ME 450 TEAM 28

UNIVERSITY OF MICHIGAN

# Final Report

April 24, 2023

Team 28: Powered Motorcycle Lift Mechanism


Becca Cuomo
Sarah Dressing
Dustin Fletcher
Emma Pickett
Grant Robertson

## *Executive Summary*

Modern day motorcycle lifts are lacking in the full combination of features and requirements that motorcycle owners and mechanics could benefit from. In the United States alone, over 8.6 million registered motorcycle users are left with imperfect options for motorcycle lifts that potentially pose safety risks (IIHS, 2021). Our team has been sponsored by the University of Michigan SPARK Electric Racing Team to design a mechanism that is able to safely, efficiently, and reliably raise and lower their motorcycle both in the Wilson Student Team Project Center and at their competitions. In addition to being adjustable to different heights, the mechanism must be portable to allow easy travel for the team between the Wilson Center and competitions.

Similar designs to this lifting mechanism already exist, however, there is no design that meets every need of the SPARK team in load bearing capacity, portability, reliability, and adjustable height. These four requirements are the most important user requirements for this lifting mechanism, each of which corresponds with an engineering specification and testable metric, that can be used to test whether the final design successfully meets that requirement. Meeting these requirements is important as we have many different stakeholders, all of which will either be impacted directly or indirectly by the success of our motorcycle lifting mechanism design.

For Design Review 2, our team had completed a concept generation process involving individual and group brainstorming as well as iteration followed by a concept selection process featuring separate Pugh charts corresponding to the four main requirements of the mechanism. The winning designs from each Pugh chart had been combined into an “Alpha Design” and the resulting design has since been modeled in CAD. The various dimensions and parameters associated with this are determined by sponsor input, results from engineering analyses, and relevant specifications. Material properties have also been explored and evaluated further.

Our third milestone, Design Review 3, led to the refinement of our CAD model and rigorous stress analysis for various parts of the design. Initially, with our material selections and thicknesses, we found our model to be unsatisfactory in multiple ways. After some design changes and continued testing we landed on a design that utilized two double acting hydraulic pumps, a scissor lift, thin galvanized steel/carbon fiber, and a lockdown bar safety mechanism. This modified design resolved our previous design’s problems and successfully passed the design requirements of withstanding a heavy load (1500 lb distributed load and 350 lb point loads), portability, and adjustability.

To display and prototype our model on a basic level, we 3D printed a model using PLA. The model proved the physical capacity of our design to function on a smaller scale and allowed us to perform more validation testing. The prototype used common bolts, washers, and super glue.

The design can be viewed as a success due to a variety of successful verification and validation tests. Despite this, we have some critiques that need to be addressed when moving forward. Without a full scale model, there are still verification tests that cannot be completed. We need a detailed manufacturing plan and bill of materials to move forward. Also, addressing the heavy weight and portability issue it causes will be critical. Finally, some additional features could be added to improve the overall quality of the design.

# Table of Contents

**To:** Kira Barton
Rm. 3256 Ford Robotics Building
2505 Hayward St
Ann Arbor, MI 48109

**From:** Rebecca Cuomo - Communications Lead
Sarah Dressing - Documentation Lead
Dustin Fletcher - Manufacturing & Embodiment Lead
Emma Pickett - Modelling & Analysis Lead
Grant Robertson - Budget and Finances Lead

**Subject:** Final Report for Powered Motorcycle Lift Mechanism

**Date:** April 24, 2023

**Distr:** Mustafa Khan - Mechanical Director, SPARK Electric Racing
Peter Jaskoski - Project Manager, SPARK Electric Racing

# Final Report

## Revised Abstract

SPARK Electric Racing needs an adjustable and portable motorcycle-lifting mechanism to aid in efficient and safe repair work on their motorcycle. Currently, the team uses a winch to lift their motorcycle onto a rigid table. The lack of adjustability and high effort process is time-consuming and inconvenient for various tasks performed by the team on a regular basis (Khan, Initial Email, 2023). Our goal for this project is to design a mechanism that can withstand various loading conditions through several years of use while remaining adjustable and portable for transport to competitions.

## Project Introduction, Background, and Information Sources

According to Nationwide's guidelines on safe motorcycle ownership, oil changes and chain checks should occur about every 4,000 miles driven or every six months, whichever occurs first. This could occur more frequently for owners who use their motorcycles regularly for long trips or racing. Such frequent maintenance could be too expensive to be done professionally, so many motorcycle owners may choose to do it themselves for a lower cost (Nationwide, 2023). Our sponsor, SPARK Electric Racing, for example, has team members operating on their motorcycle almost daily when in season. Besides oil changes and chain checks, the Motorcycle Safety Foundation recommends that riders perform a T-CLOCS inspection before every ride (Tires, Wheels, Controls, Lights and Electrical, Oil and Fluids, Chassis, and Sidestand), some of which may require inspecting areas of the motorcycle that are difficult to see standing straight up or may require suspending the motorcycle off the ground (Motorcycle Safety Foundation, 2023). According to the Bureau of Labor Statistics, about 80% of workplace back injuries are caused by strain on the lower back which can be a result of excessive twisting and improper bending

(UVA-EHS, 2023). Motorcycle owners performing frequent maintenance on their motorcycles could potentially develop such injuries due to operating on their motorcycles with improper posture, meaning they may be frequently twisting or bending their back to access certain areas of the motorcycle. As a motorcycle racing team, SPARK regularly performs maintenance and assembly tasks on their motorcycle. Providing SPARK with an ergonomic and convenient way to work on their motorcycle by ensuring it is in the proper position to avoid discomfort and injury will not only increase member safety, but will also aid in improving team morale, team members' work ethics, and construction efficiency, all of which could positively influence SPARK's competition performances.

### *SPARK's Current Setup*

SPARK's current setup for motorcycle maintenance and assembly - a rigid table with a set of purchased chocks to suspend the motorcycle off its wheels shown in Figure 1 below - could cause back injuries for members bending down or twisting their back to access different areas of the motorcycle since the table is low to the ground.

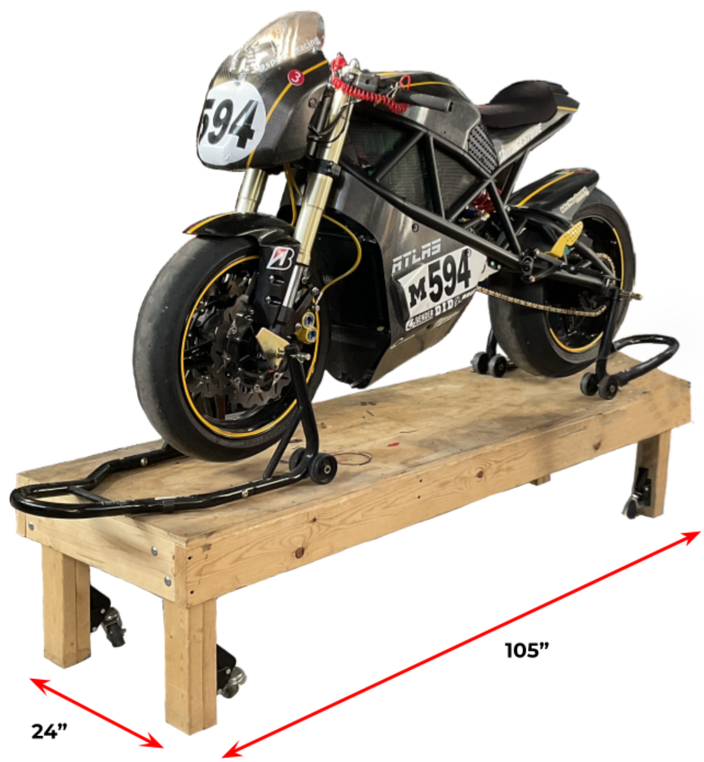



**Figure 1:** SPARK's Current Motorcycle Setup. Pictured is their current project, ATLAS, on the wood platform held in place by purchased Venom chock stands. Not pictured is the overhead winch used to lift the motorcycle from floor level onto the platform. The dimensions of the platform are shown by the red arrowheads.

Aside from injuries, the physical discomfort and difficulty caused by their current setup results in a detriment to the team dynamic by making daily operations on the motorcycle less enjoyable for team members. Additionally, this decreases the productivity of the team since the current process to lift the motorcycle onto the table is a task that requires multiple team members (Khan, Initial Interview, 2023).

### ***Benchmarking: Comparing Commercially Available Products***

Investigating existing motorcycle lifting mechanisms leads us to discover various commercially available products. As seen in Figure 2 below, which includes a few examples of the kinds of products available, there is a variety of types and styles. In general, the available products can be grouped by stands, tables, and overhead hoists.

(a) (b) (c)

**Figure 2:** Examples of Commercially Available products. (a) represents stands (shown is a Pit Bull Spooled Rear Motorcycle Stand), (b) represents lift tables (shown is a Pittsburgh Motorcycle Lift Table), and (c) represents overhead hoists (shown is a Auxx-One Lift 1400).

Although there are numerous available products, SPARK has not purchased any due to these products not meeting all of their needs. Our sponsor has expressed that they do not wish to use a stand style lift as this only raises the motorcycle a minimal distance above the ground (Khan, Notes from Design Review, 2023). Furthermore, the overhead hoist style lift relies on having a ceiling with the hoist equipment already installed- SPARK would be unable to use this lift during their races, which take place outdoors. This style also echoes the current setup that requires a winch to lift the motorcycle; the issues with which have been expressed above. The table style has some promising elements for SPARK's needs. They often have wheels and are adjustable in height. These units, however, can weigh up to several hundred pounds making them less portable than what SPARK would need in their new lift mechanism (Pittsburgh Motorcycle, n.d.).

A detailed analysis of currently available products and how they compare to SPARK's expressed requirements can be found in Table 2 in the *User Requirements and Engineering Specifications* section below.

### ***Gauging Success on This Project***

Being successful in this project means that we will have improved SPARK's lifting mechanism and existing products to design a lift mechanism that has the necessary load-bearing capacity, portability, and adjustability. To ensure the design is also ergonomic we will apply the insight gained from our research into how hobby mechanics work on their motorcycles to inform our design. Additionally, our sponsor specifically mentioned that the resulting mechanism must be compatible with various motorcycles rather than one specific model to ensure that they are able to use it on their future builds (Khan, Initial Interview, 2023). Knowing the competitions in which SPARK has previously participated, we can utilize the databases from the host motorcycle associations to gain a deeper understanding of the types of motorcycles our mechanism should strive to accommodate. For example, the team intends to compete in the Isle of Man TT in the future. Utilizing IOMTT's database provides a rough idea of the motorcycle that SPARK would be building for this competition (IOMTT, n.d.).

In addition to meeting sponsor needs, by the end of this project, we will have adhered to engineering standards relevant to the project. Some standards that we have identified are ANSI/ALI ALOIM-2008 (Occupational Safety and Health Administration, 2023), from the Automotive Lift Institute, ANSI Z244.1-1982 (R1993) (ANSI/ALI ALOIM, 2023), otherwise known as Lock Out/Tag Out, and ASME PASE 2019 (ASME Standards Collection, 2023), which is a safety standard for Portable Automotive Service Equipment. These standards are further discussed in the *Applicable Existing Standards* section below.

## Design Process

The design process that our team has chosen to closely follow for each stage of our project is the one carefully defined in the ME 450 curriculum shown in Figure 3 below.

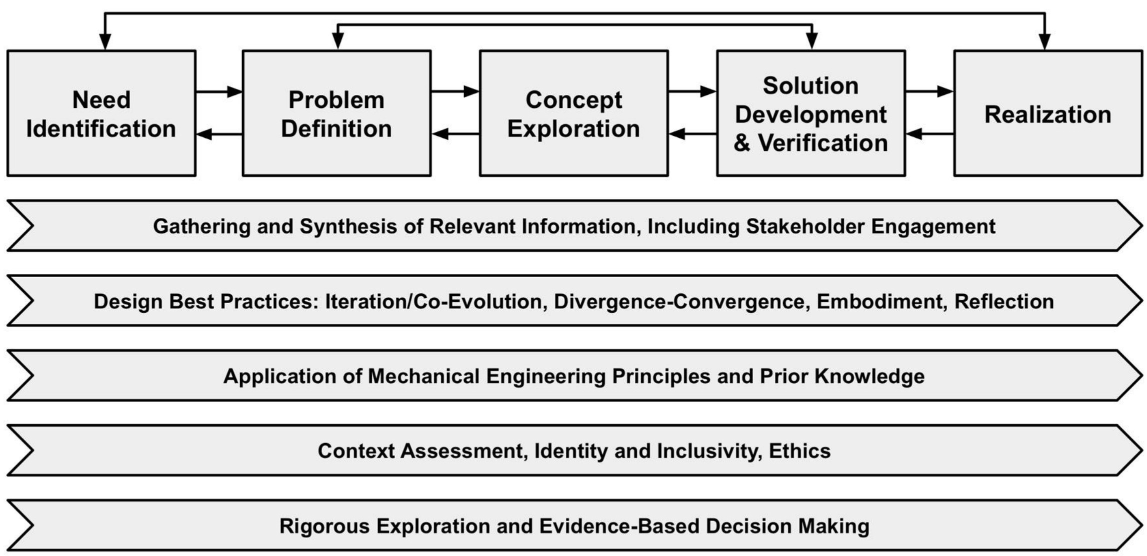



**Figure 3.** The design process above is provided by the ME 450 curriculum. Each stage consists of engaging in the specified tasks while applying basic mechanical engineering principles.

This design process is most applicable to our project because it is a robust method that has been tested time and time again by the Mechanical Engineering Department and proven to be successful. Additionally, our team felt that an emphasized problem definition phase would allow us to better connect our project in a larger context. Originally, our view of the project was strictly limited to the immediate task, not realizing it could be relevant to motorcyclists around the world. We considered other design models, however our team chose to stay with the ME 450 process defined through the curriculum for the course, as the structure of the semester strongly reflects that of this design model.

## Stakeholder Analysis

In order to effectively analyze the implications of our design on various levels, we need to assess our stakeholders and their motivations/importance. A full breakdown of each stakeholder and their connection to the project is included.

***Stakeholder Map Explanation***

Stakeholders are individuals or groups that have a stake in our project in some way. There are a large number of stakeholders that are impacted by this project, but some are considerably more important than others. This section will focus on the three primary divisions of our stakeholders: primary, secondary, and tertiary. Their ecosystem categories will also be discussed; these are resource providers, status quo supporters, complementary organizations, beneficiaries and customers, opponents or problem makers, and finally affected or influential bystanders. See the following sections for more depth on the stakeholders' contextually.

Seen in Figure 4 below is our stakeholder map. The legends on the left portion of the figure explain the system we used to divide the stakeholders into their categories.

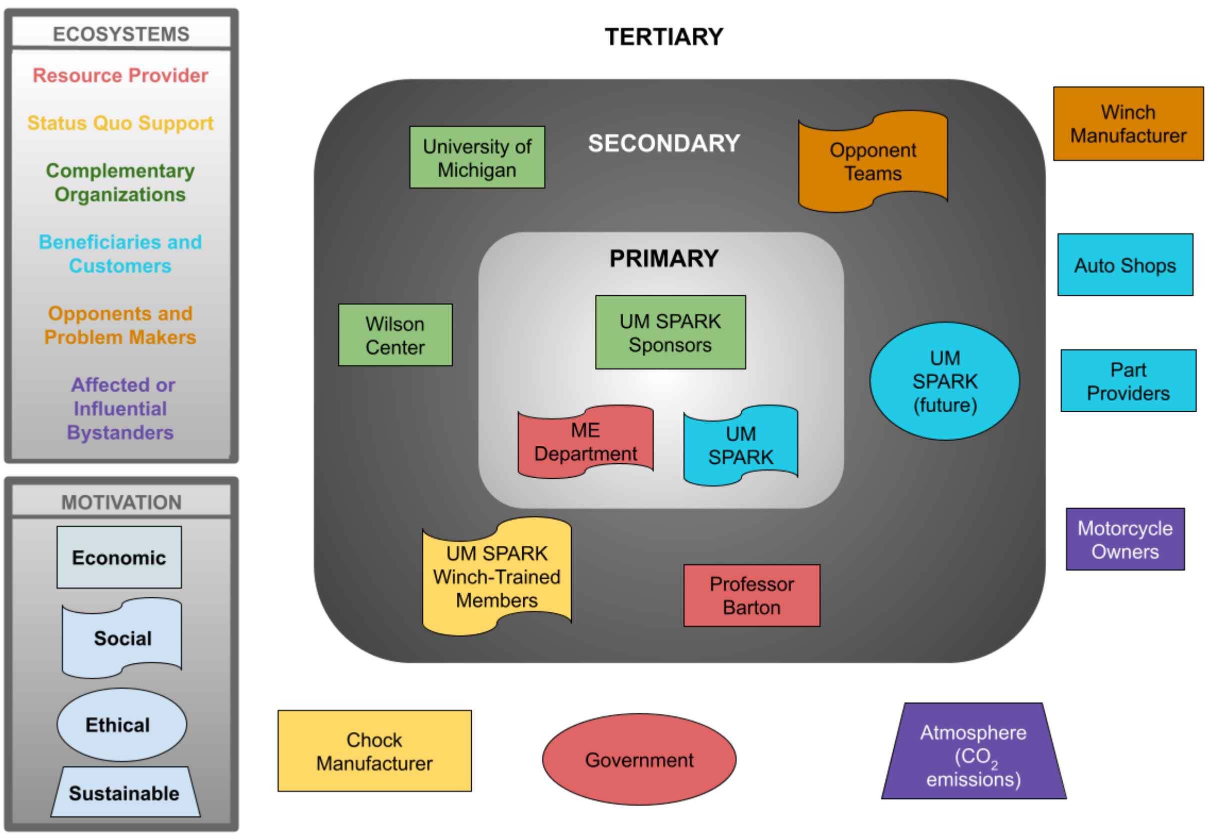



**Figure 4:** Stakeholder Map. The primary motivations for the stakeholders are indicated by the shapes as shown on the legend to the lower left. The ecosystem category by which each stakeholder is labeled is indicated by color, which is shown in the upper left legend. Stakeholders are also divided by their importance through the three tiers, primary, secondary, and tertiary, which are clearly indicated on the chart through the background colors and labels.

The map above shows the various ecosystems, motivations, and divisions between primary, secondary, and tertiary stakeholders. Primary stakeholders are the most important/influential to our project. These stakeholders, if displeased, could cause the end of our project or force us to implement significant changes (with minimal options for recourse from our team). They also have the most impact on the specific design decisions we will make throughout the design process. Next are the secondary stakeholders. These groups are less interested in the specific nature of our solution, and more invested in the problem simply being solved. These groups are impacted by our solution, but their level of investment/care is notably less than the primary stakeholders. Finally, there are the tertiary stakeholders. These groups hold the least amount of stake in our solution strategy and may not even be aware of this project's existence. They are mainly impacted by the big picture implications of our solution, and, even so, are only minimally impacted.

The ecosystem categories (represented by color coding on stakeholder map) are meant to divide the stakeholders by the role in which they will play regarding the project. There are six categories that are used to divide them:

- Resource Providers
    - Stakeholders that provide support through finances, knowledge, connections, or other means.
- Status Quo Supporters
    - Benefit from the continuation of the status quo. Not necessarily for or against a solution, but primarily hope for little to no changes to the problem space.
- Complementary Organizations
    - These stakeholders provide helpful or complementary services and/or support the same cause.
- Beneficiaries and Customers
    - They benefit from the development of a solution, whether indirectly or directly.
- Opponents and Problem Makers
    - These stakeholders are part of the problem or contribute to it in some way. They may even undermine the development of a solution.
- Affected or Influential Bystanders
    - They have no direct impact but may be impacted by wide reaching implications of the solution.

The last method of organizing our stakeholders that is displayed in the stakeholder map is their motivation or primary driver. The shapes of the stakeholder boxes reflect their specific motivation. Four main motivations are used to classify the stakeholders: economically motivated, socially motivated, ethically motivated, or sustainability motivated. While most stakeholders could be placed into more than one of these categories (this is also true for the ecosystem categories), they are placed into only one motivation category on our stakeholder map for clarity.

### *Project Sponsors*

The first, and arguably most important, primary stakeholder is our SPARK sponsors. They are from the ecosystem of beneficiaries and customers, and they are socially motivated. From our communication with them, we have gathered that the social benefits of this project's completion are more important than the other priorities (except safety which is nearly always top priority). Ultimately, an improvement in the process of lifting/working on the motorcycle will lead to increased success for the team. This success will show through improved rankings at competitions, which leads to a litany of social benefits including: more student interest, more sponsor interest, more attention from the University; along with the benefits of the improved experience for the SPARK team members who will spend less time leaning over and performing the tedious task of using the winch. The ethical implications (improved ergonomics for teammates), sustainability implications (manual lift reduces emissions), and economic implications (successful teams are more likely to acquire funding) are present, but less important in the eyes of our sponsor.

Our sponsor's focus on the social impacts of our design impacts our focus during the design process. While sustainability may be important, it will not be on the forefront of our minds when considering design choices. For example, if a non-manual design is selected in our design selection process, maximizing speed would not be prioritized over the most energy efficient design. Economic and ethical based design choices may also be neglected in favor of maximizing the efficiency and effectiveness of the design, a choice that favors the social benefits of improved success in competitions. These priorities may lead our design to having less of a positive impact on sustainability, ethical, or economical implications in favor of a stronger social impact.

### *Additional Primary Stakeholders*

Beyond the project sponsors, the other two primary stakeholders are the University of Michigan Mechanical Engineering Department and SPARK's Sponsors. The Mechanical Engineering Department is a resource provider due to their financial support, as well as providing professors, lab resources, and access to the Wilson Center. Their primary motivation is social, as the success of the SPARK team that comes from our project reflects well on the department and may improve their reputation. SPARK's Sponsors are complementary organizations who have significant financial power, and benefit from the success of SPARK (SPARK, 2023). Their main motivation is economic, as that is the ultimate goal of most sponsors (even if indirectly), and they will see more benefits from sponsoring a more successful team.

### *Secondary Stakeholders*

As previously mentioned, secondary stakeholders are invested in the problem space and the overall solution for the project. They are not, however, as interested in the specifics of the project, nor are they as heavily involved as the primary stakeholders. The secondary stakeholders we identified for this project include the University of Michigan, opponent teams, future SPARK team members, Professor Barton, SPARK winch-trained members, and the Wilson Center.

The University of Michigan, Wilson Center, and Professor Barton are listed as economically motivated. The university could profit from the increased success of the Mechanical Engineering Department as a result of our lift. Because of their status over the organization, they are viewed as a complementary organization. The Wilson Center will see financial incentive in the decreased usage of their winch as well as less maintenance for their employees; they are also complementary as they provide the workspace and are legitimized by its use. Finally, Professor Barton is economically motivated to complete her job effectively, although she is also a resource provider due to her expertise and time commitment to the project.

SPARK winch-trained members and opponent teams are classified as socially motivated. Opponent teams are opponents or problem makers due to their drive to win competitions and see the SPARK team lose to them. This desire for competitive advantage is social by nature.

Additionally, the SPARK winch-trained members may lose some of their unique value to the team when the system is replaced. They would also likely be pleased with an improved system that still uses the winch, so they could also be viewed as status quo supporters.

Finally, future SPARK team members are ethically motivated. It is clear how they could benefit from the creation of our solution, so their status as beneficiaries and customers is justified. Their ethical motivation stems primarily from the ergonomic benefits they will receive, removing a strain on teammates from bending over.

### *Tertiary Stakeholders*

Tertiary stakeholders are affected only by the big picture implications of the solution. Due to their lesser importance, less detail is required for their analysis. Chock manufacturers are economically motivated by status quo support as the current lift system uses their product. Winch manufacturers are similarly economically motivated however they are in opposition as our solution is meant to remove the winch entirely. Auto shops and part providers are beneficiaries because they could have financial benefits from our product using their parts or our product making auto shop work easier. Motorcycle owners stand to benefit from an improved ergonomic process for working on their motorcycle, but for the most part are minimally affected as our design will likely be tailored to competition settings (so they are affected or influential bystanders).

