel and flush with the scale. Figure 24 shows a sketch of this idea.

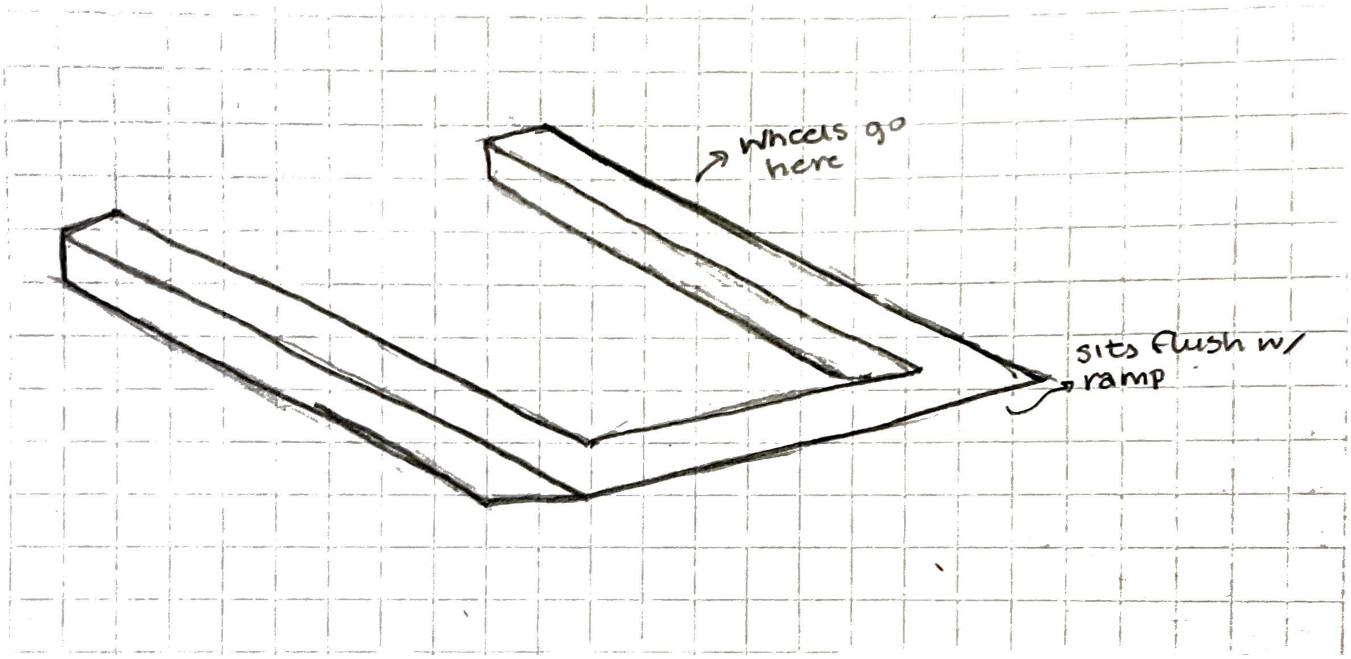


Figure 24: Hypothetical bridge unit with two arms joined by a section spanning the width of the tank.

6.4 Design for Usability

6.4.1 Impact of a Vision Impairment on Usability of Device

An impairment such as color blindness would not have a very strong effect on the usability of the device, since there will not be any color-dependent elements involved in its construction. Someone with an impairment like farsightedness or nearsightedness may have a slightly harder time using the device, as it is necessary to be able to see both up close to operate the lift and also far away to navigate the tank and lift. The biggest visual impairment challenge one might face is total blindness. We could make the elements easier to find for a person with such an impairment by adding tactile coverings on handles or levers, and making the device produce a loud click at the end of each stage of its operation.

6.4.2 Impact of a Hearing Impairment on Usability of Device

Someone with hearing loss would likely not have a very hard time operating our device because it does not rely on sound to accomplish its task. They might face challenges with detecting failures with the device, though; the most prominent feature of a lot of potential failures (broken lever, screw falls loose, something crashes) is the loud sound that it makes. Hypothetically, we could make the device vibrate or light up when it detects a sudden decrease in load, but the low likelihood of such a failure coupled with the fact that the members of Dr. Flores' lab do not have presbycusis, makes this a superfluous fix.