The final tertiary stakeholders are various levels of government, and the atmosphere. The government is a resource provider due to its funding to the University of Michigan that ultimately has led to our project. They may also provide us with the codes necessary to ensure our product's safety. These are ethical concerns and, thus, have been labeled as such. The atmosphere is an affected bystander that has sustainability related motivation. Simply put, reduced emissions from a manual system would be beneficial for the atmosphere.

### *Stakeholder Engagement*

The stakeholders with whom we plan to keep the highest level of engagement with are our sponsors, the UM Mechanical Engineering Department, Professor Barton, and the SPARK team. Communicating with our sponsors has been streamlined through our usage of a shared Slack space, as well as bi-weekly meetings. The SPARK team members are being engaged through forms that we have sent them where they are able to submit feedback about our design process/decisions/ideas. Professor Barton meets with us twice a week at minimum and will be engaged throughout the process. Finally, we do not plan to engage with the Mechanical Engineering Department as often as the other three stakeholders mentioned, however we do plan to continue to reach out to and collaborate with the university librarian.

## Design Context

For a full design context analysis, it is important to consider the global, cultural, social, and environmental contexts of our project. Ethical considerations including inclusivity and power dynamic considerations are also key.

### *Societal Impact*

There are societal impacts of our project that are not rooted in the interest of our sponsor. Our sponsor wishes to use a new motorcycle lift to aid in competition, however an improved motorcycle lift mechanism could be used in many more applications. There are an estimated 126,356 Automotive Repair Shops in the United States alone, with many more across the world (SICCODE, 2023). Each of them may stand to benefit from improved efficiency and ergonomics that come from our product.

Also, motorcycle owners themselves may benefit from the portability of our design. For example, if one of the 8.6 million registered motorcycle owners in the United States have mechanical issues while away from home and on the road, the ability to easily bring a workstation to the side of the road would save considerable time and effort (IIHS, 2021). On top of this, the number of registered motorcycle owners is increasing over time, with a mostly positive trend in the past 20 years (IIHS, 2021). This lends urgency to our project's completion.

An effective manual option would benefit the environment greatly, as if each of the previously mentioned 126,356 were to stop using motor operated lifts and switch to a manual option, emissions would be reduced (SICCODE, 2023). Also, if we do manage to have a high level of reliability, we could create a product that requires less frequent replacement (less material usage, less strain on the environment).

The cultural impact of our design is small compared to the global, social, and environmental impacts listed above, however it is still present. This product could lead to an increase in motorcycle users when the product displays a high ease of use for motorcycle repair. This minor cultural change could lead to other changes such as a decrease in travel in winter seasons (when motorcycles are less convenient) or an increase in the frequency of shopping trips that citizens will make as a motorcycle does not have the trunk space of a car. These impacts are highly speculative (and likely minimal), but are included for the sake of thorough analysis.

Almost all of our stakeholders would be affected positively by the creation of a new motorcycle lift, as displayed in the stakeholder map on page 12, however there are some that would be affected negatively. As per the stakeholder map, opponent racing teams and winch manufacturers are stakeholders that we have already identified as being negatively impacted due to their reduced chance of winning and the decreased usage of their product, respectively. Two other examples of potential tertiary stakeholders that are negatively impacted include tow truck companies (a portable motorcycle lift work station reduces the need for transport) and chiropractors (less back pain from poorly designed motorcycle lifts leads to less customers).

### *Ethical Considerations*

Ergonomic improvement and emission reduction are the two primary ethical considerations of our project. As referenced, the 8.6 million registered motorcycle owners in the U.S. (and considerably more globally) could benefit from reduced instances of back or spine injuries (IIHS, 2021). Ensuring the absolute safety of our product through a significant safety factor and multiple fail-safes is ethically essential to ensure we do not inadvertently increase the frequency of injury. Also, if our product has a manual option that is difficult to use and is included for the sole purpose of being a backup plan, this could lead to users ignoring the eco-friendly manual option in favor of a convenient powered option. It would be ethically irresponsible for our final design to have a poorly made manual option.

### *Inclusivity and Power Dynamic Considerations*
This product will be used by many different types of people. Ideally, we would like it to be inclusive and have it able to be used effectively by any person. To accomplish this, we need to ensure that the various height settings are comfortable for people at different heights. Also, the manual option for lifting the motorcycle should not require a significant amount of strength to operate, so that even weaker individuals can lift the motorcycle. Moving the product when in portability mode should also be within a reasonable difficulty level.

Within the confines of our group, inclusivity is also important. During design meetings, we are careful to allow all members of the team to speak. The usage of Slack as a communication tool also ensures that louder voices do not outweigh quieter ones. Also, in order to ensure all members of SPARK can contribute, we have made sure to send out forms to the entire team where they can voice their concerns/opinions on various design decisions. While they do not have final say in our design, their voices will be heard.

Within our group we do not have a designated leader, so there is not a power dynamic in that sense. The biggest potential issue that we foresee occurring in regard to power dynamics would be if our sponsor disagrees with the methodology/design process that Professor Barton has tasked us with following. If this were to occur, we would be in a very difficult position. Luckily, this outcome is extremely unlikely given our sponsors have not only taken ME 450 already, but also are aware of the design process we plan to use.

### *Intellectual Property (IP) Analysis*
This project did not require our team to sign an IP agreement before beginning our work, and, therefore, intellectual property has not played a large role as of yet. Because this project is not protected by any IP from outside teams or organizations and we are not employed by anyone, our team will entirely own our legal rights to our proposed solution. If the project is successful, this will legally prevent others from copying the idea and labeling it as their own.

The most appropriate IP protection that could be applicable to our project would be filing for a patent because our team is essentially producing a new invention, whereas copyright is intended for artistic applications, trademarks for logos, and trade secrets for secret devices. In order to qualify for a patent, an invention must be non-obvious, new, and useful. If our team is to accurately navigate through patent laws and requirements, a motorcycle lifting mechanism that is portable, adjustable, and safe to use that differentiates from what is already available on the market could allow us to file for patent IP protection.

## User Requirements and Engineering Specifications
The user requirements and engineering specifications are a vital part of the design process as they provide a baseline of the features that the final design is to be evaluated against. The user requirements for our design were determined based on our meetings with our sponsor from the SPARK team. Our sponsor communicated the requirements of a mechanism design that would prove to be successful for the purposes of the SPARK team's needs.

### *Applicable Existing Standards*

Because motorcycles are so widely popular around the world, there are standards that must be adhered to when they are suspended above the ground or when using powered mechanisms to lift them. These standards are ANSI/ALI ALOIM-2008 (Occupational Safety and Health Administration, 2023), ASME PASE 2019 (ASME Standards Collection, 2023), and ANSI Z244.1-1982 (R1993) (ANSI/ALI ALOIM, 2023) and relate to the safety, inspection, and maintenance of all vehicle lifts and automotive hoists, the safety of Portable Automotive Service Equipment, as well as requiring a safety lockout method in case of an emergency with a machine-powered lift. These standards are regarded in the engineering specifications in Table 1. Additional caution to keep in mind in regard to official documents will be the research of preexisting patents of similar lifting mechanism designs. This will be addressed more specifically in the Project Plan section of the report down below.

### *Verification Plan, Validation Plan, and Importance of User Requirements*

The priority of each of the requirements was determined from conversations with our sponsor and understanding what the most desirable outcomes of a motorcycle lifting mechanism design would be for SPARK. We developed a list of requirements alongside our sponsor, and then created matching quantifiable engineering specifications for all user requirements that can be tested in future stages of the design process. The engineering specifications were first discussed with and approved by the sponsor as well.

The following table shows the finalized list of user requirements as well as each requirement's corresponding engineering specification. Additionally, there are columns for the justification or the reason behind the incorporation of each user requirement, as well as a method to verify that the mechanism successfully meets each requirement.

**Table 1.** The user requirements and engineering specifications for the lifting mechanism design.

| User Requirement | Engineering Specifications | Importance | Justification | Verification Plan |
|---|---|---|---|---|
| **Reliable*** | ● Must operate 150 load/unload cycles without requiring regular maintenance<br>● Maintenance must be able to be completed with only the tools available in the Wilson Center<br>● Lift must be able to operate without the need for an electrical outlet | Necessary | Sponsor estimated 150 cycles as # of cycles per season | ● Perform 150 load/unload cycles on model<br>● Confirm Wilson Center tools<br>● Assess failure modes<br>● Verified through design through incorporation of actuators that can be battery powered |
| **Adjustable** | ● Minimum of 4 discrete height settings spanning a range of $\geq 45$ cm with equidistant offsets between each height<br>● Rear axle of motorcycle must be able reach "hip height" 2.5 ft (Mills, 2007) | Necessary | Allows users of various heights to use mechanisms | ● Physical testing (measure discrete heights on model) and CAD inspection<br>● CAD model inspection |

| | | | | |
|---|---|---|---|---|
| **Able to support heavy load** | • Supports a load of 1500 lbs<br>• Support point loads of up to 350 lbs | Necessary | Estimated max load as 1000 lbs with an applied a safety factor of 1.5 | • CAD stress analysis and static analysis calculations<br>• CAD stress analysis and static analysis calculations |
| **Portable** | • Requires a maximum of 2 adults to transport in trailer<br>• Must have an average time of < 15 minutes for a cycle of mounting and unmounting the motorcycle | Necessary | Allows efficient use by the team | • Ensure weight under 500 lbs through CAD<br>• Mathematical model for time<br>  ○ Time to actuate up<br>  ○ Time to actuate down<br>  ○ Load time<br>  ○ Unload time |
| Easy to use | • Requires only 1 adult to mount/unmount motorcycle | Necessary | Requested by sponsor | • Mechanical advantage calculation for inclined plane<br>• Model investigation |
| Sturdy | • Withstand lateral forces of 200 lbs | Necessary | The mechanism will experience forces and torques by tools through user engagement | • Mathematical model investigation/CAD model investigation<br>  ○ Math model include mass and center of gravity to perform analysis of impact of force |
| Free rotation of motorcycle wheels | • Both front and rear wheels must be able to rotate 360 degrees at speeds up to 150 mph without interference from the mechanism | Necessary | SPARK currently runs the bike while mounted on the table | • Verified through design process |
| Clear sight lines to working areas | • ≥ 7” of clearance under motorcycle | Necessary | Requested by sponsor | • CAD model (measure full scale model to confirm dimensions) |
| Compact | • Packs down into 8.75’ x 2’ x 1’ space | Necessary | Requested dimensions by sponsor to fit into team trailer | • Measure length, width, and height dimensions of mechanism when it is folded down to its most compact form on CAD model |
| Safety | • Have at least one additional safety lockout method for the mechanism<br>• Meet all Wilson Center safety codes (Wilson Student Team Project Center, 2023) | Necessary | Adhering to standard safety code ANSI Z244.1-1982 (R1993) (ANSI/ALI ALOIM, 2023) | • Ensured through design process (lockout bar)<br>• Ensure through Wilson Center safety investigation |

| | | | | |
|---|---|---|---|---|
| Move mechanism with motorcycle mounted | • Require ≤ 100 lbs (Load Movers INC, 2012) of force to move while motorcycle is mounted | Nice to have | | • Use a force scale to measure the maximum amount of force to move the mechanism with the motorcycle mounted on scale model |
| High friction work surface | • Working surface's static coefficient of friction ≥ 0.5 | Nice to have | A high friction working surface to place tools and other supplies | • Verified through design process (material selection of table surface) |
| Travel multiple surface types | • Require ≤ 100 lbs (Load Movers INC, 2012) of force to push mechanism over gravel, dirt, or epoxy coated concrete surfaces | Necessary | The SPARK team travels to competitions in which the mechanism must cross different terrain types | • Use a force scale to determine force required when mechanism is wheeled over specified surfaces on model |
| Damage Resistant | • Will not be visibly damaged by contact with foreign substances, including cleaning supplies, typically used by SPARK team | Necessary | Provides a long lifetime to the lifting mechanism | • Verify by researching material choices |
| Tool Storage | • Must be able to store basic hand tool supplies | Nice to have | Not required, but additional feature that SPARK requested would be nice to have | • Verified through design process |
| Affordable | • Keep entirety of project cost under a $1,000 budget | Necessary | Budget provided by SPARK and UM ME Department | • Verify through bill of materials |

**Bolded** = most important requirements

The results of the verification processes can be found in the "Verification Results" section later in the document on page 65. Detailed validation plans that correspond to these various requirements and specifications can also be found later in the document in the "Final Product Validation Plans" section on page 68.

Most of the user requirements for this project are ones that must be met, however there are some that do not need to be met. Requirements that do not need to be met act as an "added bonus" and do not necessarily contribute to the intended functionality of the design, and serve more as user "wants", rather than "needs".

All of the user requirements and engineering specifications in Table 1 above represent the list of desired outcomes of the motorcycle lifting mechanism that will lead to a successful design as per the needs of the SPARK team. The requirements and specifications are reasonable in a sense that each requirement can be further tested whether it be through finite element analysis (FEA), computational analysis, or physical on-site testing.

### *Understanding Specifications of Existing Products*

Another aspect that was considered during the formulation of the user requirements and engineering specifications was to understand why no other pre-existing mechanisms on the market were of interest to the SPARK team. After taking cost and some of the more important user requirements (specified by our sponsor) into consideration, we compared these against existing lift mechanisms already on the market, as well as SPARK's current mounting method. This information is reflected in Table 2 below.

**Table 2.** A comparison of our project's user requirements and already available lifting mechanisms.

| | | Similar Mechanisms that are already Commercially Available | | | | |
|---|---|---|---|---|---|---|
| | | **Current SPARK table** (Khan, Initial Interview, 2023) | **Pit Bull** (Pit Bull - Spooled Rear, Motorcycle Stand, 2023) | **Pittsburgh** (Pittsburgh Motorcycle, n.d.) | **Auxx-One Lift** (Auxx-One-Auxx-Lift Store, 2023) | **Black Widow** (Black Widow ProLift Heavy, 2023) |
| **Mechanism Features** | **Cost** | – | $200 | $600 | $1,100 | $1,700 |
| | **Supported Load (lbs)** | – | 400 | 1000 | 1400 | 1500 |
| | **Portable?** | No | Yes | No | No | No |
| | **Adjustable?** | No | No | No | Yes | Yes |
| | **Free Wheel Rotation?** | Yes (w/ chock) | Yes | Yes (w/ chock) | Yes | Yes (w/ chock) |

The green highlighted boxes correlated with the success of the mechanism against our user requirement, whereas a red highlighted box correlates to the failure of that user requirement. Not a single one of the already available alternatives for the SPARK team fits their needed criteria, hence why SPARK has reached out to our design team for help. This highlights the importance of how each of the user requirements requested by SPARK must be met in order to ensure the success of the design for their team's purposes.

## Problem Domain Analysis and Reflection

Analyzing the problem domain is one of the most crucial aspects of the design process. It defines the project scope, guides the design process, and lays the foundation for a successful product. Thorough exploration of the problem domain early on in the design process helps to avoid problems down the road and keeps the project on schedule without any major bottlenecks. In addition, it allows the engineering team to recognize and subsequently bridge any gaps in knowledge, information, or resources that may be required to solve the problem at hand.

## Concept Generation

In order to thoroughly investigate the design space and all potential solutions, our team followed a structured concept generation process. Utilizing various techniques, methodologies, and strategies, we worked both individually and collectively to generate a plethora of concepts. By the end of our concept generation phase, we had dozens of ideas that were organized, analyzed, iterated on and prepared for down selection processes. The ultimate process included:

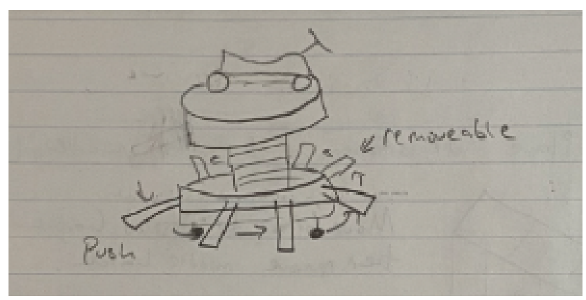
1. Initial Individual Concept Generation
2. Iterated Individual Concept Generation
3. Gut Check and Functional Decomposition
4. Group Concept Generation

Each of these processes are detailed below in the following sections.

### *Initial Individual Concept Generation*

To start the concept generation process, each of us first broke down the project into its major design requirements. Individually, we each came up with the same four requirements of: reliable, portable, adjustable, and able to support a heavy load. Then, we created 20 designs that were meant to be solution concepts for one or more of the design requirements. These designs were meant to be very simple and take no more than 1-2 minutes to complete. This process led to the creation of many unique ideas, as the process of making them encouraged divergent thinking and caused us to think creatively. Some examples from our team are seen in Figure 5 below:


(a)




(b)

**Figure 5:** Examples of Initial Concept Generation. (a) was a quick sketch for a gurney style lift from Becca, and (b) was a rotational corkscrew style lift from Grant.

All 100 of the initial individual designs/sketches produced by the team can be found in Appendix A. Note that the quality of these designs are not meant to be pristine, moreso they are simply vessels to convey ideas and prompt new, more fleshed out design ideas.

### *Iterated Individual Concept Generation*

The next stage in concept generation was to each individually produce 20 new, unique designs. These could either be completely new ideas or iterations of previous designs. Most of these 100 total new designs that the team created were iterations rather than brand new designs. In order to iterate off of the previous designs effectively, we all used our preferred strategy for design iteration.

The three main processes used were functional decomposition, a morphological chart, and design heuristics. Functional decomposition involves breaking a project into its main "functions", and organizing various ideas into set functions. For the sake of our individual concept generation, those of us who used this strategy kept our functional decomposition rather simple and did not break the project down fully into its various components (which occurred later in a group setting). An example of the simple functional decomposition taken directly from Sarah's notebook to aid in her iteration process is shown below in Figure 6:


**Figure 6:** For Sarah's iterated ideas, she first broke down the project into what she considered to be its main functions: lift weight, hold weight off ground, and secure bike.

Functional decomposition (explored more thoroughly later) is useful to help designers get an idea of which areas of the project are not being explored fully, as well as providing a different frame of reference/viewpoint to analyze current ideas. On top of this, functional decomposition works as a great launching point for the creation of a morphological matrix.

A morphological matrix (or morphological chart) is a systematic approach to generating a huge amount of potential ideas. It works by placing one function of the design on an X axis, and another function on the Y axis, then filling the axes with various designs for each function. The individual cells of the matrix represent an idea that combines the two functions. Note that there are other variations of a morphological matrix with tweaks to how it works, but an example of the modified version that some of us used can be seen below in Figure 7:

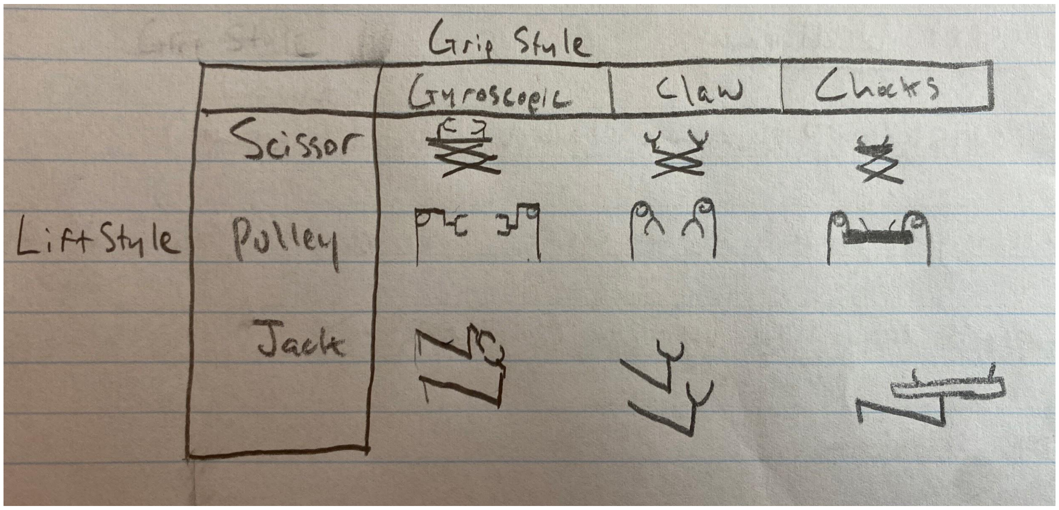



**Figure 7:** Morphological matrix variation from Grant's iteration process. The Y axis shows three design ideas for the lifting mechanism, and the X axis shows three design ideas for the bike grip style. In total, 9 unique and quick ideas were created from this process.

Some of the ideas that occur in a morphological matrix can reveal incompatibility between various function designs, however the quantity of designs this method can produce is very helpful regardless. These designs can be further explored through other techniques, such as the previously mentioned design heuristics. Taken from designheuristics.com, "The Design Heuristics are a result of combined outcomes from research studies, including protocol studies of industrial and engineering designers at varying expertise levels and extractions of characteristics of award-winning products." Each design heuristic card provides two sketches along with a description of the application of the heuristic. Simply put, they are techniques and problem solving strategies that help designers to form and evaluate potential new ideas. Seen below in Figure 8 are two examples where Becca iterated on a previous design using a design heuristic (in blue).

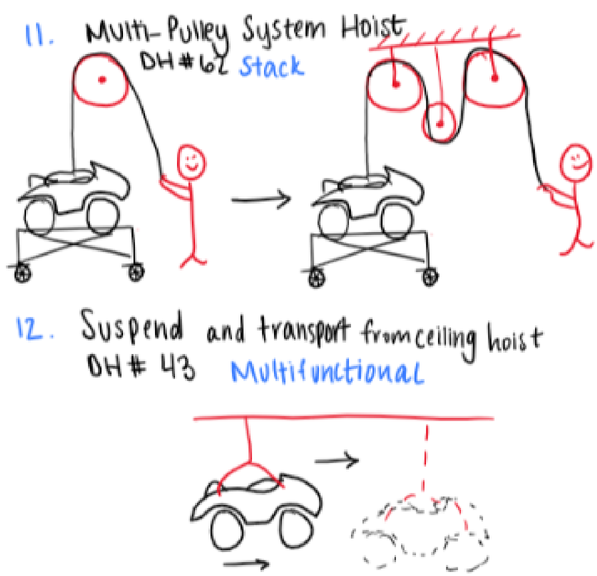



**Figure 8:** Taken from Becca's design iterations, the design heuristic used to iterate on a previous design can be seen written in blue font.

Dozens of different design heuristics cards were used across our combined individual concept generation phases.

One last technique used to help stimulate concept development was quick research into existing mechanical solutions. A brief google image search for “mechanical lifting mechanism”, “claw mechanism”, or “hydraulic lift mechanism” proved for some to be useful in providing examples of existing mechanical solutions that could be incorporated into our designs or simply inspired us to create entirely new ideas we wouldn’t have thought of otherwise.

Finally, with the heuristic cards, functional decompositions, morphological matrices, the original 100 ideas, and some preliminary research, a combined 200 ideas were created. Each of the new 100 designs can be found in Appendix B.

### *Group Gut Check and Functional Decomposition*

The next step in our concept generation process involved each of us presenting and going through all 40 of our individual designs, and writing them out. Rather than spending significant time processing all 200 designs, we allowed ourselves the ability to gut check out the more ridiculous or outlandish ideas. Only around 10% of the ideas listed were gut-checked, proving we kept an open mind even at this stage. Ideas such as “jello-bike lift” and “UFO bike lift”, while fun and creative, were gut-checked out for obvious feasibility reasons.

Our next path forward was functional decomposition. As mentioned earlier, functional decomposition involves breaking down the project into its core functions and dividing our various designs (or components of the designs) into these functions. As a group, we decided the core functions for our project were:

- Lifting Style
- Motorcycle Mounting Style
- Input/Power
- Portability Style
- Extra ideas

With the final category being a catchall for any extraneous ideas that do not fit into any of the other categories. After reviewing each of the 200 designs and dividing them by component functions, we came up with the following list of designs (reformatted with software for legibility) on Figure 9 below.

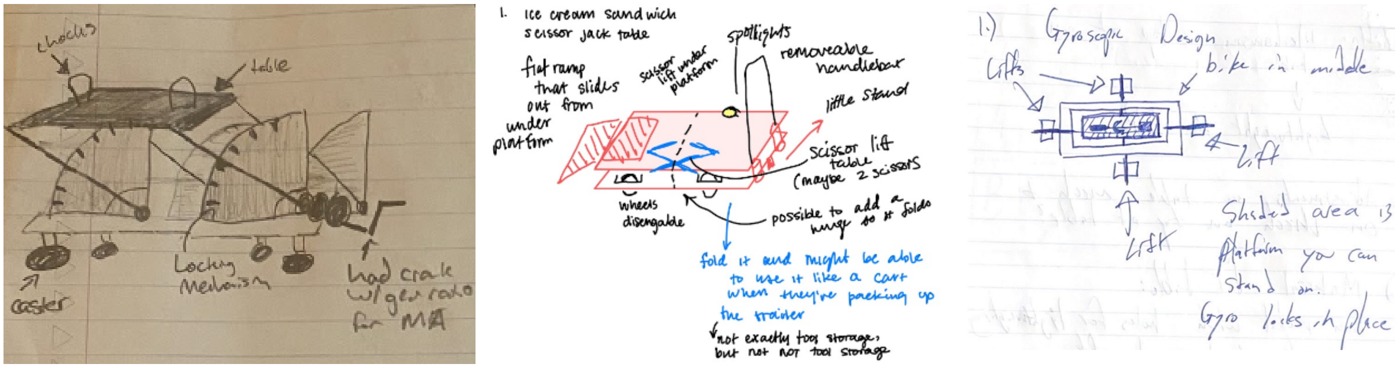
After organizing the designs into these functions, we emphasized the ideas that were formed by multiple teammates independently. This is indicated by the grayed out boxes in Figure 9. This functional decomposition was effective in illustrating which functions had the most/least ideas. The lifting style had the most ideas by far, followed by input/power, mount, portability, and finally extras. It is not surprising that the lifting mechanism had the most ideas, as it is arguably the most crucial function that is most central to our overall design. Regardless, we kept this knowledge in mind when moving forward to our group concept generation phase, focusing on creating new designs in the portability and bike mounting functions specifically, as well as the others.

| Lifting Style | | | Input/Power | | Mount | Portability | Extras |
|---|---|---|---|---|---|---|---|
| Gurney | Car Jack | Snatch Block | Battery | Wheel turn | Table Chocks | Omni-Wheels | Wheel Housing |
| Crane/Dual | Incline Plane | Chock Stand | Autonomous | Capacitor hand crank | Gyroscope | Handlebars | Tool Storage |
| Pulley System | 4 Bar Linkage | Log Cabin Method | Hydraulic | | Straps | Hand Straps | Truss Style |
| Vise-Type | Car Lift | Power Screw | Combo Rack | | Hydraulic Arm | Conveyor Belt Ramp | Hip Sensor |
| Air-Pump | Adjustable Desk | Worm Screw | PiezoElectric | | Gantry | Modular | Hidden Battery |
| “Home Depot” Staircase | Desk Chair | Forklift | Magnetic Step Motor | | Axle Mount | Folding | Lighting |
| Scissor Lift | 3D Printer | Elevator | Pneumatic Motor/Press | | Delta Mount | Transitional Wheels | |
| Dual Scissor | People Lift | | Powered by bike itself | | Magnets | Removeable Mechanism | |
| Winch | 2 Tall Stands | | Pirate Ship Style Input | | Crutch Style | Trailer Ratchet Straps | |

**Figure 9:** The functional decomposition chart. Lifting style function had the most ideas, followed by input/power, mount, portability, then extras. Grayed out blocks represent ideas that multiple teammates had when individually coming up with ideas. Note that this image is a digital rendition of our notes.

### *Group Concept Generation*

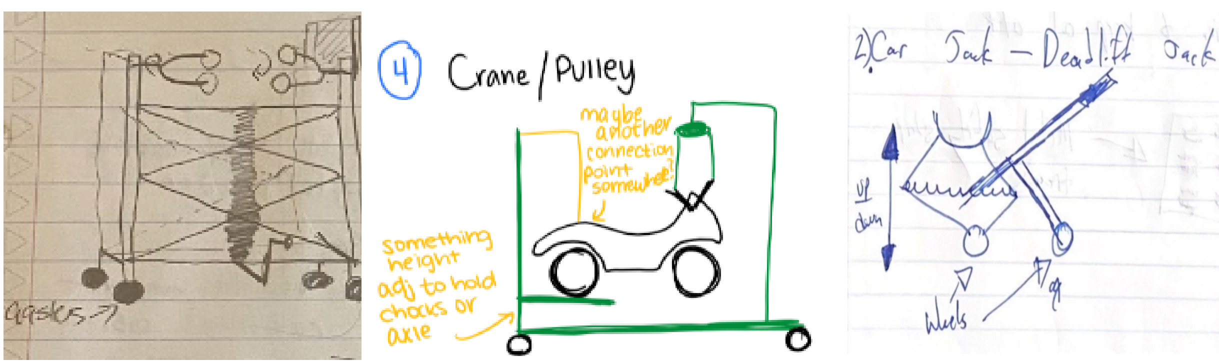
The final stage in concept generation was group concept generation/design. All working in the same physical space, we used large whiteboards as a medium for displaying ideas. To start our collaborative idea creation, we performed functional exploration. This involved using our functional decomposition chart as a pseudo-morphological matrix, combining various function designs with each other to consider their compatibility. We would start by focusing on a single function from the lifting style, then considering the implications of combining it with designs from the other function categories. After doing this for dozens of iterations (documenting some on paper), we began a more loose and freeform brainstorming process. Some of the designs that were recorded are found below in Figure 10 below (the rest of the more detailed concept generation ideas from this phase can be found in Appendix C):




(a) (b) (c)

**Figure 10:** From left to right are figures (a), (b), then (c). Each of these designs spawned from our group concept generation. (a) shows a four bar linkage mechanism that incorporates casters for portability and a hand crank lifting mechanism with gear trains for mechanical advantage. (b) shows a scissor lift mechanism that utilizes a fold down ramp for bike loading, disengageable wheels, a removable handlebar, tool storage additions, and spotlights for increased visibility. (c) shows a gyroscopic bike mount that is supported by 4 power-screw jacks as the lifting mechanism. This design features a removable "skirt" design that fits around the bike and allows for users to stand on it, while still allowing for free-wheel rotation, and allows the gyroscopic rotation when removed.

As previously mentioned, during this brainstorming process, we prioritized ideas that were relating to our less fleshed out functions (while still allowing all ideas from any category to be considered). At this stage, anybody could come to the board and explain/write their idea. We were strict about using "Yes! And?" brainstorming, where no ideas were shut down and all ideas were given at least some time to be considered. After some time with the freeform brainstorming, we added some structure by using mind mapping. Mind mapping is a strategy of brainstorming that involves physically writing ideas on the whiteboard and drawing lines to connect ideas that are related. This process allowed us to better understand how ideas interconnected and played off of each other. Three more designs that resulted from this process and were documented for reference can be found in Figure 11 below:




(a) (b) (c)

**Figure 11:** From left to right are figures (a), (b), then (c). (a) shows a scissor lift mechanism that utilizes a gyroscopic bike holder that is intended to allow rotation of the bike along with discrete height capabilities. (b) displays a crane/pulley baked lift that utilizes a portable frame that connects to a platform for the back wheel and handlebars for the front portion of the bike. (c) features a design that was inspired by the adjustable deadlift jack lift, followed by "Yes! And, what if we made it continuously adjustable?", which produced a design that was a combination of a deadlift-jack lever arm and a power-screw jack.

A timelapse video that captures a small portion of the group brainstorming process can be found below in Figure 12:

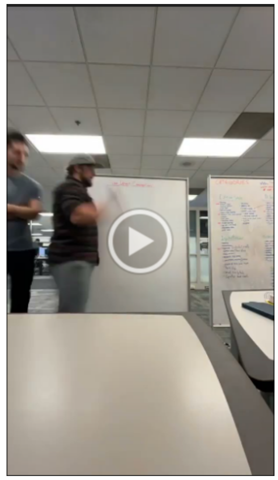


**Figure 12:** Timelapse video from Group Brainstorming process. The video can also be found at https://drive.google.com/file/d/1VCY775YALiS9BIRaAeuuV90g9r2ZC8-s/view

The process of design generation as a whole was very lengthy, taking many hours to do properly, but by the end we were able to feel confident in our exploration of the design space and thoroughly investigated a significant variety of ideas.

## Concept Selection Process

Once our group had completed the concept generation process, we moved on to concept selection. As described above, our group did some informal concept selection by doing a gut check during the concept generation process in order to help manage the large volume of ideas, however a formal down selection process was used as well. As part of our formal down selection process, we used a Pugh chart for every functional decomposition category (with the exception of the extra ideas category). For each chart, various requirements relevant to a particular function were listed and given a weight from 1-5 indicating their importance. The designs were then scored from -2 to 2 for each requirement compared to the current design (Figure 1). A score of 2 indicated that a design was substantially better than the current design according to a given requirement while a score of 1 indicates that the design was still better though not to the same extent as 2. A score of -2 indicates that a design was significantly worse than the current design according to a given requirement while a score of -1 indicates that the design was still worse though not to the same extent as -2. A score of 0 indicates that the design is equivalent to the current design. The Pugh charts were completed as a group and each individual's thoughts were essentially averaged to determine the written scores in the Pugh charts. During DR3, in hindsight, we realized that perhaps a way to reduce bias in this exercise would have been to have each team member complete the pugh charts individually, coming up with our own justifications for the scoring and not being influenced by our teammates, and then comparing across the group and averaging the values.

Note that not every design idea from the concept list that the group generated (seen in Figure 9) was included in the Pugh charts; some ideas that were deemed to be implausible were eliminated by group consensus through a concept screening exercise (Dugan et al, n.d.), while others that were similar were combined into one slightly broader idea and represented this way. Furthermore, ideas that were included in the Pugh charts were not credited to any team member(s) to reduce personal biases by forcing team members to consider each idea objectively and not giving preference to any ideas they personally had contributed. The extra ideas category was not given a Pugh chart as, one, no ideas within it are considered necessary and would not significantly impact the basic functions of the mechanism, and, two, many of the ideas were not mutually exclusive with each other nor any other aspect of the mechanism design so many of the ideas could be incorporated into an Alpha or Beta Design as needed.

### *Lifting Style*

Table 3 depicts the lifting style Pugh chart. Within this chart, the scissor lift design won out with 19 points total. For this chart, the ability to reach different discrete heights was determined to have a weight of 5 as being adjustable in height was a major motivation for our sponsor to commission this project as their current mount is stationary and uncomfortable to use (Khan, Initial Interview, 2023). Bearing a heavy load was determined to have a weight of 4 as it is a safety concern if failure such as buckling occurs or if the mechanism cannot actually lift the motorcycle; it was given a score of 4 rather than 5 as many of the lifting methods can be robust enough to support the necessary 1500 lbs that we have defined, but finding a lifting design that can be set to different heights could be more difficult so we sought to let discrete heights have more weight in the decision. Portability is relevant as the current lifting method is an overhead winch and cannot be transported outside of the Wilson Center (Khan, Initial Interview, 2023)- a weight of 3 indicates that this requirement is important, but as the majority of mechanism usage will be when users are working on the motorcycle and the mount is stationary, it doesn't have the same safety and sponsor driven importance that the previous requirements have. Maintenance is given a weight of 2 as there is some incentive to ensure the lifting mechanism can be maintained and kept clean by users such that the mechanism has a longer lifespan and users can ensure it is safe to use.

**Table 3.** Lifting Method Pugh Chart. Scissor lift is the winner with 19 points.

| | **Design Requirement** | Discrete Heights | Heavy Load | Portability | Maintenance | **Total** |
|---|---|---|---|---|---|---|
| | **Weight** | 5 | 4 | 3 | 2 | |
| **Lift Style Design** | Current Design | 0 | 0 | 0 | 0 | 0 |
| | Gurney | 2 | 0 | 2 | -1 | 14 |
| | 4 bar linkage | 1 | -1 | 2 | -1 | 5 |
| | Deadlift jack | 0 | 2 | 2 | 2 | 18 |
| | Overhead lift | 2 | 2 | 0 | -1 | 16 |
| | 3d printer | 2 | 0 | 1 | -2 | 9 |
| | **Scissor** | **2** | **2** | **1** | **-1** | **19** |

In regards to scoring the designs, for Discrete Heights, all designs were given positive scores indicating that they are capable of meeting multiple heights, which the current design is not capable of doing. If a design was capable of a position on the ground and one additional raised position then the design was given a score of 1. If a design was capable of a position on the ground and multiple raised positions, then the design was given a score of 2.

For Heavy Load, with 4 bar linkage, it was thought that it could be possible to support high loads, but concerns over failure at the joints left the team scoring this as a -1. Deadlift jack, overhead lift, and scissor lift were all given scores of 2 as they were seen as being readily capable of supporting heavy loads due to existing products that use similar designs. A score of 1 was not given for any design, however this would have been given to a design that we felt could support the weight with some modifications or additional structural support. A score of -2 would have been given to designs that would not support the high loads under any circumstances.

With regards to Portability, any design chosen for this Pugh chart was inherently going to be more mobile that the current design. A score of 2 was given to designs that are known to be highly portable, such as the gurney, 4 bar linkage, and the deadlift jack. A score of 1 was given to 3D printer and scissor lift as there was the potential that these may be more bulky and heavy.

For Maintenance, deadlift jack was given the highest score of 2 as it is a single solid piece, easy to wipe down if needed, and usually used none-too-gently in gym settings so maintenance was predicted to be nearly nonexistent. Designs with more hinges and surfaces, like the 3D printer, were given a value of -2 to reflect that some maintenance at these joints or with moving parts could be expected. Gurney, 4 bar linkage, and overhead lift were all given scores of -1 to reflect that they all have some hinges and moving parts, but the team felt that these designs were more reliable and less prone to needing routine maintenance than the 3D printer design. Designs that would have been given a score of 1 would have been low maintenance, but possibly multiple parts or more complex than the deadlift jack.

### *Mounting Style*

Table 4 depicts the mounting style Pugh chart. As shown below, there was a tie between an axle mount and straps. The team determined that axle mounts were ultimately the best mounting design as they were more compatible with the winning designs from the other Pugh charts.

Our team perceived that the mounting style would be less constraining than some other functional design aspects like the lifting style and input style would be. The weights assigned to these requirements are lower because of this. Free wheel rotation, sturdiness, and access to the motorcycle are all given a weight of 2 as they relate to the direct functionality of the mechanism. Free wheel rotation is necessary if the user would like to actuate the drivetrain while working on their motorcycle- a feature our sponsor made sure to mention to us (Khan, Initial Interview, 2023). The user must be able to work on various areas of the motorcycle without their access being obstructed or worrying about the motorcycle mount being unstable, potentially damaging the vehicle or injuring a user.  Feasibility is given a weight of 1 to indicate that how the mounting style will be implemented will be considered.

**Table 4.** Mounting Style Pugh Chart. Axle mounts and straps tied for the win with 5 points each. The team determined that axle mounts were ultimately the best mounting design as they were more compatible with the winning designs from the other Pugh charts.

| | **Design Requirement** | Free Wheel Rotation | Sturdy | Access to Motorcycle | Feasibility | **Total** |
|---|---|---|---|---|---|---|
| | **Weight** | 2 | 2 | 2 | 1 | |
| **Mounting Style Design** | Current Design | 0 | 0 | 0 | 0 | 0 |
| | Gyroscopic | 2 | -2 | 2 | -2 | 2 |
| | Gantry | 1 | -1 | 1 | -2 | 0 |
| | **Axles** | **2** | **0** | **0** | **1** | **5** |
| | **Straps** | **2** | **-2** | **2** | **1** | **5** |
| | Handles | 2 | -1 | 0 | 1 | 3 |

Upon further discussion with our sponsor, as long as our design includes a flat table surface, our mechanism does not need its own built-in mounting feature. This is because the team's current chocks (seen in Figure 1 above) are standalone and can be used on any flat surface. Our sponsor has stated that they have no issues with the current chocks and would use them with a new mechanism (Khan, 2/23/2023 Meeting Notes, 2023). A potential advantage to this option is that the current chock stands have been purchased by SPARK so we know that this mounting style is compatible with their motorcycle and we can potentially reduce costs by not having to design and build a new mounting method.

For Free Wheel Rotation, any method that would allow the wheels to spin freely was given a value of 2 while gantry was given a value of 1 as depending on the design of the gantry, there is some potential for interference with the free rotation of the wheels. Designs that did not allow free rotation or locked the wheels were not considered in this Pugh chart.

With regards to Sturdiness, the gyroscope was given a -2 due to the number of hinges being seen as potential weak points. The straps were also given a score of -2 because they can only support things in tension and need to be applied taunt in order to properly do this. Gantry was predicted to be more sturdy than straps, but may still allow some movement so it was rated as -1. Mounting by the handles was seen as somewhat problematic as the handlebars can rotate relative to the body of the bike for steering purposes and there is some give in the suspension- these movements were predicted to be slight, but not zero so this was given a value of -1. The current setup uses an axle mounted stand thus axle mounts were seen as nearly identical as the current design and given a score of 0.

For Access to Motorcycle, gyroscope and straps were both given a score of 2 as these methods would allow flexibility in the orientation of the motorcycle and should give the best range of access because of this. Gantry was given a score of 1 for potentially allowing different orientations, but having more of a harness and marginally less access than the gyroscope and straps. Designs that did not necessarily improve access, but also didn't impede access were given a score of 0.

For Feasibility, anything that was deemed to be expensive or complicated was given a score of -2. If a design was cheap-but complex or expensive-but simple, it would have been given a score of -1. Designs that were actually capable of supporting the bike in an upright position were given a score of 1. Due to the similarity in the costs and logistics of use for many of these designs, nothing was scored higher than a 1.

### *Input Style*

Table 5 depicts the input/power style Pugh chart. The hydraulic design was the winner of this Pugh chart. Safety was given a weight of 5 due to the predicted heavy load the mechanism will be responsible for lifting. Cost was given a weight of 4 as this is potentially a design constraint of ours (see *Anticipated Challenges* for more details). Feasibility was also given a weight of 4 as there are many options for potential ways to input work into the mechanism system, however not all will be plausible for this specific application and giving this a weight of 4 will help to ensure that the input style compatibility with this mechanism is given proper consideration. Effort and Volume/Portability were both given a weight of 3 as they are conducive to the user experience; a mechanism that is more compact, easy to transport, and does not require an excess amount of manual labor to use will be more enjoyable. The Environmental Impact was given a weight of 1; the input has the potential to be the most environmentally taxing aspect of the mechanism so at least considering this was decided to be conducive to a thoughtful, inclusive design.

**Table 5.** Power Input Style Pugh Chart. Hydraulic is the winner with 21 points.

| | **Design Requirement** | Cost | Safety | Effort | Volume/ Portability | Environment Impact | Feasibility | **Total** |
|---|---|---|---|---|---|---|---|---|
| | **Weight** | 4 | 5 | 3 | 3 | 1 | 4 | |
| **Input Style Design** | Current Design | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Hydraulic** | **-1** | **2** | **2** | **2** | **-1** | **1** | **21** |
| | Lever Arm | 2 | -1 | -1 | 1 | 2 | 2 | 13 |
| | Battery Powered (motor) | -1 | 1 | 2 | 2 | -2 | 1 | 15 |
| | Hand Crank | 1 | -1 | -2 | 2 | 2 | 1 | 5 |
| | Piezoelectric | -2 | 2 | 2 | 2 | -2 | -2 | 4 |
| | Bike Powered | 0 | -1 | -1 | 0 | 0 | -2 | -16 |
| | Manual Capacitor Charge | -2 | -1 | -2 | 0 | 2 | -2 | -25 |

For Cost, we searched online for a rough estimate of the cost of each design. From this, designs that cost more than the entire budget were automatically given a score of -2. The lever arm was given a score of 2 because it was predicted that this could be purchased/fabricated for less than $100, which is very possible within our budget. If something took up the majority of the budget, it was scored as -1. If something was realistically affordable, but not as cheap as the lever arm, it was given a score of 1.

For Safety, piezo electric and hydraulic were given a score of 2 due to the power they could provide. All of the manual options were given a score of -1 because manual actuation could potentially be strenuous if done incorrectly or for extended periods of time.

For Effort, manual designs that require extensive movement were given a score of -2. The lever arm was given a score of -1 as this was predicted to not require as much movement to actuate. The bike was also given a score of -1 as this would still require some human effort to complete. Anything that required near zero effort on the user's part was given a score of 2. A design that would have required some user effort, but not seriously strenuous effort would have been given a score of 1.

For Volume/Portability, all of the input styles could be easily designed to be as good or better than the current design or they would not have been considered in this Pugh chart. Designs that would not add significantly to any one of the overall dimensions were given a value of 2. The lever arm- because of the prediction that in order to get the necessary mechanical advantage, it would have to be quite long- was predicted to greatly extend at least one of the overall dimensions and was given a score of 1 to reflect this.

For the Environmental Impact, designs that did not require electricity were given a score of 2. Designs that used some power, but whose manufacturing was deemed to average in terms of the environmental impact, were given a score of -1. Designs that both used power inputs and had chemicals/environmentally taxing manufacturing were given a score of -2.

For Feasibility, designs that we could not afford (piezoelectric), were not allowed to use (bike powered), or would have near impossible to use (manual capacitor charge) were given a score of -2. Designs that would be reasonably easy to use, validate, and implement were given a score of 2. Designs that were still usable, but more difficult to use or validate were given a score of 1.

### ***Portability Style***

Table 6 depicts the portability style Pugh chart. The removable mechanism was the winner of this Pugh chart. It can also be noted that some of the designs included within this Pugh chart are not mutually exclusive so it may be possible to incorporate more than one into a full mechanism design.

The portability style, like the mounting style, was not deemed to need the same considerations for safety and high priority design specifications. The lower weights reflect this. Sturdiness and Feasibility each have a weight of 3. For this function, it is still important that the style is robust enough to be usable and durable and that it is compatible with the rest of the mechanism. Compact was given a weight of 2 as being compact can directly impact portability. Fast was given a weight of 1 as the user experience is improved if the time taken to pack up and transport the mechanism is short. Maintenance was given a weight of 1 as the portability design feature is something that ideally the user can maintain and keep clean helping ensure functionality and longevity.

**Table 6.** Portability Style Pugh Chart. Removable mechanism is the winner with 10 points.

| | **Design Requirement** | Compact | Fast | Sturdiness | Maintenance | Feasibility | **Total** |
|---|---|---|---|---|---|---|---|
| | **Weight** | 2 | 1 | 3 | 1 | 3 | |
| **Portability Style Design** | Current Design | 0 | 0 | 0 | 0 | 0 | 0 |
| | Modular | 2 | -1 | 0 | -1 | 1 | 5 |
| | Folding | 1 | 1 | -1 | 1 | 0 | 1 |
| | **Removable Mechanism** | **2** | **2** | **-1** | **1** | **2** | **10** |

For Compact, modular and removable mechanism were both given scores of 2 as these would allow users to remove parts and store/move them as they saw fit. Folding was given a score of 1 as it would allow for 1 alternate configuration for storing/moving the mechanism, but you would not be able to completely detach pieces and move them separately if needed.

For Fast, modular was seen as taking too much time to assemble and disassemble earning it a score of -1. Folding was seen as reasonably quick, but potentially taking some preparation or multiple steps and was given a score of 1. Removable mechanism was given a score of 2 as this was expected to be something you could almost just lift off and go.

For Sturdiness, concerns over strength at the hinge landed the folding design a score of -1. Similar concerns over how secure the removable mechanism would be able to attach to the rest of the mechanism earned this a score of -1. Because modular designs in other uses are usually meant to still be sturdy, we felt that a modular design that we came up with would be designed with this in mind and felt that this design was roughly as sturdy as the current setup that SPARK has.

For Maintenance, folding and removable mechanism designs were both given a score of 1 as they were predicted to not need too much maintenance. Modular was given a score of -1 because attaching and detaching the parts was seen as a potential for wear and potentially more maintenance in the long run.

For Feasibility, we had ideas for how to complete a folding design, but we had some concerns as well- the combination of potential improvement and logistical concerns left us rating this as 0. Modular was given a value of 1 because we could potentially work modularity into the mechanism when we are thinking about how to connect and assemble the final design. Removable mechanism was seen as easy to implement and thus given a score of 2.