6.4.3 Impact of a Physical Impairment on Usability of Device

Someone with a physical impairment would probably have a significant amount of difficulty operating our device. The tank itself weighs at least 1000 pounds, and while the device is intended to make moving it easier, it will still require some strength. We could potentially automate the lifting mechanism by adding a motor, which would allay some of the physical effort required by the user, or add frictionless bearings in the device to make lifting and traveling require less force.

6.4.4 Impact of a Control Impairment on Usability of Device

This device should not be used by anyone with a control impairment. Someone who is very distracted, intoxicated, or otherwise incapable of directing all their attention to the task of lifting and moving a very heavy tank containing a dangerous gas could lose focus long enough for the tank to become unbalanced and tip over, crash into the wall behind the scale, or raise the lift too fast and damage the device. If someone *really* wanted to use the device in this state, we might add a wider lift contact area to minimize balance risk, or make the base of the device heavier to distribute the weight so that the tank won't fall over.

6.5 Design Considerations

Table 3: Factors considered for design solution

Design Factor	Applicable	Not Applicable
Public Health		X
Safety	X	
Welfare		X
Global		X
Cultural		X
Societal		X
Environmental		X
Economic	X	

Table 4: Contexts considered for ethical judgments

Situation	Applicable	Not Applicable
Global context		X
Economic context	X	
Environmental context		X
Societal context		X

7 Final Prototype

7.1 Overview

Looking back to the performance goals we set, this device system accomplishes all three. First, it was estimated by lab personnel that the process of getting the tank onto the scale took about 6 minutes. In testing the device, the time to get the tank onto *and* off the scale was 3 minutes and 3 seconds, which is just above half the time without the device. The second goal was to make the device fit within $9ft^2$. The total space occupied by the lift and bridge pieces was $5.11ft^2$, which is smaller than the goal by about 57%. Finally, perhaps the most difficult goal to achieve was to decrease the force required throughout the entire process to $\frac{1}{5}$ of what a user would exert without the device. The force to move a full tank was roughly measured to be about 100lbs. When using the device, this force was decreased to about 15lbs, concentrated mostly in moving the relatively heavy bridge pieces; this constitutes approximately an 85% decrease in required force. This goal could have been achieved with an even greater margin if lighter materials had been chosen for the bridge pieces, like aluminum, or even wood.

7.2 Documentation

Figure 25 and 26 illustrates the final prototype of the tank lift.

Figure 25: Final Design of low-profile lift and bridge pieces

Figure 26: Demonstration of wood wedge offsetting the ramp

Figure 25 also shows the device pieces in their suggested storage location.

During our final prototype testing, we encountered an unexpected issue where the bottom of the tank did not conform to the anticipated flat surface as shown in Figure 27. This posed a challenge during lift testing, as accessing the center became problematic, leading to tilting and an imbalance due to the tank's non-flat bottom.

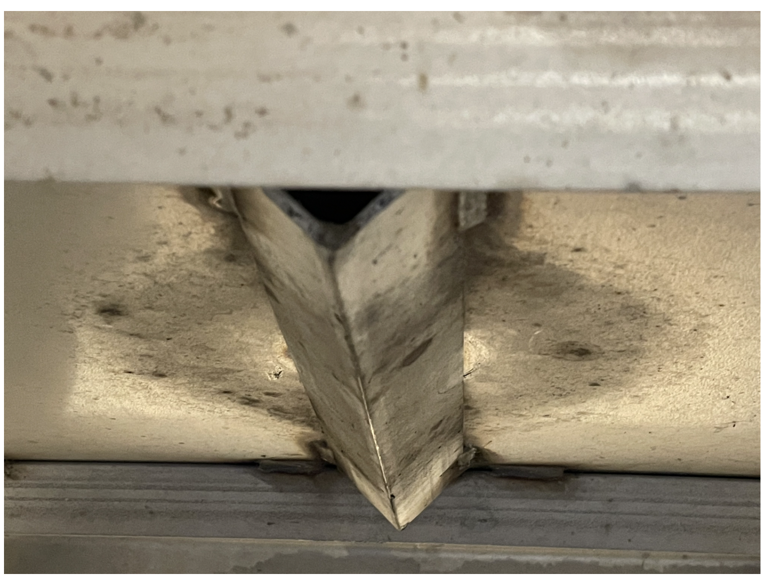


Figure 27: Bar under the tank

We brainstormed a solution involving the use of wooden pieces to establish the flat surface required for testing our ultimate prototype, which is shown in Figure 28.

Figure 28: Wooden pieces under tank, creating a flatter surface

This setup gave the jack a flat contact surface large enough to be able to lift.