### ***Results of Down Selection***
With all functional Pugh charts completed, combining these winning designs from each into one Alpha Design was possible. The Alpha Design is to include:

- Scissor lift
- Axle mounts
- Hydraulic input power
- A removable mechanism

Some designs that did not win their respective Pugh charts are considered for usage in Beta Designs. Throughout the down selection process, we did have some ideas in the back of our mind on how to design a mechanism based on designs from the benchmarking that we did. Our concept generation process did draw on some aspects of these as inspiration, however, the wide variety of ideas generated provided us the opportunity to consider other designs. Some designs, for example, a scissor lift, may be considered an "obvious" solution as existing lifting tables use similar designs (for example, Figure 14 page 38), but when considering that these are capable of meeting discrete heights and there is existing proof of concept that they are capable of supporting heavy loads, it still meets our requirements objectively.

## Selected Concept Description: The "Alpha Design"
After methodically exploring all of the possible subfunction mechanisms and determining the strongest mechanism candidates from our Pugh charts, our team was then tasked with creating an "Alpha Design". This is a preliminary iteration of the project design that includes the strongest subfunction ideas from our team's research assembled together to form a single cohesive mechanism that will serve as a foundation for our team to build upon as we move into more detailed design work, embodiment and testing, and direct stakeholder feedback. Our team has created a preliminary sketch of the design to visualize the mechanism shown in Figure 13 below. Additional Beta Designs were generated as well from ideas that were strong but not quite as effective as the Alpha Design's elements. See Appendix D for reference.

# Team 28 – Alpha Design Sketch

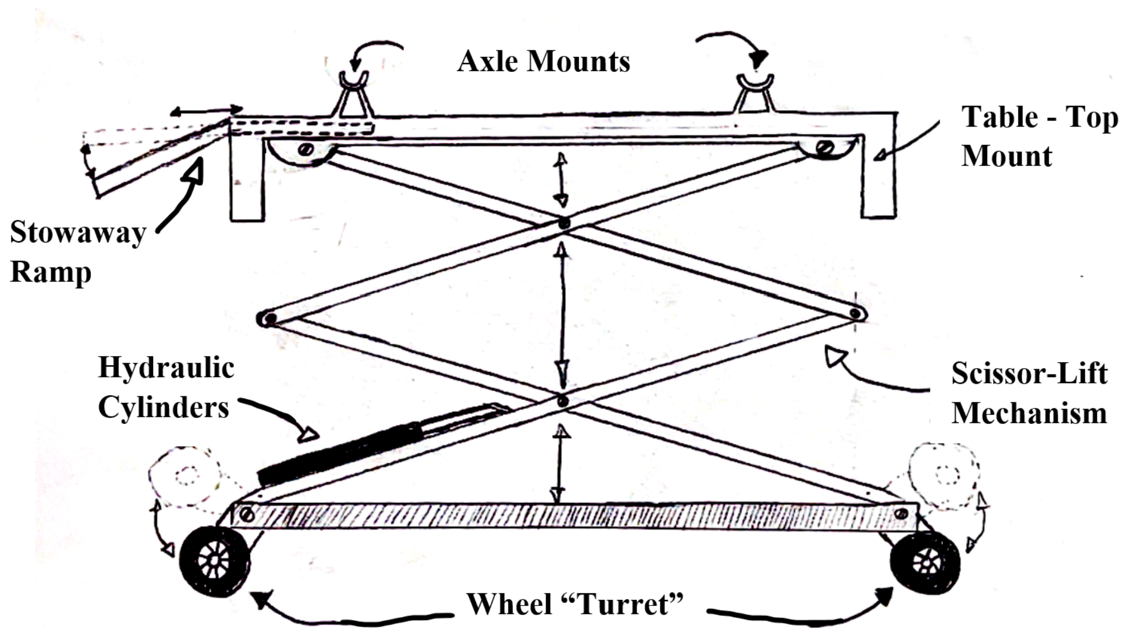



**Figure 13**: Alpha Design. Callouts depict the key features of the design. Note that dimensions are omitted as further investigation is needed to determine them. See Final Design Description below for further detail regarding dimensions and further improvements to this design.

### *Critical Features*

Our Alpha Design incorporates all of the critical features that our team has identified through our Pugh charts, as well as extra concepts that had been discussed in the concept generation phase.

Scissor Lift

> The scissor lift mechanism was chosen as the means to lift the motorcycle, due to its compact dimensions, small floor area requirement, and its ability to adjust easily to the preferred height of the operator (IQS, n.d.). Our proposed design was meant to include some variation of hydraulic cylinder to extend a linear piston, which in turn will apply a force on the scissor lift that will cause the scissor lift links to move into a more vertical position, in turn actuating the linear vertical lifting motion of the mechanism. A scissor lift is compatible with various forms of actuation such as hydraulics, pneumatics, power screws, and electric motors, due to its single degree of freedom. Further, the relative simplicity in design and manufacturing of a scissor lift allows our team a higher probability of success in manufacturing a working mechanism by the end of the semester.
>
> A scissor lift has a complex geometry that is dependent on the force that needs to be applied, the load that is being lifted, the distance that the load needs to be lifted, and the stroke distance of the hydraulic cylinder. These constraints, when analyzed through various engineering methods, ultimately determine the geometry of the final scissor lift design.

Hydraulic Actuation
Our Alpha Design features a hydraulic cylinder with the sealed end attached to the bottom of a scissor link and with the piston end attached to the adjacent scissor link at a point slightly above the bolt connecting the two arms. This allows for the force produced by the hydraulic actuator to be applied at a distance from the axis of rotation, creating a torque that forces the scissor arms into a more upright position. The hydraulic piston can be actuated either through the manual use of a lever-arm jacking mechanism, similar to a hydraulic car jack, or it can be powered with an electric pump. Our current plan is to provide both options through the use of a rechargeable battery as well as a detachable lever arm. This allows for the ease of use of an electric pump, but also the versatility of a manual jack in the scenario that the battery runs out of charge. The exact configuration of the hydraulic actuator at this point in the design had not yet been finalized, as several static analysis tests needed to be performed to determine which configuration is the most optimal. Other possible configurations of the hydraulic cylinder include a horizontal hydraulic cylinder that forces the base of the scissor linkage closer together or a hydraulic piston applied vertically on one (or both) sides of the scissor lift, shown below in Figure 14. Another consideration in the final configuration is the feasibility of mechanical stops to prevent the collapse of the mechanism in the case the hydraulics fail.

To gain an understanding of the magnitude of forces that need to be generated, our team performed a mechanical advantage analysis on the scissor lift. Mechanical advantage is defined as follows:

$$MA = \frac{F_o}{F_i} = \frac{D_i}{D_o} \tag{1}$$

Where MA is Mechanical Advantage, $F_o$ is the output force, $F_i$ is the input force, $D_i$ is the distance over which the force is applied, and $D_o$ is the Distance that the load moves. With the assumptions of a hydraulic piston that has a stroke length of ($D_i = ⅔$’) and through that stroke length will travel from a height of 0 to a “hip height” of $D_o = 2.5$’, the Mechanical Advantage could be determined as 4/15. For this preliminary calculation, the weight of the lift itself was assumed to be zero, meaning the scissor lift only lifted the mass of the load and not its own mass. Rearranging the equation, we are able to obtain

$$F_i = \frac{F_o}{MA} \tag{2}$$

Where $F_o$ is the required load weight of 1500 lbs, and F is the force of the hydraulic piston required to lift the load. From this analysis, the required input force of the hydraulics is 5625 lbs. This force exceeds some typical market hydraulic pistons, however the total input force can be increased through the use of more pistons in parallel. Two pistons would cut the required input force per piston in half, and thus a generic hydraulic piston such as the Magister 1.5" bore x 8" stroke cross tube hydraulic cylinder (Magister Hydraulics, 2019) could be used.


(a) (b)

**Figure 14:** Examples of Different Scissor Lifts. (a) depicts a vertically actuated scissor lift (Eoslift USA, n.d.) while (b) depicts a horizontally actuated scissor lift (Vestil, n.d.).

Removable Mechanism

One of the main goals of making a removable mechanism was to allow for flexibility in the choice of the table surface. With a removable mechanism, the scissor lift has the potential to lift the current table that UM SPARK is using. With this design consideration in mind, our team can prioritize the creation of the scissor lift mechanism, which will expedite our schedule. A removable surface will also allow for interchangeability of the surface table without needing to replace the entire lift mechanism. Having this capability can prove useful if the construction of the motorcycle severely damages the table surface, or if the team has differing work-surface needs for future applications. The securing method of the table is an important consideration for user safety. Our team has not finalized a design, but current considerations are latches, spring loaded bolts (similar to an adjustable weightlifting bench), bolt and cotter pins, and other similar methods. In this design consideration, safety of the user is paramount.

Axle Mounts

The Alpha Design uses a similar mounting style to what the team currently uses. By adding to existing design, the axle mounts incorporated into the table eliminate the user’s need for chocks to mount the motorcycle. The axle mounts allow for easy mounting, as the motorcycle is rolled between the two stands, where it is then lifted.

Stowaway Ramp

While a scissor-lift provides excellent vertical range and can become very compact, one problem that arises is the issue of getting the motorcycle on top of the mechanism in the first place. After weighing out several options, our team determined that a scissor-lift can collapse close enough to the ground to wheel the motorcycle onto the platform with the use of a simple ramp. The current design is a stowaway ramp built into the top of the scissor-lift mechanism. The ramp will not be part of the working-table surface, but rather the scissor-lift mechanism itself.

### *Extra Features*

The goal of our product is to create a product that holistically improves the experience of UM SPARK team members. Because of this, our Alpha Design incorporates extra features that allow for efficiency increases, quality of life improvements, and aesthetic appeals (not shown in CAD but to be incorporated into final product)

Slip-Resistant Metal Tread Grating

> This feature is applied to the working-surface table and serves several purposes. First and foremost, it reduces safety risk for users by preventing unwanted slipping. Secondly, the holes in the surface prevents puddling of any fluids that are commonly used in automotive uses, such as oil or transmission fluids, and allows for easy washability of the surface. Further, using a metal material increases the stiffness to volume ratio, ensuring that the surface can withstand any bending moments or applied stresses. Finally, it lightweights the product by reducing the volume of material used in construction. This decreases the stress on the scissor-lift mechanism, as it will contribute less to the total mass that needs to be raised, as well as improves the ease of portability, making the design have a higher probability of passing the portability validation test.

RGB Light Strips

> This idea came from a teammate's family member that is a tertiary stakeholder (general motorcycle user). By attaching customizable RGB light strips to the surface of the table, the design simultaneously provides extra lighting to the underside of the motorcycle to aid in construction, as well as enhances the overall aesthetics of the setup. While not a necessary requirement, the aesthetics of the mechanism are important to consider as it helps to attract more prospective members and improve the overall image of the team.

Tool Storage

> During our initial stakeholder meeting, our sponsor emphasized the importance of having available space on the working surface to store tools. Our team's Alpha Design will incorporate detachable tool storage pockets, allowing for easy swapping between tools, as well as flexibility in tool storage placement. This allows the user to move the tool storage pocket to a location that minimizes the time it takes to switch tools, as well as preventing the tool storage bag from getting in the way of accessibility to the motorcycle.

### *Alpha and Beta Stakeholder Feedback*

A crucial part of the design process is having continuous stakeholder engagement throughout its duration. By incorporating direct, unbiased feedback from stakeholders that are familiar with the problem domain area, our team can gain insight into potential challenges in the design, as well as identifying the features and functionality that should stay in the final product.

Our team has scheduled meetings with our sponsor multiple times throughout the design process thus far, and we have had direct contact as well through Slack for any small questions that arise. We met with our sponsor on February 23, 2023 where we presented our initialAlpha Design. Our aim in the meeting was to receive feedback from our sponsor without influencing his responses through any sort of bias. To ensure this, we presented our initial Alpha Design and allowed our sponsor to lead the discussion. From this discussion, our team received extremely valuable feedback for our design. The feedback we received is as follows (Khan, 2/23/2023 Meeting Notes, 2023):

Most Critical:
- Design must ensure that slipping is not an issue.
- A locking mechanism that ensures there is zero chance that the mechanism falls while a user is on it in the case of a mechanism failure.
- Prioritize having a form of manual actuation over anything. The current design of a manual hydraulic pump would meet this requirement very well. Having a backup form of actuation would however be very nice to have, such as a battery.
- Built-in axle mounts are not necessary, and the current chock design will meet the functions that the team needs.

Other Feedback:
- Removable table surface is a major positive. This is wanted in the final design version.
- Intermediary steps such as our folding step-ladder design are not necessary. The team has step-ladders available in case shorter members are unable to step up onto the platform.
- Heavy-duty casters that can lock in place will meet their needs for transportation.

## Engineering Analysis

Static analysis was conducted on various parts of our mechanism to determine whether our design would be able to withstand the maximum loading conditions without significant stress concentrations or deformation. This analysis was used to determine whether the design could meet the loading requirements while minimizing mass and volume when possible. Our team deemed that static analysis most accurately represented our system, as the lift will be held in static equilibrium for the majority of its duty cycle. The acceleration of the lift was small enough that static equilibrium equations would accurately give results that will reflect the behavior of the lift.

Due to issues with constraints and boundary conditions in CAD, we were unable to perform an FEA analysis for the entire system at once in SolidWorks, and thus had to find an alternative method. To circumvent this issue, we split the table into 3 subsystems that would be analyzed: Table Subsystem, Scissor/Base Subsystem, and Hydraulic Axle Subsystem. This broke the analysis down into manageable parts, and the connections between subsystems could be represented with torques and point loads in the CAD model for FEA analysis of each subsystem.

### *Table Subsystem*

The table subsystem consists of the table surface, a support beam, the scissor-arm slider connecting joint, and the scissor-arm pin joint. The goals of the analysis on this subsystem were to determine the deflection and stress concentrations on the table surface and verify that the table could withstand operating conditions required by the SPARK Racing Team. The results of this analysis are a change in connecting joint locations (and subsequently, scissor arm length), and the addition of a support beam under the table. The CAD subassembly also allowed us to determine the location of the Center of Mass (CoM) of the table surface subassembly, which would be used in the static analysis of the scissor/base subsystem.

Static Analysis

In the initial design of our mechanism, the table surface had a thickness of 2 inches and the pin and slider joints were at the very corners of the table. We performed two static analysis tests in CAD with an evenly distributed mass of 1500 lbs applied to the top face of the table surface in one test and 2000 lbs in the second, and applied the external forces due to gravity in both, which accounted for the table's own mass in the deflection and stress calculations. The fixtures applied were a "Roller/Slider" applied in each of the two slider joints, and a "Fixed Hinge" applied to each of the pin joints. Figures 15 and 16 show the results from the 2000 lb test.

Assumptions for FEA analysis of table subsystem:
- Uniform density in table
- Uniformly distributed force applied to top surface

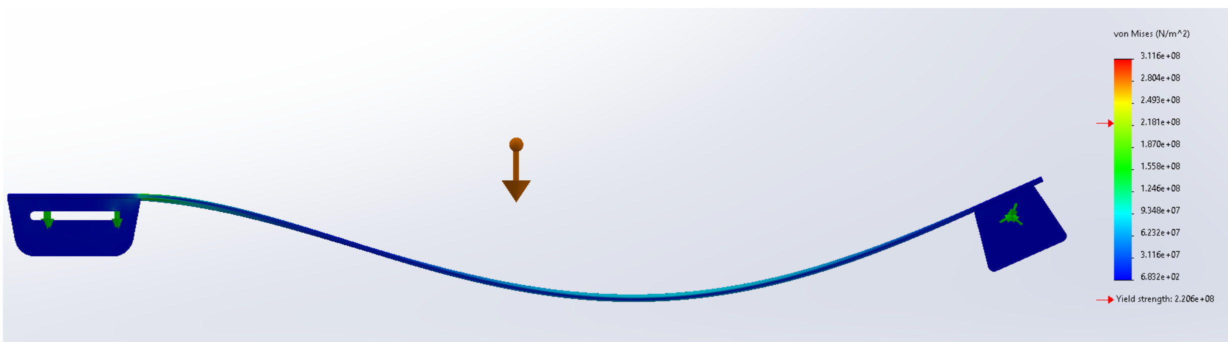



**Figure 15:** Stresses experienced by the table surface under a distributed load of 2000 lbs. The maximum stress is about 311.6 MPa, which is greater than the yield stress. Therefore, the table surface would yield under these conditions.

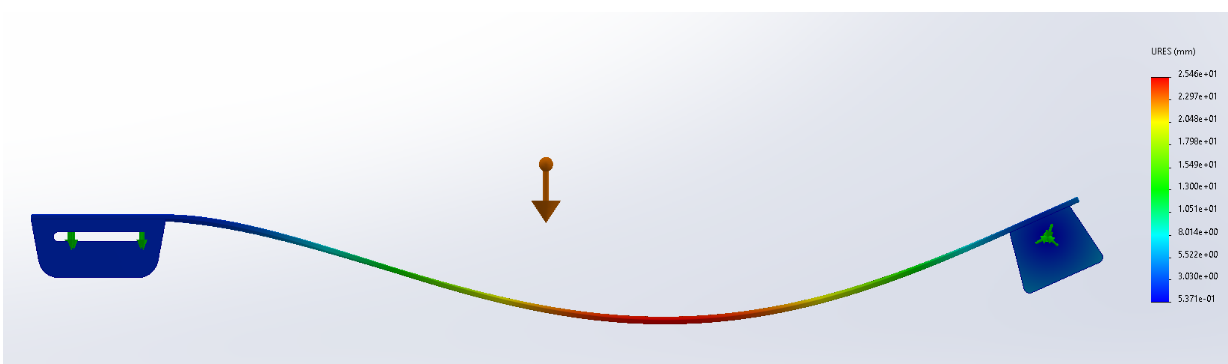



**Figure 16:** Displacement of the table surface under a distributed load of 2000 lbs. The maximum deflection is approximately 2.5 mm.

These figures may appear to be heavily distorted, but the deflections were exaggerated to emphasize where the maximum deflections would occur. The actual deflections can be seen in the legend on the side of the figures. These results made it clear that an additional support was necessary under both the 1500 and 2000 lb loading conditions. While the surface had not reached yield stress, it was close enough to produce more deflection than was deemed acceptable. Another consideration that went into this decision was the goal of a long lifespan - although it is not reaching yield stress, repeated cycles of stresses close to yield will cause the material to fail sooner due to fatigue. The addition of the support beam reduced the stresses in the beam by magnitudes of 10, and thus will drastically increase the lifespan of the table. We plan to also use a metal safety grating surface for our table surface in the final product, which would alter the mechanical properties of the table. The sheet metal undergoes work hardening when the perforations are made, thus making the metal stronger, however the holes may cause stress concentrations in the metal netting. SolidWorks could not mesh properly when this design was incorporated, so we added an additional safety factor to hopefully account for those variables, and a support beam underneath provides more confidence that the design will work. Empirical testing is recommended to find the material properties of safety grating to ensure that the final design will support the necessary 1500 lb load capacity.

Further, these stress tests made us reconsider the placement of the slider and pin supports. Placing the supports at the end of the table created the largest bending moments possible in the table, so we revised our design to bring the supports closer to the middle of the table, reducing the stresses on both the table and the scissor arms. With the same fixture conditions as stated above, tests were conducted with the edge of the slider support at a constant 15 inches from the end face of the table, and varied the position of the pin support axis between 20 - 25 inches from the other table end face, varying by 2.5 inch intervals. The 2.5 inch increments were chosen to aid in ease of manufacturing, as it is easily measurable. The following images show the deflections of those tests.

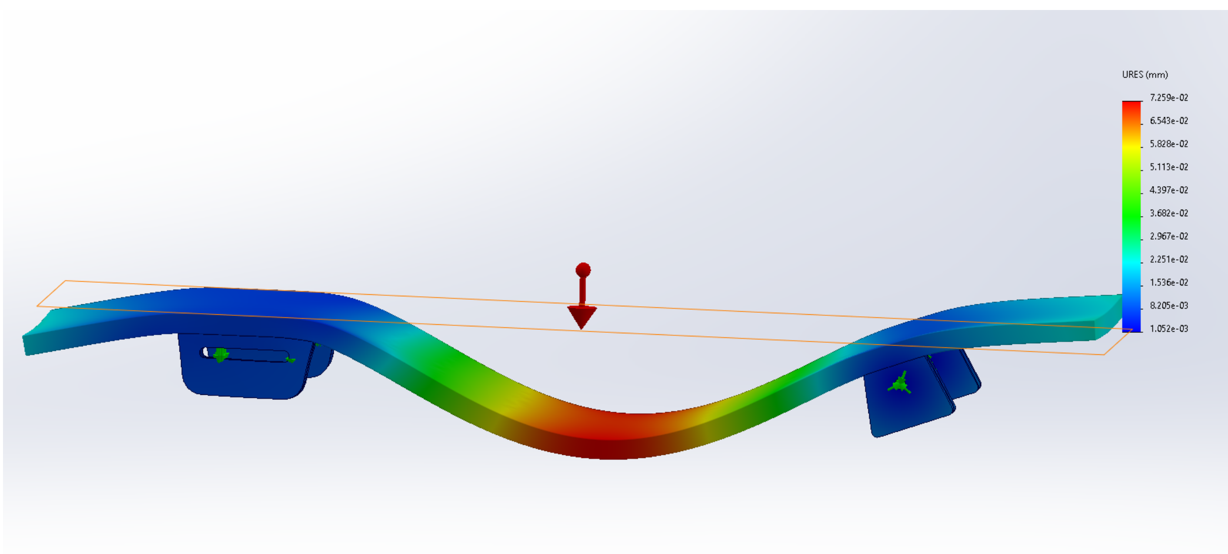



**Figure 17:** Deflection of the table surface with the Pin Axle 20 inches from the end of the table. The maximum deflection is about 0.02 mm.

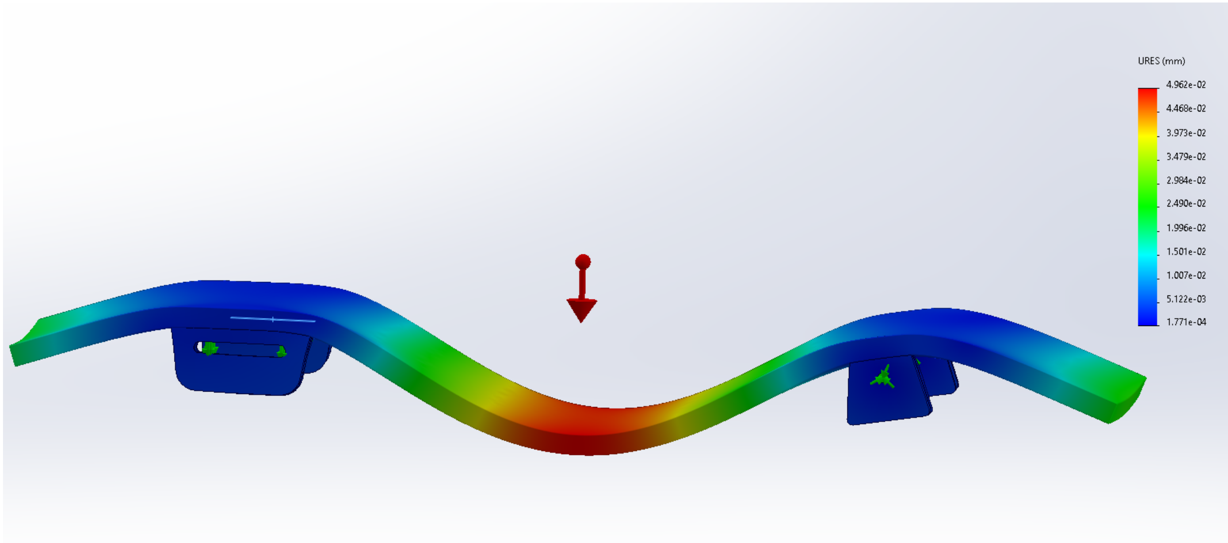



**Figure 18:** Deflection of the table surface with the Pin Axle 22.5 inches from the end of the table. The maximum deflection is about 0.04 mm.

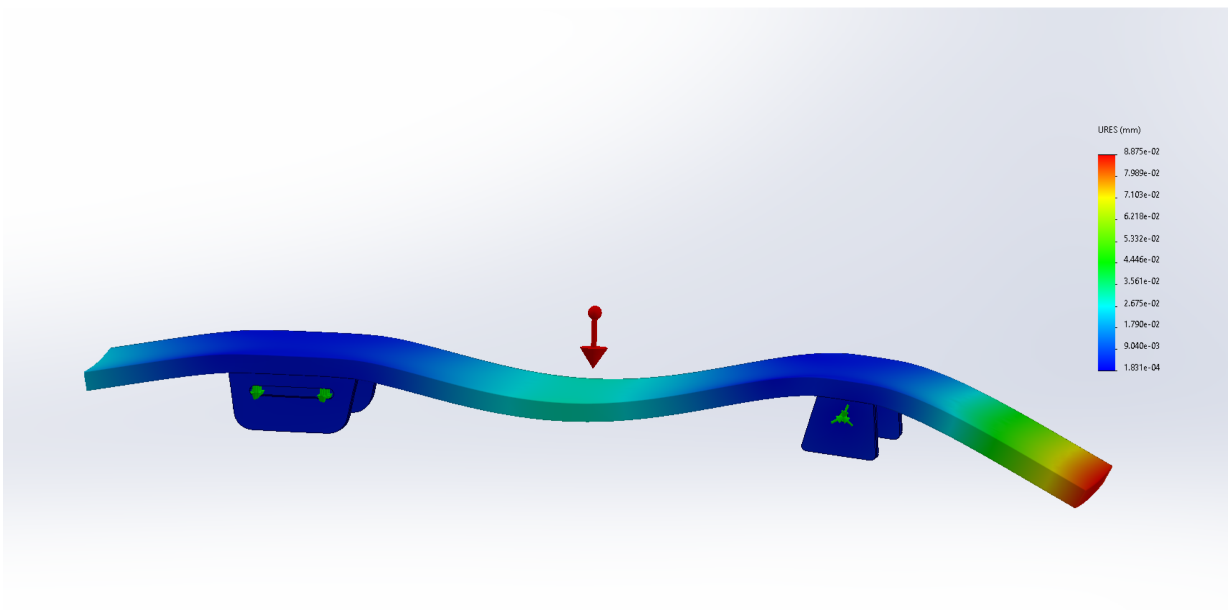



**Figure 19:** Deflection of the table surface with the Pin Axle 25 inches from the end of the table. The maximum deflection is about 0.08 mm.

*Note: All of the pin location tests were performed with a 2-inch thick table surface. The location of stress concentrations relative to the long axis of the table will remain the same, only the magnitude will change.

Lastly, simulations were performed to determine the optimal support beam height. The heights tested were 4 inches, then 2 inches, and then finally 3 inches. The 4 inch test could easily withstand the applied loads, thus 2 inches was tested next. This support beam could not support the load, and thus a middle ground of 3 inches was tested. As both the 4 inch and 3 inch heights could manage the applied loads, the 3 inch tall beam was chosen, as it minimized the additional mass of the table. Figures 21 and 20 below show the stress and deflection of the final design.

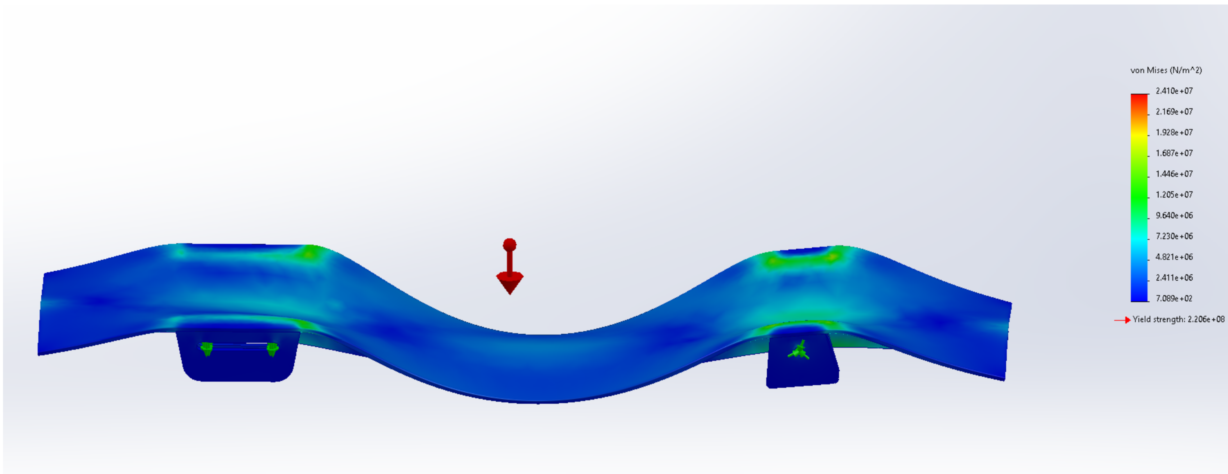



**Figure 20:** Stress of the final table surface design. The maximum stress is about 24 MPa which is well below the yield stress of 220 MPa.

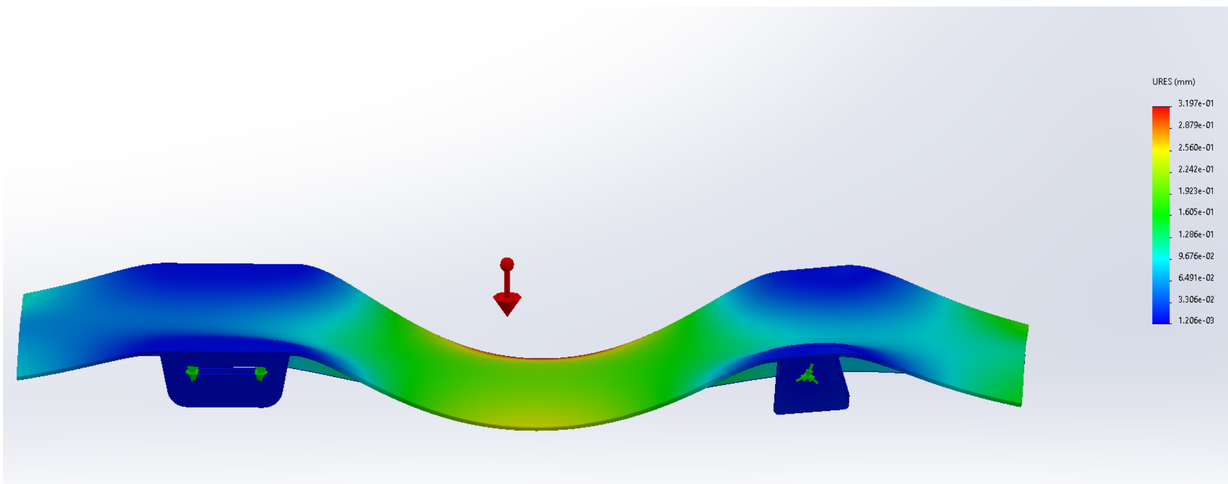



**Figure 21:** This figure shows the deflection of the final table surface design. The maximum deflection is about 0.3 mm.

## *Scissor/Base Subsystem*

This subsystem was a viable option for the scissor arms because the arms support 100% of the load weight during operation. The lockout bars will only be engaged when the lift is falling downwards due to hydraulic failure, and thus a simulation only needs to be performed under the maximum loading condition. This greatly simplified the problem, as the forces in the axles connecting the scissor joints to the table surface could be solved by using static equilibrium conditions on a Free-Body Diagram of the top surface subsystem, analyzing torque about the pin joint. With the current table mass and design, the following equations were solved for (See Appendix E for process).

$$F_{Slider} = \frac{30P + 31.21W}{X}$$

$$F_{Pin} = P + W - F_{Slider}$$

where $P$ is the applied load (1500 lbs in maximum load scenario), $W$ is the total weight of the table and connecting supports (485.56 lbs), and $X$ is the distance between the pin reaction force and slider reaction force. $X$ was chosen in 3 scenarios; Low position, where the slider pin is closest to the short edge of the table; Middle Position, where the slider pin is exactly in the middle of the slider slot; High position, where the slider pin is as close to the center of the table as the slot allows. The geometry of the isosceles triangles created by the scissor arms determines the angle that these arms are at, and thus, define the height that the table reaches in these positions as well as the forces felt.. These three scenarios were examined, and the resulting Table 7 below details the loading conditions found for each scenario.

**Table 7.** This table shows the results of the analysis performed on the scissor lift at different heights.

| | Low Position | Middle Position | High Position |
|---|---|---|---|
| X (inches) | 64.00 | 60.75 | 56.75 |
| α (degrees) | 8.73 | 20.24 | 28.783 |
| H (inches) | 9.826 | 22.404 | 31.176 |
| $F_{Slider}$ (lbs) | 939.720 | 1001.595 | 1072.191 |
| $F_{Pin}$ (lbs) | 1068.029 | 1006.155 | 935.558 |
| Stress Ok? | Yes | Yes | Yes |

These values also validate the design goal of minimizing the difference between the Slider and Pin support forces, which distributes the load more evenly and leads to a longer lifespan of the mechanism. It also confirms that the design can reach “hip height”, as shown in the H column, and thus validates that portion of the Adjustable specification.

Assumptions made in the static calculations:

- Force is evenly distributed on the table
- 2D simplification since CoM lies directly on the long axis of the table, symmetry of the forces and geometry allowed for simple 2D analysis. Forces in each axle of the scissor were then simply the corresponding forces divided by 2.

***Static Analysis***

Once these values were found, a static simulation study could be performed in CAD using Fixed Hinge conditions in the pin-side axles of the scissor arms, and Roller/Slider fixtures in the slider-side axles of the scissor arms. Point forces were then applied to each pin and slider, producing the results shown in Figures 22-24 below. All three scenarios had peak stresses well below yield stress and negligible deflection.

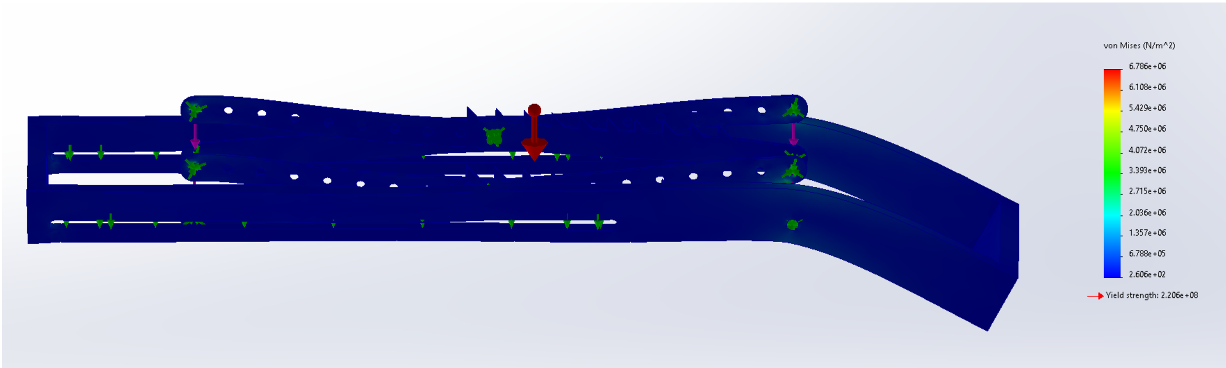



**Figure 22:** This figure shows the stresses experienced by the scissor arm and base in the low position. The maximum stress is about 6.5 MPa which is much lower than the yield stress of 220 MPa.

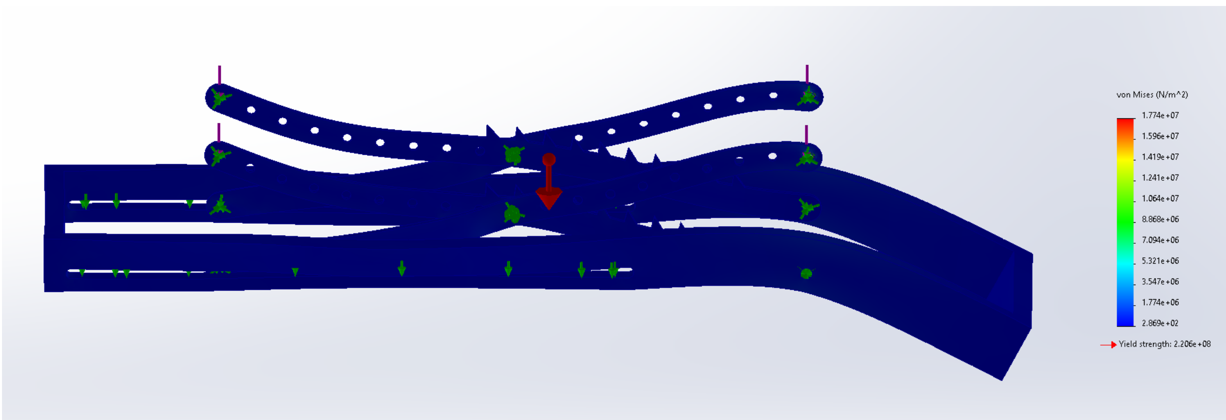



**Figure 23:** The stresses experienced by the scissor arm and base in the middle position. The maximum stress is about 12 MPa which is much lower than the yield stress of 220 MPa.

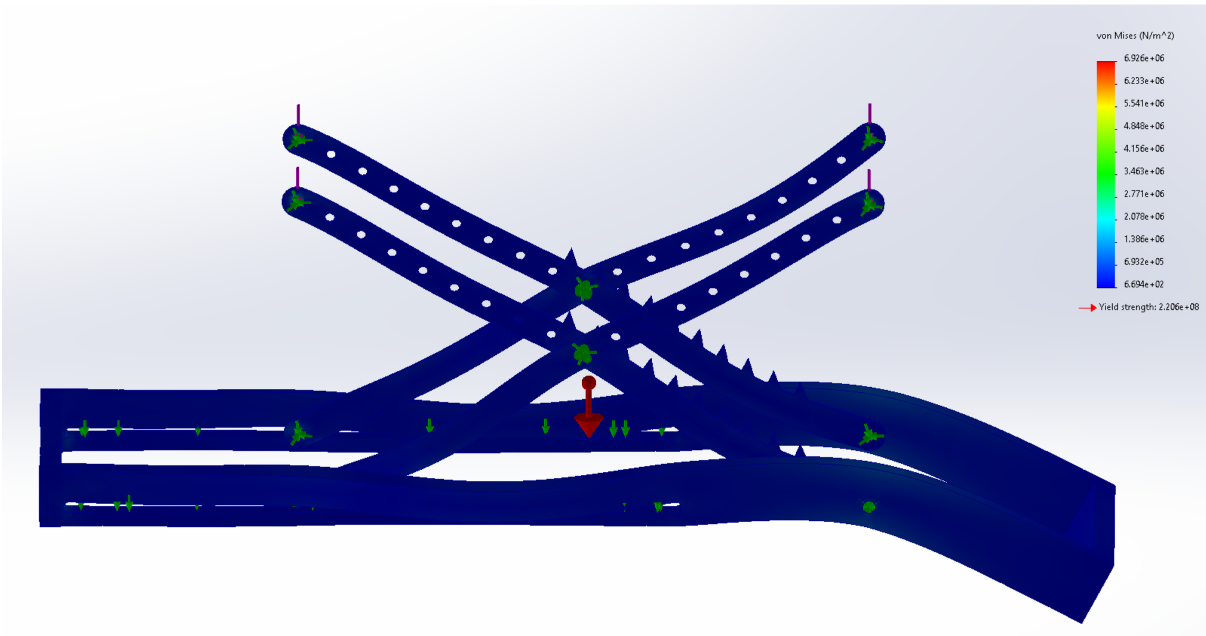



**Figure 24:** The stresses experienced by the scissor arm and base in the high position. The maximum stress is about 6 MPa which is much lower than the yield stress of 220 MPa.

## *Hydraulic Axle Subsystem*

An analysis of the stresses and deformation on the axle that connects the bottom of the scissor arms on the side experiencing forces directly from the hydraulic piston was needed. Due to the complexity of the analysis on a curved surface on the CAD software, we decided that it would be easier to do a static analysis by hand. The analysis is shown in Figure 25 below.

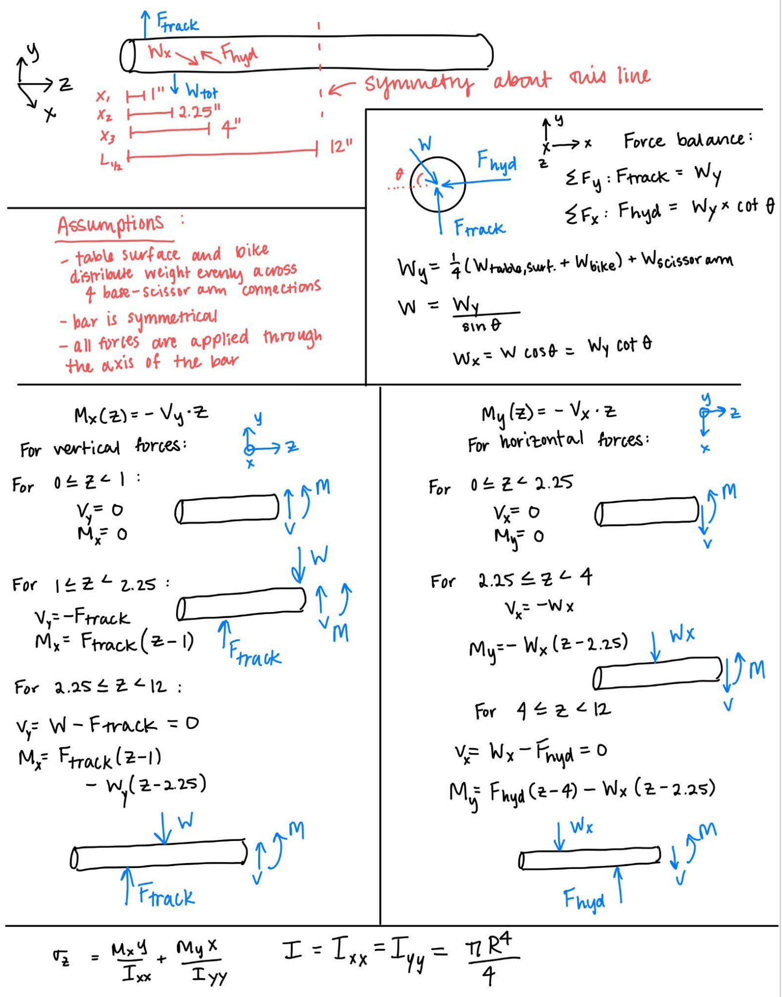



**Figure 25:** This figure shows the process used in the static analysis of the axle bar.

For the remainder of the requirements (Adjustable, Portable, and Reliable), we relied heavily on visual inspection of the CAD model since the specifications did not require calculations to be verified. In regards to the "adjustable" requirement, we were able to raise and lower the mechanism to at least four discreet heights over a span of 17 inches, which can be seen in Figure 26 below (previous iteration of lockout bar shown).

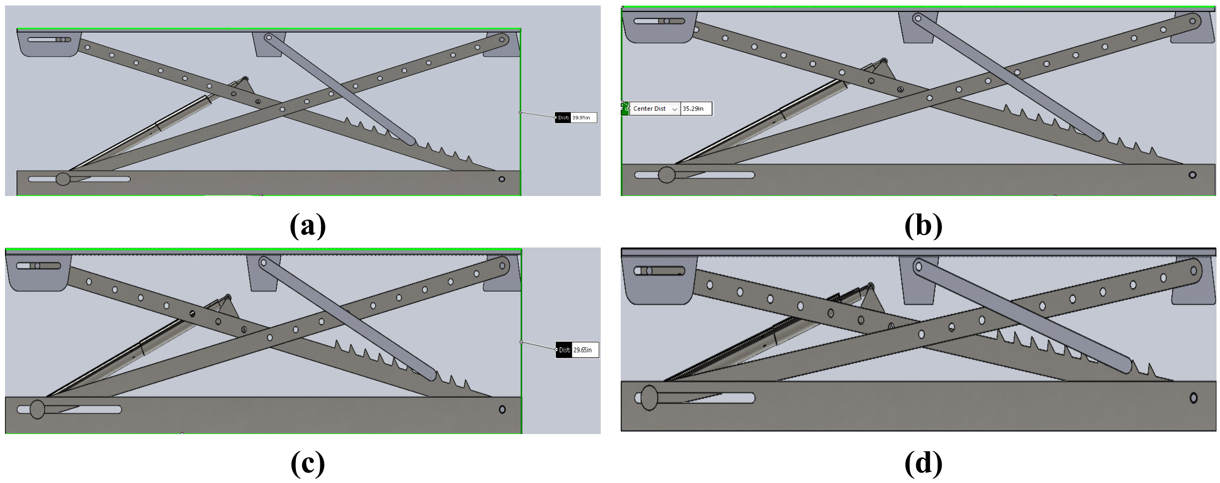



**Figure 26. (a)** Shows the mechanism at a height of 39 inches with the lockout bar secured on the fifth notch from the bottom. **(b)** Shows the mechanism at a height of 35 inches with the lockout bar secured on the fourth notch from the bottom. **(c)** Shows the mechanism at a height of 29 inches with the lockout bar secured on the third notch from the bottom. **(d)** Shows the mechanism at a height of 22 inches with the lockout bar secured on the second notch from the bottom. Note that these images do not contain the second lock out bar which was added later in development. Other dimensions have remained the same so the pictures are accurate.

To verify the “portability” requirement, we looked at the mass of the entire mechanism on the CAD software. In order to satisfy the portability specifications, the mechanism needed to weigh less than 500 lbs to allow for minimal human effort in loading the mechanism into SPARK’s trailer for transport to competitions. From this analysis, the total weight of the mechanism was 1600 lbs, which is well over 500 lbs.

For the reliability requirement, we needed to verify that SPARK would be able to repair the mechanism in case it were to fail. From the stress analyses previously described in this section, we were able to see that the most likely case of failure for the mechanism would be failure in the joints and fasteners. Therefore, we needed to ensure that the joints and fasteners could be repaired using tools that SPARK has access to in the Wilson Center. Upon communicating this with our sponsor, we were able to determine that this is the case. As for the rest of the specifications corresponding to this requirement, we were able to verify from our CAD model that the hydraulic piston can operate without an electricity source, additional tests either virtually on a physical model are needed to determine whether the mechanism would be able to withstand 150 load cycles. Although this would not accurately reflect the wear that would occur in the mechanism over its full lifetime, we do believe that these tests would give insight as to whether the mechanism could physically withstand 150 load cycles.

## Final Design Description

The Final Design can be separated into easily identifiable subsections, which allows for detailed engineering analysis to be applied, such that the analysis could inform the final design. The subsystems of the lift can be broken down into the Table Surface, Actuation, Lockout Mechanism, and Base. The overall design is pictured in Figure 27 below.

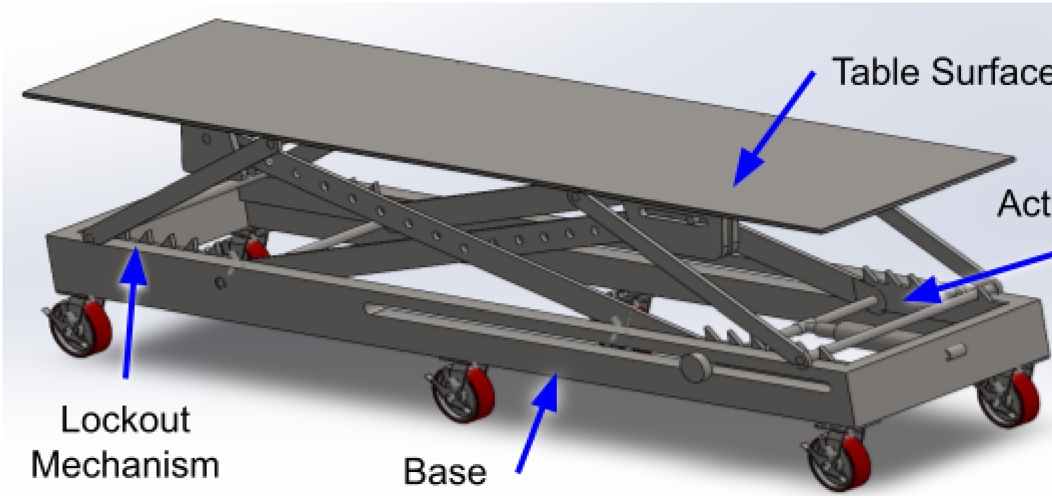



**Figure 27:** High level overview of final design. The main subsystems are labeled. More detailed descriptions of each can be found within their various subsections.

### *Table Surface Subsystem*

The table surface subsystem consists of the table surface itself, a strengthening rib, and the connection fixtures for the lockout bars and scissor arms. This is shown in Figure 28 below.

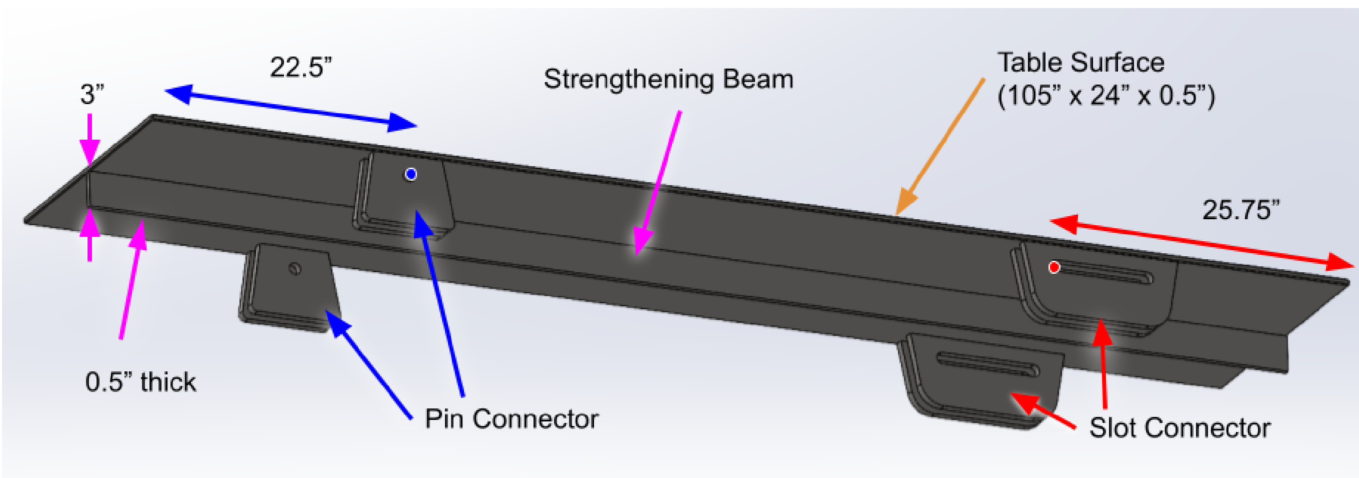



**Figure 28:** Table Surface Subsystem. Important components are labeled along some key dimensions and relations. The table has pin connectors on one end and slot connectors on the other end. Omitted from this drawing are the connection fixtures for the lockdown mechanism.

The table surface is a 0.5” inches thick plate of plain carbon steel, with a length and width of 105” and 24” respectively. The CAD depicts a solid plate, however, in actuality this would be a safety grating. The grating surface would be lighter compared to a solid plate and the surface of the table would also have more traction. Increased traction would be particularly relevant to the safety of users if something were to spill on the surface while they are standing on it. The dimensions of the table are defined by our sponsor who stated that the length and width of their current table were already working well for them (Khan, Initial Interview, 2023). The surface also includes a strengthening beam lengthwise underneath the middle of the surface which measures 0.5” wide and 3” thick. Including this enables us to use a thinner surface and reduce the overall mass of the mechanism.

Various table thicknesses had previously been tested, however, when analyzed under the weight of a 1500 lb load, the surfaces showed unacceptable levels of deformation, even when the slab was 2” thick. Reevaluating the design and seeking methods other than increasing the thickness of the table were used to eventually converge on our current table surface solution.

There are two distinct connection fixtures: a pin and a slot version. Both fixtures have a height of 5.825” in order to function as mechanical stops at the lowest position and allow clearance underneath. This helps to ensure that one, the hydraulic does not come into contact with the table, two, that the scissor arms never reach a fully horizontal position where actuation would be exceedingly difficult, and three, that additional components would not need to be added to serve the purpose of a mechanical stop. The specific geometric features of each fixture type is depicted below in Figure 29.

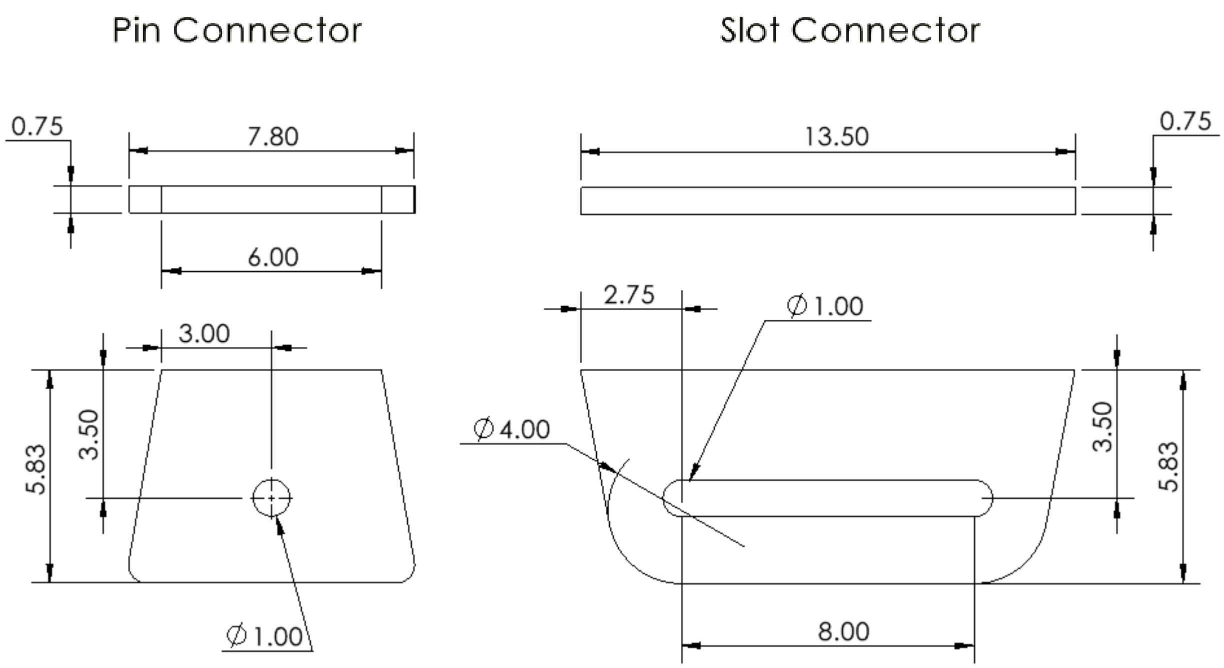



**Figure 29:** Various Surface Connection fixtures. On the left is a pin connector used for one set of the scissor arm connections. On the right is a slot connector. This is used for the remaining set of scissor arm connections and allows for more free ranges of motion. Note that the features defined in this drawing are not exhaustive, but rather highlight the more critical dimensions for reference.

All fixtures consist of a channel in which their corresponding connection components will slide into. This ensures that the axles that are connecting the scissor arms and connection fixtures have a moment couple that reduces torque on the scissor arms and distributes the loads through multiple points. The locations of the connectors from the end of the table surface is depicted in Figure 29 above. These locations were determined from various iterations of FEA, wherein these locations were altered and the stress and displacement across the length of the table was observed. The dimensions shown in the final design demonstrated that they were positioned in an ideal position such that they helped balance minimizing deflection between the connection points and minimizing deflection at the outer edges of the tables. Furthermore, this specific configuration resulted in the reaction forces across the scissor arms being nearly equal which can help with stability.

### *Actuation Subsystem*

The actuation subsystem consists of the scissors arms, axles, and the hydraulic pistons. There are 4 scissor arms in the final design. Shown in Figure 30 below, the scissor arms connect at the base, are actuated by the hydraulic pistons, cross at a hinge in the center, and attach to the table surface at their appropriate fixtures. The scissor arms are 3" wide and with a major hole spread of 64.75". For the two scissor arms that are not connected to the hydraulics, there are 11 holes (1" diameter) of the scissor arm to help in lightweighting the overall mechanism and serving as connection points for the horizontal axles. The remaining two scissor arms have a 1" hole on one end and a 1.5" hole on the other, as it needs to fit the 1.5" hydraulic axle.

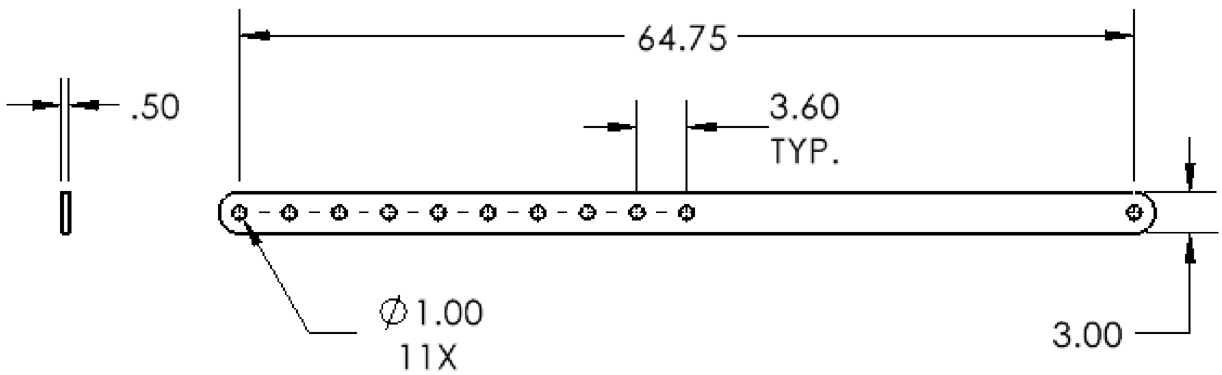



**Figure 30:** Scissor Arm Dimensions. The rightmost hole fits into the base while the leftmost hole attaches to the table surface fixtures. Note that the features defined in this drawing are not exhaustive, but rather highlight the more critical dimensions for reference.

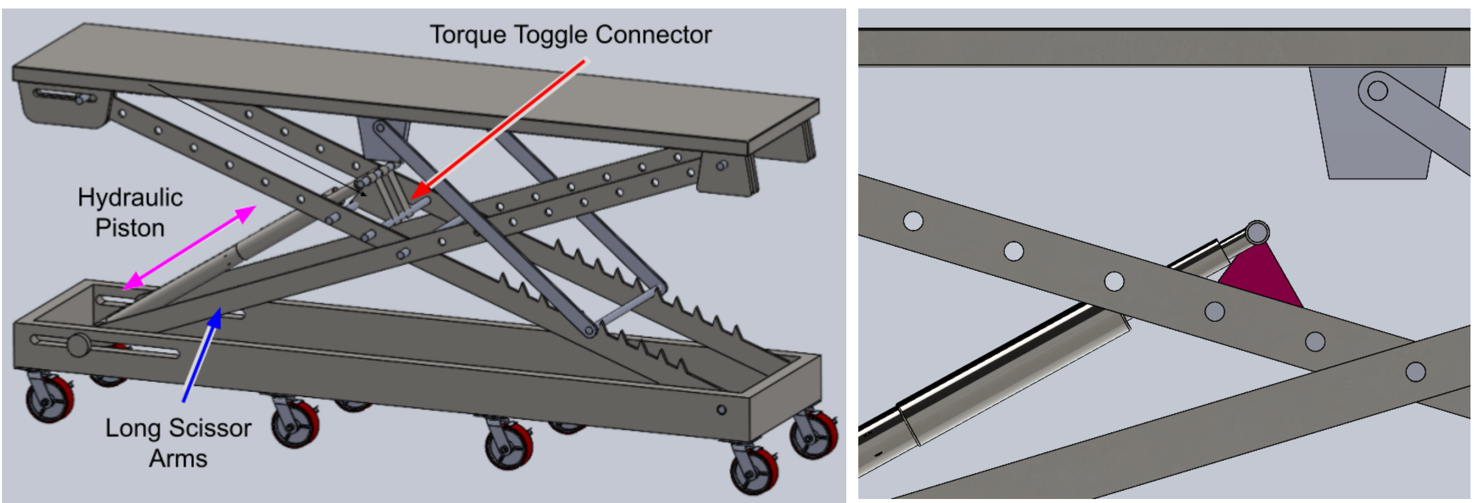
There has been some iteration with regards to the scissor arms. One change that has been made is to shorten the length of the scissor arms (for reference, the previous major hole spread was 97.25", whereas the current spread is 64.75"). Some benefits to doing this is that it would reduce the overall weight of the mechanism and it would enable us to move the scissor arm connection fixtures closer to the center of the table which helped to mitigate the deflection of the table surface.

There are two horizontally-oriented hydraulic pistons. Using two pistons means that neither piston will have to operate at their maximum capacity constantly thus improving their lifespan and providing a larger factor of safety. The axle that connects the base of the scissor arms to the hydraulics also benefits from the use of two pistons as the force from the hydraulics can be applied nearer to where the forces from the base and the scissor arms are being applied to reduce beam bending within the axle. The lower stresses the axle experiences because of this will improve the longevity of the mechanism as it reduces the potential of a fatigue failure.

Each piston has a stroke length of 8" and is attached to the frame that makes up the base of the mechanism and an axle connecting the bases of the scissor arms. The horizontal displacement of the scissor arm base causes the scissor lift to raise the table surface. The stroke of the piston is equivalent to the maximum horizontal displacement that is needed in the scissor arms to lift the mechanism to our sponsor's maximum requested height. It is more mechanically advantageous for us to make use of the entire range of motion of the pistons.

Furthermore, the type of hydraulic piston recommended is a double acting cylinder. This means that the hydraulic piston will be capable of actuating in both directions and there will always be a hydraulic force to properly control this, a 4 way directional control valve will be needed (Sarum Hydraulics, 2018). This choice is especially effective as it allows for the design to reach continuous heights rather than discrete due to the constant force from the actuator being the main source of force holding up the lift.

Several changes have been made to the hydraulic actuation during our design process. Previously the hydraulics were oriented such that they remained nearly parallel to the attached scissor arms at all times. In this design, shown in Figure 31, a connection piece we had named a torque toggle connector was needed. This component was a liability as it would have been subject to high loading conditions and eliminating this component helps to reduce one point of potential failure of the mechanism. Furthermore, through changing the piston to a more horizontal orientation, there is a greater torque advantage at the higher mechanism heights and less shear in the axles due to a more ideal load distribution.




**(a)** **(b)**

**Figure 31:** Previous actuation designs. (a) depicts the previous version of the assembly. Some features of note are the longer scissor arms, the wider scissor arm connection fixtures on the table surface, the angled hydraulic piston, and the torque toggle connector. (b) depicts the now obsolete torque toggle connector, highlighted in red for visibility.

The axles are 1.0" diameter plain carbon steel rods with lengths of 24". For the one axle that connects the hydraulics to the set of scissor arms in the track, the plain carbon steel component has a diameter of 1.5" with a length of 24". It was determined that for this specific axle, the larger diameter was capable of withstanding the forces of the scissor arm weighing down, the hydraulic actuating, and the base track's reaction force so long as the scissor arms remained at angles that are >5° as measured from the horizontal direction, which the pin and slot connection fixtures help to ensure by creating an offset between the base and the table surface.

### *Lockout Mechanism Subsystem*

As an additional safety precaution to help the hydraulics support the loads the mechanism is expected to withstand and to serve as a failsafe should the hydraulic pistons fail, lockout mechanisms have been added to the design. The lockout mechanism consists of a hanging bar that will be able to move passively upwards as the table surface is raised and will catch on a desired tooth when the mechanism has reached its final height. The hanging bar is connected to the table surface. An image of what this mechanism looks like when in use is shown in Figure 32 below while a step by step breakdown of how the mechanism works is shown in Figure 33 below.

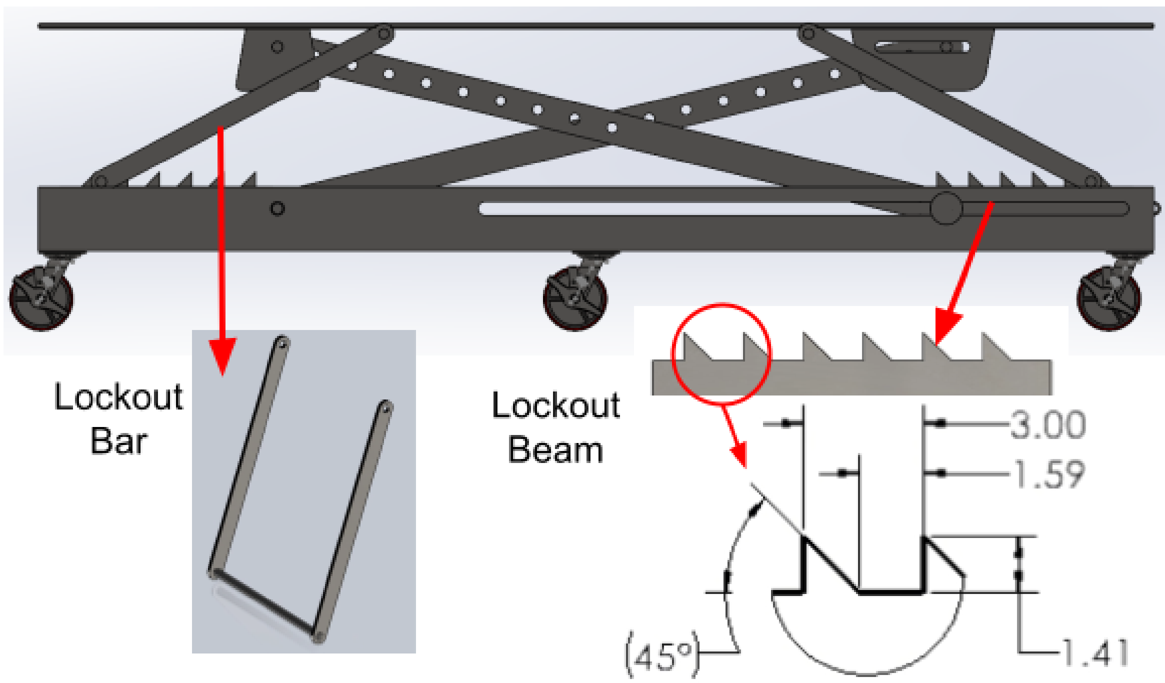



**Figure 32:** Example of lockout bars in action. As shown above, the dropdown bars rest within the notches on the base of the mechanism. The lockout bars consist of two flat stainless steel beams that are connected to each other via a round 1” plain carbon steel axle. The lockout bars are connected to the table surface at a pin fixture.

To lower the lift, the lift must be raised a short distance to disengage the lockout bar from the teeth. The bar is then lifted up and off of the notched teeth panel and the lift is able to be lowered without interference. Due to the potential of injury, before lowering the mechanism, we are advising all users to ensure the hydraulics are actively engaged, all persons and loose items are cleared off the table surface, and the lockout bar is fully disengaged before attempting to lift this bar.

The dimensions of the locking teeth are depicted in Figure 32 above. There are several previous iterations of the lockout mechanism. One iteration had the teeth on the lower half of one set of the scissor arms, but functioned essentially the same as the actual final design. Concerns were raised over whether this would result in uneven support of the mechanism- taking this into account, the design was altered such that the hanging bar lockout teeth were present on all scissor arms to better balance the load. The final design, as pictured above, moved the teeth to the base of the mechanism rather than the scissor arms.

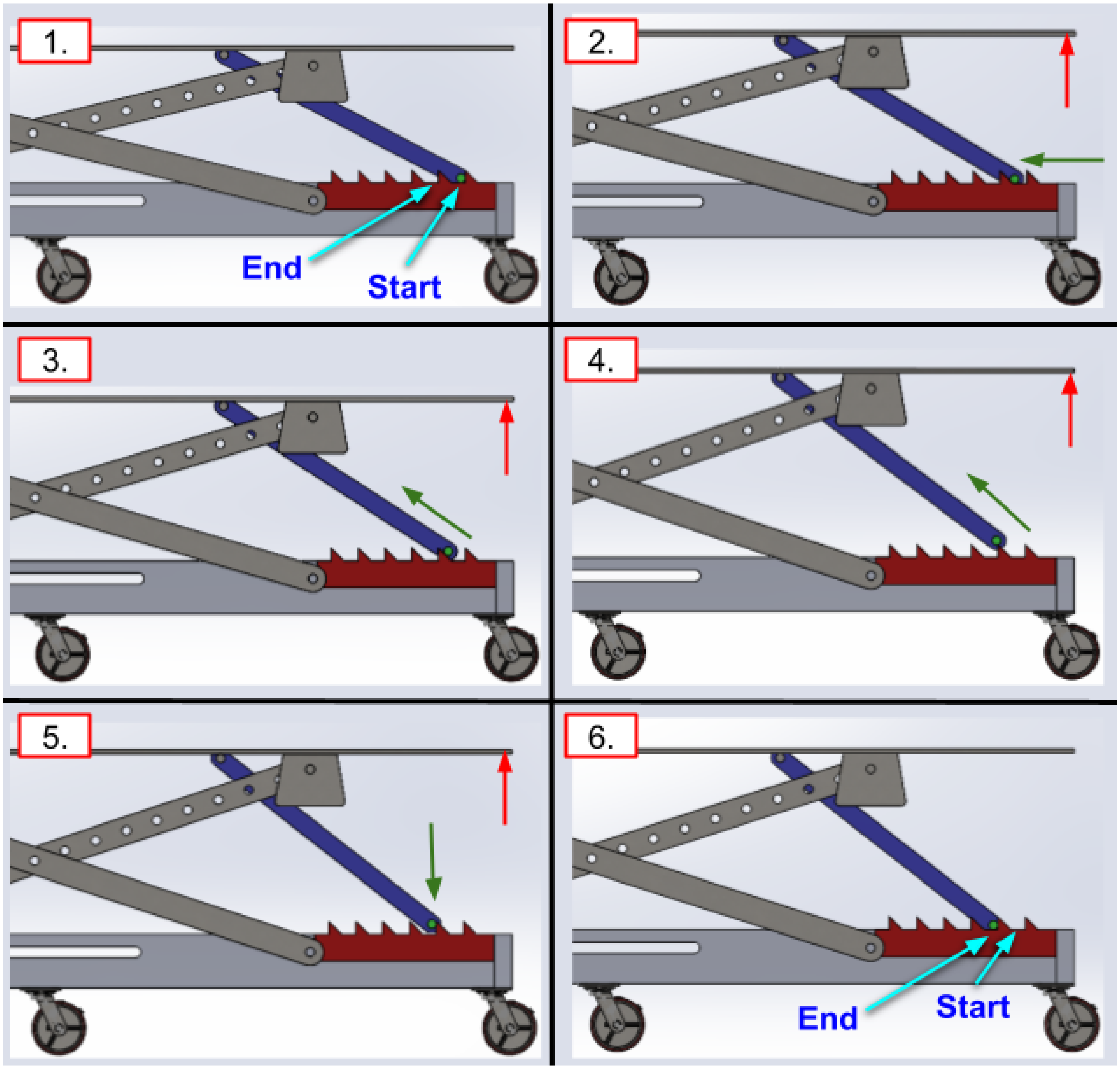


**Figure 33:** Demonstration of how the lockout bar works. A section view of the mechanism is pictured with the notched scissor arm in blue while the horizontal portion of the lockout bar is pictured in green and the lockout teeth in red for better visibility. As the table surface is raised, the lockout bar is dragged up and over the notches. Once past the peak of the notch, the bar drops down into the notch and prevents the table from moving downward.

### *Base Subsystem*

The base subsystem consists of the bottom frame of the mechanism which includes the track the base of the scissor arms glides on and additional fixture points for the other two scissor arms in addition to casters mounted to the underside. A diagram of this subsystem with some key dimensions is pictured in Figure 34 below.

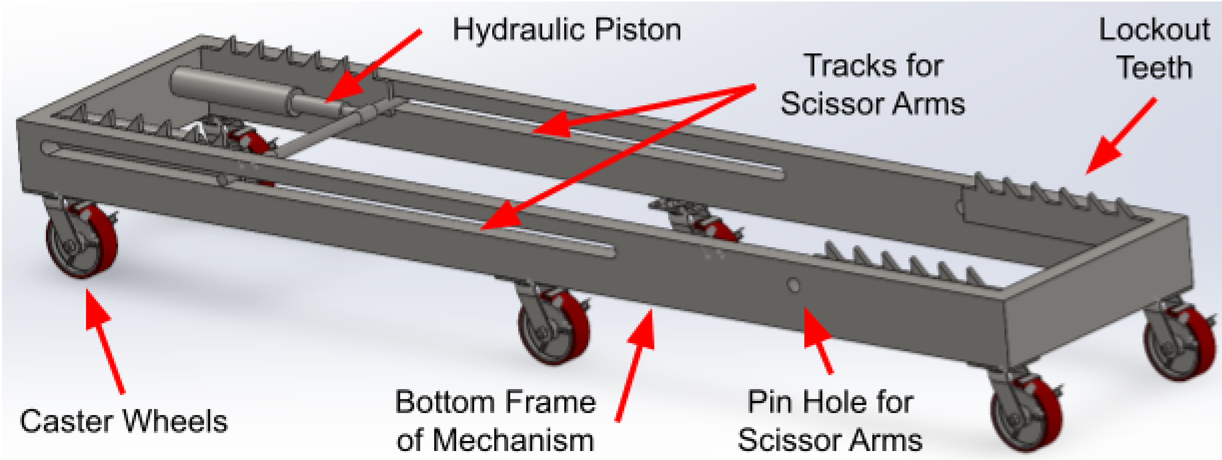



**Figure 34:** Overview of Base subsystem. Important components are labeled along some key dimensions and relations. The base frame is depicted along with casters and the tracks that the scissor arms connect to.

The frame is made out of plain carbon steel. Similar to the table surface, it has a length and width of 105" and 24" respectively. Since DR2, the frame has undergone a substantial change in that the bottom plate has been removed. This was initially done as an effort to lightweight the design and resulted in a roughly 700 lb decrease. The structural integrity was not significantly impacted by this loss, as that surface layer was extremely thin, but the resulting weight decrease was a substantial improvement over our previous design.

There are 6 casters, each with a diameter of 6" (Service Caster Corp., n.d.). The casters must be able to support the weight of the entire mechanism and ensure that the mechanism is capable of being pushed and rolled- each individual caster has a weight capacity of 1200 lbs and are capable of supporting our maximum expected loads. All of the casters have breaks to prevent rotation of the wheels while the mechanism is in use. They are separated by even intervals as well to reduce the bending moments felt by the lift base.

It is also important to ensure that there is adequate surface area such that the mechanism stability is not impacted by slight variations in the ground surface. To this end, a recommendation for users is to avoid using the mechanism when it is on uneven ground- our general guidance is to ensure that all wheels have full contact on the ground.

Another major component of the base subsystem is the scissor arm track. This is similar to the slot connector on the table surface. The purpose of the track is to serve as a guide for the ends of the scissor lift. It restricts the translational motion of the ends of the scissor arm to one direction along the direction of the track. The lockout teeth panels that are part of the lockout mechanism are located at each of the four corners of the base subsystem.

## Build Description

A 1:10 scale 'build' solution will be created to supplement the analysis already completed in CAD, as well as provide a visual representation for the functionality of the design. The goal behind this 'build' solution will be to enable the team to complete and verify analytical results discovered through FEA and computation in a physical manner.

The ‘build’ solution, though not yet fully completed, will consist of a 1:10 scale model of the design shown in Figure 27. However, because a hydraulic actuator of this size does not exist, our team will mimic its behavior with the use of medical syringes and fluid tubing. This is feasible because the same action of a hydraulic actuator is used where pressure is placed on the fluid within the actuator, resulting in mechanical energy that is able to move the mechanism up and down.

### *Bill of Materials*

For this ‘build’ design, a list of materials and supplies that will be needed for its construction are reflected in Table 8 below.

**Table 8.** Bill of Materials for the ‘Build’ Design

| Item | Quantity | Source | Catalog Number | Cost | Contact | Notes |
|---|---|---|---|---|---|---|
| ⅜” 316 Stainless Steel Washer | | McMaster-Carr | 90107A127 | $9.50 | mcmaster.com | Spacers on axles |
| Toy Car Wheels | 6 | URIMPAVIDO | n/a | $6.99 | amazon.com | Stand-in caster wheels |
| Rotary Shaft | 2 | McMaster-Carr | 1346K11 | $9.41 | mcmaster.com | Actuator shafts |
| ⅜” Nuts | | McMaster-Carr | 95462A031 | $15.94 | mcmaster.com | Secure axles in place |
| Plastic Syringe | 3 | McMaster-Carr | 7510A807 | $5.55 | mcmaster.com | Mimics hydraulic actuator |
| Plastic Tubing | 1 | McMaster-Carr | 5233K74 | $10.16 | mcmaster.com | Connects syringe to model |
| 3D Printer Filament | 1 | McMaster-Carr | 1317N24 | $28.11 | mcmaster.com | Used for rest of mechanism structure |

With the purchase of these supplies, a scaled-down version of the final build can be created and assembled. This model will provide a physical representation of the design to give potential users perspective into the look and purpose of certain components or features, all while remaining within the budget constraints of the UM-SPARK team. Our team will forward the most recent versions of all CAD files related to this design to SPARK so that they are able to 3D print any components as needed for the scaled-down ‘build’ design.

### *Manufacturing Plan*

The manufacturing plan described will produce a 1:10 scale build design model using a 3D printer with a thermoplastic monomer filament called polylactic acid (PLA). This material will be used to create the body of the design (the structural pieces of the lifting mechanism, not including the actuator, fasteners, axles, or the caster wheels). A set of mini wheels will be used to mobilize the ‘build’ design, and a set of fasteners will be used to connect the parts together to the mechanism structure. A medical syringe will be in place of an actual hydraulic actuator because of how closely it mimics the same behavior, both using the energy of the fluid (water for the ‘build’ design) for the reciprocating mechanical motion. Table 9 below shows the materials and manufacturing processes for each of the build design components listed in the Bill of Materials

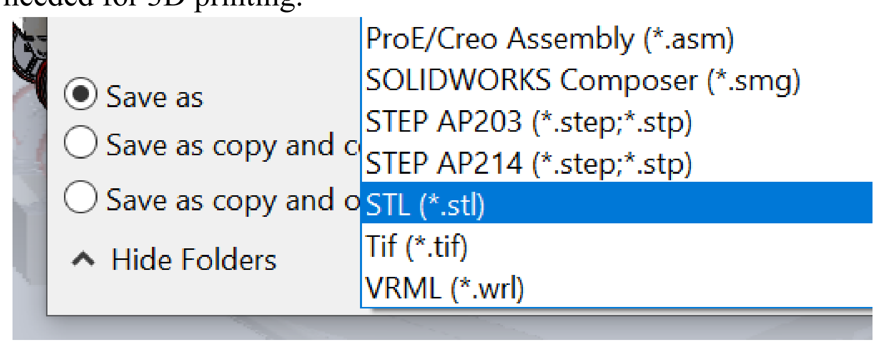
**Table 9.** Manufacturing Materials and Processes for the ‘Build’ Design

| **‘Build’ Design Component** | **Material** | **Manufacturing Process** |
|---|---|---|
| ⅜” 316 Stainless Steel Washer | Stainless steel | Stamping, heat treating, surface coating |
| Toy Car Wheels | Rubber, plastic | n/a- sourced/purchased from secondary supplier |
| Rotary Shaft | 1566 carbon steel | CNC turning |
| ⅜” Nuts | Zinc plated steel | Cold or hot forging |
| Plastic Syringe | Polypropylene plastic | Injection molding |
| Plastic Tubing | PVC plastic | Extrusion |
| 3D Printer Filament | PLA plastic | Compounding |

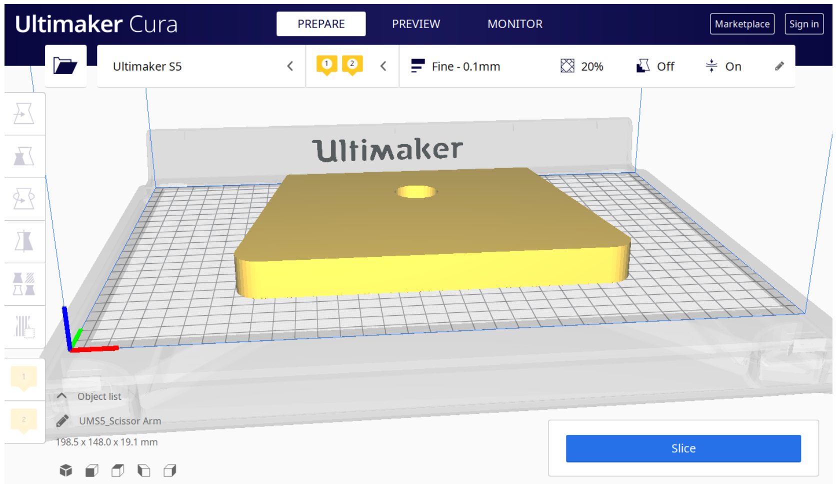
The Table below will outline a generic manufacturing plan which can be used to fully construct the ‘build’ design.

**Step 1: Preparing the CAD files for 3D printing**

A. Make sure that each individual CAD file is exported to a .stl file. This is the file extension needed for 3D printing.

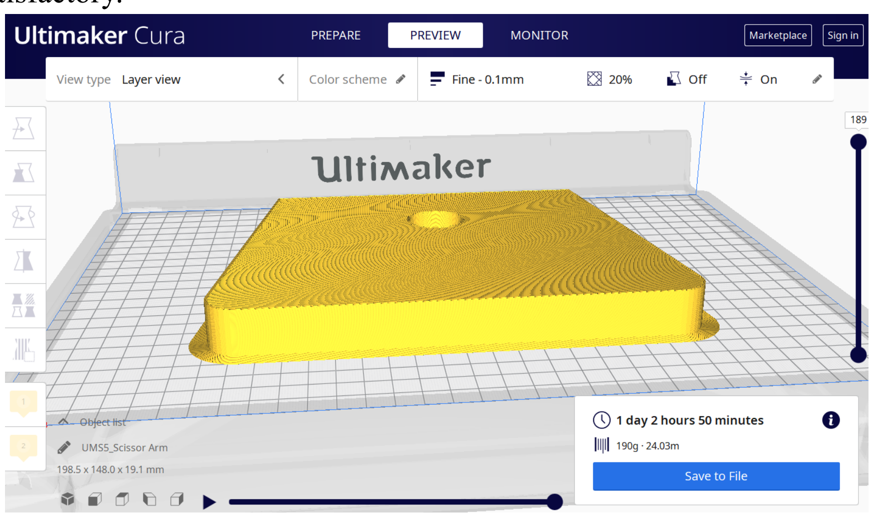



B. Open a software that can be used to translate the .stl files to 3D prints, such as Ultimaker Cura. Open individual .stl files into the 3D printer plane and orient as many on the printing surface that will fit. Use printable supports where necessary to support overhanging faces.




C. Configure your setup. The settings for this print are fairly lax, as it will just be a scaled model for the final design. Adjust your settings to preference in the software's print settings. For example, the settings used for our team's 'build' design was the "Draft - 0.2 mm" setting with a 10% infill. This model served only as a visual aid during the design expo, and thus did not require a finer quality print to achieve its purpose, nor did it require structural integrity.

D. Slice and preview your print. This stage will show you how long the print will take and what the slices or layers will look like. Adjust your part orientation and settings until this stage is satisfactory.

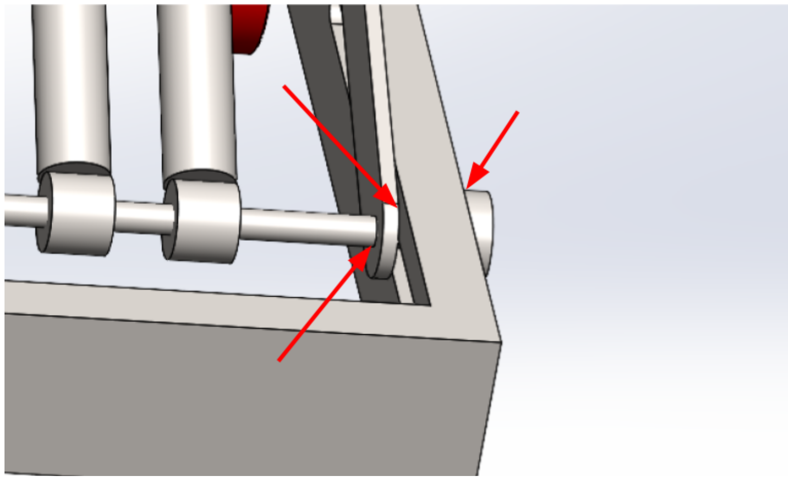



E. Print the file to the 3D printer.

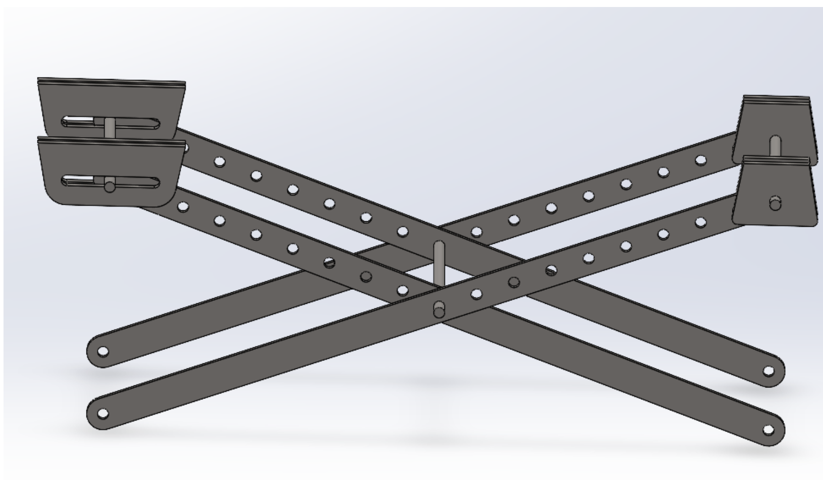
F. Post process the 3D prints after they are finished printing, such as removing support material or surface finishing.

**Step 2: Assembly of the 3D printed parts and other components**

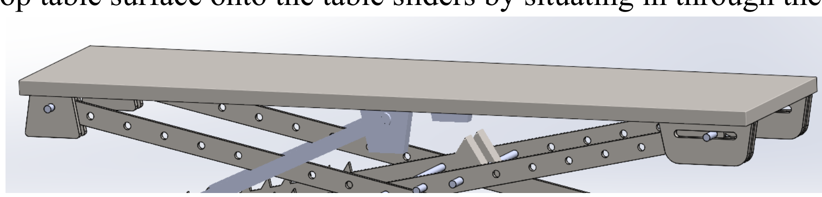
A. After the 3D printed components are finished in step 1E, you can gather together the rest of the components for the 'build' design outlined in the Bill of Materials in Table 8. Start by inserting the axles into the holes at the base of the frame with washers placed in between components, shown by the red arrows in the illustration below (CAD snapshots are used for a clearer image). Repeat this process for either side of the axles.



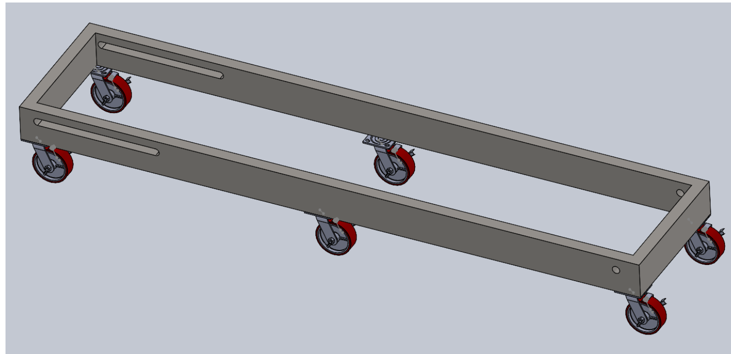
B. Cross the scissor arms with the respective joining axles in the middle. Similarly, place the table slider components with their respective axle towards the top of each scissor arm.



C. Secure all axles and their adjoining components by placing the nuts on both ends of the axle.
D. Secure the top table surface onto the table sliders by situating in through the axles.



E. Hot glue the wheels on the bottom of the 'build' design. They won't act in the same way as caster wheels, but for the purposes of the prototype, they will provide perspective and a visual for the final design. The wheels will go under each of the four corners of the base, as well as directly under the center of the longest dimension of the four sides.



F. Pull water into one of the syringes, then attach the plastic tubing to its intake pipe. Secure with superglue, hot glue, or other DIY adhesives. With the plunger fully pushed in on the second syringe, attach the plastic tubing to its intake pipe. Secure with adhesive. Now attach the second syringe to the lift base with hot glue while the lift is in the bottom position, such that the syringe is horizontal and the plunger flange comes in contact with the hydraulic axle. Hot glue the plunger flange to the axle.
G. Your model should now be fully assembled and able to move with the pumping of fluid through the plastic syringes and tubing.

Because the 'build' design will be a 1:10 scaled model, the tolerances within the part will not have to be as carefully monitored as if the team were creating a full-scale 'build' design. However, the build design could be used for further physical experiments for the validation testing. The magnitude of forces exerted on the 'build' design would have to be adjusted down in scale as well, matching the scaled-down size of the mechanism. Additionally, due to the fact that the 'build' design will be printed using PLA, which has a lower Young's Modulus and Ultimate Tensile Strength (UTS) value (Material Properties Database, 2023) as compared to the chosen plain carbon steel for the final product, considerations will have to be made when evaluating magnitudes of stress at points of failure.

### *Relationship Between 'Build' and Final Design*

The 'build' design will show great resemblance to the final design in terms of how the mechanism is able to maneuver and operate. It will provide SPARK as well as any other stakeholders the opportunity to view a physical model that performs the intended movements behind the team's final design. Differences between the two designs will include the material chosen, the overall size, and the actuation method. PLA filament will be used for the structure of the 'build' whereas the final design will be constructed from steel, the 'build' will be one tenth of the final size, and the hydraulic actuator will be mimicked with the use of a medical syringe and tubing.

Additionally, the 'build' design should be able to be tested on for further validation testing as most of the team's testing so far has been performed through computational analysis and analysis through FEA software. The fluid in the actual hydraulic actuator will be hydraulic fluid whereas the fluid in the 1:10 scale hydraulic actuator will be water. With this, the viscosities, or each fluid's resistance to flow, will also be significantly different. Because the hydraulic actuators used in this project will be producing maneuvers with high magnitudes of force, a hydraulic fluid with a higher viscosity will be used to increase the actuator's efficiency (Totten, 2017). The use of a lever to move the hydraulic actuator will also ease this movement and increase mechanical advantage. For the 'build' design, because our team is attempting to provide a visualization of the mechanism and how it functions, water should be a sufficient enough fluid to utilize in the medical syringes' tubing to mimic this behavior.

Overall, the main intent of the 'build' design is supposed to show the movements of the final design on a smaller scale. This will provide perspective of the design in terms of design proportions, the implementation of the lockout bar method and the scaled-down loads that will be able to be supported.

## Verification Results and Plans

The results of our completed verification have led to a number of design decisions and lessons as well as successful verification of many specifications and requirements. Many of the results have led to the creation of plans for new verification on top of the plans already used. *Note that the full list of verification plans can still be found on Table 1* with their associated user requirements and specifications. This section will first go through the most important results from completed verification, and then dictate plans for remaining verification tasks left to be completed. For each completed verification's associated analysis, refer to the *Engineering Analysis* section above.

### *Verification Plan Justification, Assumptions, and Limitations*

The verification plans initially spelled out in Table 1 are found below in Table 10 below with accompanying justification for the plans. Additionally, the table includes assumptions made, limitations of each form of verification, and a confidence assessment of the quality of the results. The following section (found further below) will go into detail on the results of the analysis that accompanied each verification plan.

**Table 10:** Verification of Specifications, Justification, Assumptions, and Limitations

| Engineering Specification | Verification | Justification of Verification | Assumptions Made | Limitations of Verification |
|---|---|---|---|---|
| Must operate 150 load/unload cycles without requiring regular maintenance | • Perform 150 load/unload cycles on model | Predictions regarding maintenance are often difficult to make and unfeasible to create. Utilizing a physical model for testing aids in discovering any difficult to predict maintenance needs. Fairly high confidence. | Physical model is similar enough to final product to need the same style of maintenance. | Physical model made of different and smaller materials. |
| Maintenance must be able to be completed with only the tools available in the Wilson Center | • Confirm Wilson Center tools<br>• Assess failure modes through inspection of model and CAD model | Physically going to Wilson Center and assessing available tools is clearly the best way to confirm their tool availability. Assessing failure modes through inspection of model and CAD model is vague but necessary. Most failure modes are found through the engineering analysis of structure. Fair confidence. | Wilson Center tool availability will not change. All most likely failure modes are considered. | Unpredictable modes of failure are possible, and may cause the need for tools that are unavailable to Wilson Center. |

| | | | | |
|---|---|---|---|---|
| Lift must be able to operate without the need for an electrical outlet | • Verified through design through incorporation of actuators that can be battery powered | Verified through the design process, no additional verification needed. High confidence. | Not applicable. | This process is robust and not truly limited beyond the lack of a final model for testing. |
| Minimum of 4 discrete height settings spanning a range of ≥ 45 cm with equidistant offsets between each height | • Physical testing (measure discrete heights on model) and CAD inspection | The design specifications as displayed through the CAD model are effective at verifying project's ability to reach discrete heights as they match the dimensions exactly. Utilizing the physical model provides additional security and confidence in the verification. High confidence. | Physical model will accurately reflect the usage of the final model. | Neither the CAD nor physical model will use the actuators found in the final design, which are critical for the final project to work effectively for discrete heights. These will need to be further assessed later on. |
| Rear axle of motorcycle must be able reach "hip height" 2.5 ft (Mills, 2007) | • CAD model inspection | CAD model inspection will provide proof that is accurate to our exact dimensions. High confidence. | CAD model and design will not change. Floor will be flat. | For this specification, the verification process is not limited significantly. |
| Supports a load of 1500 lbs | • CAD stress analysis and static analysis calculations | CAD stress/displacement analysis is the best way to go about this, the powerful software allows us to visualize the high stress areas and make design changes quickly as needed. Retesting is fast with new dimensions when using this rather than hand calculations. CAD performs more calculations quickly and reliably than a human can. Using static analysis calculations (by hand) also allowed us to determine the critical points of failure and change our design accordingly. Fairly high confidence. | The 1500 lb distributed load will be symmetrically placed on the table. New weights will not be added onto the table while it is moving. | No computer we used was powerful enough to run the static/displacement analysis for the entire assembly. It became necessary to break the assembly into chunks and test forces individually. Our analysis assumes we performed this correctly and did not glance over important connections. |
| Support point loads of up to 350 lbs | • CAD stress analysis and static analysis calculations | See: Above. CAD stress/displacement analysis is the best way to go about this, the powerful software allows us to visualize the high stress areas and make design changes quickly as needed. Retesting is fast with new dimensions when using this rather than hand calculations. | Assuming point loads are not moving. | Verification process is fairly robust but faces similar issues as listed in the "Supports a load of |

| | | | | |
|---|---|---|---|---|
| | | CAD performs more calculations quickly and reliably than a human can. Using static analysis calculations (by hand) also allowed us to determine the critical points of failure and change our design accordingly. Fairly high confidence. | | 1500 lbs" limitations listed. |
| Requires a maximum of 2 adults to transport in trailer | • Ensure weight under 500 lbs | Without access to a final model, this is the most efficient way to predict the difficulty of transporting the project into a trailer. Medium confidence. | Assuming the casters chosen are able to easily roll and not too frictionally limiting. Assuming the process to load into the trailer uses an inclined plane. | Lack of a final model ignores other difficulties involved in transporting the device such as handle points, slippage, tipping, or caster difficulties. |
| Must have an average time of < 15 minutes for a cycle of mounting and unmounting the motorcycle | • Mathematical model for time<br>○ Time to actuate up<br>○ Time to actuate down<br>○ Load time<br>○ Unload time | A simple mathematical model (simply adding up the time it takes to load, unload, and actuate) is the best way to estimate this process without a final model. Fairly high confidence. | Assuming the loading and unloading time are reasonable and take less than 5 minutes each. | Without a final model, we cannot predict with certainty the time these tasks will take. |
| Requires only 1 adult to mount/unmount motorcycle | • Mechanical advantage calculation for inclined plane<br>• Model investigation | Using an inclined plane calculation (combined with estimated weight and model investigation for bumps or issues with loading) provides our best guess into the force needed to push the bike onto the lift. Fairly high confidence. | Assuming an inclined plane will be available to use. | This method does not account for difficulties holding the bike steady. |
| Withstand lateral forces of X | • Mathematical model investigation/CAD model investigation<br>○ Math model include mass and center of gravity to perform analysis of impact of force | A mathematical model that includes center of gravity (on Matlab) is useful for considering lateral forces and effective as is. The additional use of the CAD model to simulate these forces provides additional security in our calculations. Both are easily adjustable and provide a high degree of confidence. Fair confidence. | Assumption that casters will be aligned correctly and locked into horizontal position. | Verification limited by lack of final model to account for any missing considerations (bending with extra weight, bowing). |
| Both front and rear wheels must be able to rotate 360 degrees at speeds up to 150 mph without interference from the mechanism | • Verified through design process | Design process and usage of chocks verifies this design fully as our sponsor's current design utilizes them effectively. High confidence. | Chocks will continue to work for our design. | This process is robust and is not truly limited beyond the lack of a final model for testing. |
| ≥ 7" of clearance under bike | • CAD model (measure full scale model to confirm dimensions) | CAD model utilizes our exact final dimensions, so it is the best and most clear way to verify this clearance. Using a scale model to confirm | No obstructions will be present near and around the lift. | This process is robust and not truly limited beyond the |

| | | | | |
|---|---|---|---|---|
| | | dimensions provides extra assurance. High confidence. | | lack of a final model for testing. |
| Packs down into 8.75' x 2' x 1' space | • Measure length, width, and height dimensions of mechanism when it is folded down to its most compact form on CAD model | CAD model utilizes our exact final dimensions, so it is the best and most clear way to verify these dimensions. High confidence. | Assuming there are no undetected issues in the CAD model. | This process is robust and not truly limited beyond the lack of a final model for testing. |
| Have at least one additional safety lockout method for the mechanism | • Ensured through design process (lockout bar) | Verified through the design process and addition of a lockout bar. High confidence. | Not applicable. | This process is robust and not truly limited beyond the lack of a final model for testing. |
| Meet all Wilson Center safety codes (Wilson Student Team Project Center, 2023) | • Ensure through Wilson Center safety investigation | This is a thorough way to verify the specification. High confidence. | Assuming we can read the safety rules correctly. | Does not utilize actual Wilson Center employees. |
| Require ≤ 100 lbs (Load Movers INC, 2012) of force to move while motorcycle is mounted | • Use a force scale to measure the maximum amount of force to move the mechanism with the motorcycle mounted on scale model | Using a force scale on the scale model can provide us an estimate of the force needed to move the mechanism and additionally provide us with an idea of what issues may be found when trying to move the model on various terrain. Due to significant weight differences and material differences in the model and final design, this process is fairly low confidence and thorough validation testing is critical. | Scale model is accurate to the real world model in regard to friction and weight factor. | Realistically the scale model does not provide an accurate verification for this test. Many factors are not the same on the scale model including friction, weight, material choice, grip points, motorcycle inclusion, and more. |
| Working surface's static coefficient of friction ≥ 0.5 | • Verified through design process (material selection of table surface) | This is a thorough way to verify the specification. High confidence. | Assuming the friction will not be reduced over time through usage. | This process does not account for usage over time. |
| Require ≤ 100 lbs (Load Movers INC, 2012) of force to push mechanism over gravel, dirt, or epoxy coated concrete surfaces | • Use a force scale to determine force required when mechanism is wheeled over specified surfaces on model | Using a force scale on the scale model can provide us an estimate of the force needed to move the mechanism and additionally provide us with an idea of what issues may be found when trying to move the model on various terrain. Due to significant weight differences and material differences in the model and final design, this process is fairly low confidence and thorough validation testing is critical. | Scale model is accurate to the real world model in regard to friction and weight factor. Also assumes that different sized casters will act similarly over the same types of material which is likely not | Realistically the scale model does not provide an accurate verification for this test. Many factors are not the same on the scale model including friction, weight, material |

| | | | | |
|---|---|---|---|---|
| | | | accurate. | choice, grip points, motorcycle inclusion, and more. |
| Will not be visibly damaged by contact with foreign substances, including cleaning supplies, typically used by SPARK team | • Verify by researching material choices | This is a thorough way to verify the specification. High confidence. | Assuming the cleaning materials listed to us are all the most damaging foreign substances to contact the lift, and the electrical pieces are protected. | Limited by lack of a final model for testing and access to unlimited materials to experiment with (such as for oil tests or more intense foreign substance tests). |
| Must be able to store X amount of supplies | • Verified through design process | This was verified through sponsor approval of our designs' supply storage ability. Fairly high confidence. | Assuming the table surface will retain well enough to continue storing supplies without slippage. | Limited access to time to see if friction reduces over time heavily on the table surface. |
| Keep entirety of project cost under a $1,000 budget | • Verify through bill of materials | A budget analysis is the most effective way to perform this analysis. High confidence. | Importing materials will significantly increase costs. Actuators will not be well above expected cost. | Prices of materials frequently change and we cannot account for prices when ordering occurs. |

***Verification Results***

A large amount of engineering analysis was performed for the verification processes above. While many of the verification processes remain to be completed, a majority of them were completed and explained in the "Engineering Analysis" section. This section will review the results of verification processes that required engineering analysis. Verification processes that were verified through the design process and did not require analysis are not included in this section as their results are already confirmed as explained in the table (example: 'Lift must be able to operate without the need for an electrical outlet' was verified through the design process and incorporation of a battery powered actuator). Also, processes that are not yet completed due to our lack of a completed model are included instead in the following section "Remaining Verification Tasks". The following list displays relevant specifications and associated verification process followed by a description of the results and lessons learned. The formatting style is:

---

- Specification
  - Completed relevant verification method
    - Explanation

---

- Maintenance must be completed with only tools available in Wilson Center
    - Assess failure modes through inspection of model and CAD model
        - Our analysis showed that any typical maintenance or predictable failure modes would be easily fixed using the tools available at the Wilson Center. The worst case scenario from failure analysis would be material failure/fracture. In the case that this occurs, the MSPARK team would need to have extra materials on hand to replace the damaged parts. The most likely piece to fail from our stress analysis would be a scissor arm. Overall we view this analysis as a success as material failure is unlikely.
- Minimum of 4 discrete heights spanning a range of 45 cm or more with equidistance offsets
    - CAD inspection
        - Our CAD inspection of the ability to reach the range of heights requested proved successful. What we found, however, was that making these heights equidistance was difficult with our choice of a lockout bar for a backup mechanism. This was one of the factors that led to our design decision to utilize double-acting actuators rather than single acting. These actuators maintain their pressure (even without power) and allow for the full support of the lift to come from actuators rather than the lockout bar. With this decision, the lockout bar is allowed to be a secondary safety mechanism and is not required to lock into position for the table to steady (allowing continuous heights to be reached). With the design change, we successfully meet this specification.
- Rear Axle of motorcycle must reach “hip height” or 2.5 feet
    - CAD inspection
        - Our CAD inspection of this specification proved fully successful. The scissor arms and actuators allow for the design to reach this height and far higher/lower as needed.
- Supports a Load of 1500 lbs
    - CAD inspection and static analysis calculations for table
        - The initial results of our CAD analysis for the table surface individually proved that it is not strong enough to hold the 1500 load without significant deflection. After experimenting with various materials, we found carbon steel to be generally a strong choice for the base building material of the design due to its cost, availability, and strength. This led to the design change of us including a support beam that runs horizontally across the entire table. This support beam had its own set of tests ran for thickness, and the result led us to concluding a 0.5” wide 3” tall beam placed in the center is enough to aid the table significantly. New tests led to the conclusion that, with the support beam, the main table thickness of 0.5” is adequate when using steel.
    - CAD inspection and static analysis calculation with “new” support beam for table
        - On top of the table itself, we needed calculations for the location of the rigid axle that connects to the table (not the horizontally sliding axle).

Tests were completed with the scissor arm in the highest position, middle position, and lowest position. In order to minimize the deflection, our CAD static analysis testing for the bar at various distances from the edge of the table proved that the optimal location for the bar is 22.5 inches from the edge of the table.

- Mathematical inspection for the axle connected to the actuators
  - Results from mathematical analysis of the primary axle that is connected to the actuators and experiences the strongest forces (it holds the scissor arms and the force of the hydraulic actuators) proved that with a 1.5” bar, the axle does not experience stress beyond yield strength unless the scissor arm goes beneath 5 degrees (which it will not in our design).
- Analysis for lock down bar
  - A similar style of analysis for the axle was performed for the lockdown bar that proved its ability to hold the necessary weight for the 1500 lb load if the actuators were to be depowered. While the bar was able to withstand the load, the scissor legs themselves were not strong enough. To fix this, in our design, we included a second lock down bar that will distribute the weight between the four legs.
- CAD inspection for bottom half of the lift
  - Unfortunately due to limitations in computing power, we were unable to run a stress test for the entire lift assembly at a time. To remedy this, we performed force analysis (including center of mass calculations for the table) to determine the positions and directions of the forces experienced on the structures beneath the table and ran a test simulating those forces. After performing this test numerous times, we determined that 0.5” is the optimal thickness for the scissor arms. The test was successful and we experienced no deflection beyond expectations.
- Actuator force verification
  - After selecting our materials and thicknesses, we were able to calculate the total force the actuators need to create to lift the mechanism/bike. At its lowest point, we calculated the force needed from the actuator is 10,600 lbs. With this new value determined, we realized we needed to increase the number of hydraulic actuators from 1 to 2.
  - With all of these tests completed and changes made to the design, ultimately we proved this design capable of performing the 1500 lb lift requested in the specification.

- Support Point Loads of 350 lbs
  - CAD stress analysis and inspection of table
    - Because we have proven the mechanism’s ability to handle 1500 lbs, the only potential issue we foresaw with 350 lb point loads would occur on the table. Our CAD stress tests with 350 lb point loads with the 0.5” table and 0.5” support beam proved successful and there was a lack of critical stress or deflection. Ultimately successful.
- Requires Maximum of 2 Adults to Transport into Trailer
  - Ensure weight is under 500 lbs

        - From our CAD analysis and material selections, we unfortunately realized that our weight is far higher than initially expected. We ended up with an estimated weight of 1600 lbs. We plan to make changes to the design or incorporate an easier method of transportation moving forward beyond this design report.
- At least 7 inches of clearance under the electric bike
    - CAD model analysis
        - CAD model analysis proved the success of our model's design in allowing for at least 7 inches of clearance under the electric bike. The usage of chocks as a design choice also verifies this as a success.
- Packs down into a 8.75' x 2' x 1' space
    - CAD model inspection
        - The CAD model in its lowest, most compact state, proves that the lift successfully fits into the requested dimensions. This test was easily proven to be successful.
- Not visibly damaged by contact with foreign substances, particularly SPARK cleaning supplies
    - Research material choices
        - As part of our selection of carbon steel we performed research into the damage that it would take from common cleaning materials used by the UM SPARK team. Fortunately, the research was promising and led to successful results.

Ultimately, the verification tests confirmed our design choices and has left us in a strong position of confidence moving forward (in addition to the multitude of lessons and design changes we experienced). Despite that, we still have much more testing to complete before we move onto validation testing.

### *Remaining Verification Tasks*

The remaining verification tasks that need to be completed are seen in the list below. The formatting style is:

---

- Specification
    - Verification test that needs to be completed

---

- Must operate 150 load/unload cycles without requiring regular maintenance
    - Perform 150 load/unload cycles on scale model
- Minimum of four discrete heights spanning a range of 45 cm with equidistant offsets
    - Physical testing on scale model for investigation
- Must have an average time of less than 15 minutes for a cycle of mounting and unmounting
    - Mathematical model for time to actuate up, down, and load/unload
- Requires only 1 adult to mount/unmount motorcycle
    - Mechanical advantage calculation for inclined plane, and, more essentially, model testing and investigation on small scale
- Must be able to withstand 1500 lb total load

    - Perform CAD analysis of the teeth for the locking mechanism and ensure they are deep/strong enough at current thickness
- Withstand acceptable lateral forces
    - Mathematical model investigation including center of mass and force impact analysis
- Require less than 100 pounds to move while bike is mounted
    - Use force scale to measure maximum force needed to move mechanism with bike mounted on scale model, including various terrain
- Budget under $1,000
    - After material selections and designs are finalized, a budget for final estimated cost will be made.

## Final Product Validation Plans

Due to the limited time available to complete this project, we will not be manufacturing a final product. If given the opportunity/time to complete more testing and create detailed manufacturing plans leading to the construction of a final product, we would complete a set of validation plans that are separate from our preliminary verification plans. Many are only possible with a fully completed model. These final validation plans would provide the ultimate level of assurance that the product is meeting all of the needs of our sponsor. This section systematically analyzes potential tests required for each user requirement in order to validate the final design as well as the fundamental engineering fundamentals required.

In regard to initial validation, our stakeholders reviewed our design multiple times and provided feedback. We got approval from our sponsor for the design of our lockout mechanism and scissor lift design, as well as the table surface and utilization of chocks/hydraulic actuators. Additionally, we got direct sponsor approval to remove any stairs/steps to get onto the table, thus simplifying our design.

### *General Validation Plan*

For a generalized validation, we will show our SPARK sponsor our design and seek approval on all fronts. They would, at their discretion, show the design to their team members for feedback. Also, we would provide our final manufacturing plans to mechanical engineering staff at the University of Michigan for feedback and eventual approval. Finally, we would ensure each of the design requirements meet all of the validation criteria spelled out in the following section.

### *Individual Specification Validation Plans*

On top of sponsor approval for each of these requirements, the following validation tests can be performed, which each correspond to the previously documented specifications for the listed requirements (individual specifications omitted for redundancy considerations).

Reliable

- Perform 150 cycles of lift/lower on a full-scale physical model without requiring critical maintenance.
- Ensure battery life for the hydraulic pump is sufficient for a full day’s worth of usage through trial .

Adjustable

- Perform 50 cycles of lift/lower targeting specific discrete heights.
    - Ensure the success of the locking mechanism each cycle.

Able to support heavy load

- Load 1000 lbs worth of weight onto the lift.
    - Cycle up and down the entire range 50 times.
- Load 350 lb point loads at the determined weak points of the table.
    - Cycle up and down the entire range 50 times.

Portable

- Approve through inspection of final design
    - Transport lift through various environments
        - Gravel, concrete, gym matting
        - Two people should be enough for this task
        - Perform without bike on lift
    - Have SPARK members load the lift into the trailer
        - Two people should be enough for this task
        - Load and unload the trailer

Easy to use

- Hold an optional instructional session for the SPARK team where our team informs members of how to use the lift. Once completed, have every interested member load and unload the motorcycle without help from others. If every interested member is able to complete this at least once, the design is a success. Important to ensure one member is all that is needed.

Sturdy

- Further research is required into the mechanical operations that will be performed on the motorcycle. These specifications however will be validated through two basic tests: Applying the specified horizontal force to the top of the mechanism, and applying the specified torque about the mechanism's vertical axis. The design is a success if the mechanism does not translate or rotate during the two tests.

Free rotation of motorcycle wheels

- Spin the motorcycle wheels at speeds varying from 0 mph to 150 mph. The design is a success if the wheels are able to freely rotate without being stopped by the mechanism.
    - In actuality, this design was validated through the design process by utilizing the same chock system the MSPARK team already uses.

Clear sight lines to working areas

- If there are at least 7 inches of clearance under the motorcycle, the design is a success.

Compact

- Pack up the final design into its compact form. Measure the box volume that it is contained within. If less than or equal to the volume in the specification, the design is a success.

Safety

- A series of 10 tests will be performed to ensure that when the primary locking mechanism is disengaged suddenly (simulating failure scenario) the secondary locking mechanism will hold the mechanism in place. The design is a success if the mechanism is held in place every test without any plastic deformation done to the secondary locking mechanism. The mounting process must also adhere to all of the safety standards set by the Wilson Center to be considered a success.

Move mechanism with motorcycle mounted

- Using a force scale, determine the maximum amount of force required to move the mechanism while the motorcycle is mounted on top of it. The design is considered a success if the maximum required force is less than 100 lbs.
- A more practical followup test would include having actual SPARK team members attempt to move the mechanism with motorcycle mounted and assess difficulty.

High friction work surface

- Perform a static friction test using a known mass with a rubber surface (such as the bottom of shoes), to simulate that of the motorcycle tires or treads of shoes. Use a spring scale to measure the force needed to overcome the static friction, and then using this value and the mass, calculate the coefficient of friction between the two surfaces. Perform this test 3 times in 10 different locations (for a total of 30 tests) on the surface to find the average coefficient of static friction. Ensure it is above 0.5.

Travel multiple surface types

- Using a force scale, determine the maximum amount of force required to move the mechanism on each of the 4 surface types. The design is considered a success if the maximum required force is less than X N.
- A more practical followup test would include having actual SPARK team members attempt to move the mechanism with motorcycle mounted and assess difficulty.

Damage Resistant

- The design is a success if the operation of the mechanism is not affected by fluids or operations performed by SPARK during motorcycle construction. Physically using the cleaning supplies typically used by the team and checking for damage would provide validation.

Tool Storage

- Store the maximum amount of supplies on the mechanism. If the sponsors approve of the amount of tools stored, the test is a success.

Affordable

- Create a comprehensive budget from the bill of materials and every other cost that went into the project. Design is a success if total cost is less than the allowed budget of $1,000 (or sponsor approved).

## Risk Analysis

The limited time between the validation and verification stage and the Design Expo will prevent our team from building a full-scale model of our mechanism, which is why we opted to build a 1:10 scale model for proof of concept. We will ensure that the scaled model accurately represents the function and features of our full-scale product. It will not, however, be a perfect representation of the mechanism since it will consist of different materials which interact differently than the materials selected for the final full-scale design. We can not be 100% certain that a full-scale product will behave the same way as the model, and thus the final design will require additional validation and verification to ensure that it completely fulfills our sponsor's needs.

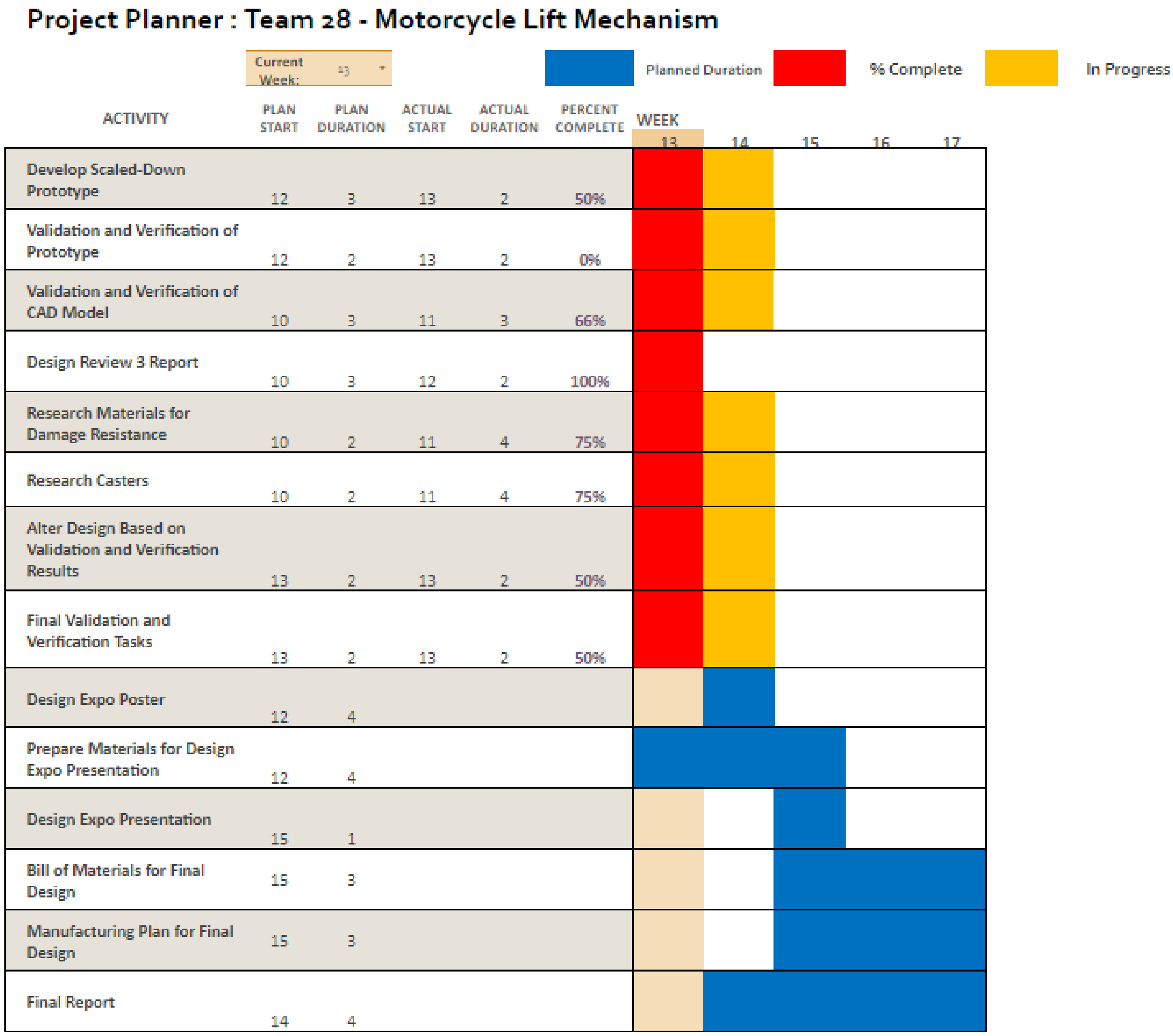
There are few different issues that may have potentially been overlooked for a full-scale final design. For example, friction in the scissor arm tracks is not necessarily accounted for in the CAD model and may affect the overall performance of the mechanism. However, this may not be a serious threat as added lubrication in these areas can be applied to reduce the friction and allow for smoother motion of the mechanism. Additionally, because our team is sourcing design components from outside suppliers, there is always the chance of manufacturing errors, which are beyond our control. In the case of a faulty hydraulic actuator, or any other faulty components for that matter, our team has created a final design that allows for easy replacement of parts.

Other examples of potential issues that may develop over time include the loosening of fasteners, damage to bearings, and damage to the casters. The fasteners may loosen over time due to vibrations from power tools being used on the bike or vibrations that may occur when the mechanism is in motion. Over time, both fasteners and bearings could sustain damage simply from use in supporting such heavy loads. This could be prevented by doing an analysis of the lifetime of the fasteners and bearings and implementing preventative measures such as selecting bearings and fasteners that will be able to withstand such heavy loads and adding elements such as spring washers to absorb vibrations. The casters may become damaged over time due to experiencing impacts on bumpy surfaces or simply failing under the heavy loads. To prevent this, the selected casters for the final design each individually have a maximum capacity of 1,200 lbs, and with 8 caster wheels, they will be able to support more than 6 times the weight of the maximum load outlined in the “Able to support a heavy load” engineering specification of 1,500 lbs.

Finally, because this is a heavy mechanism being used to perform dangerous tasks, our team will also need to ensure that all users of the final design on the SPARK team use it safely. Since the lockout bar is only put in place when the mechanism has reached a certain desired height, there is no way to ensure the safety of the mechanism while it is in motion. As a result of this realization, we will be creating a safety plan for the members of the SPARK team along with when we hand off our final manufacturing plans and bill of materials. These safety plans will ensure the team is aware they cannot stand on the mechanism or disturb it while it is in motion. We will also be instructing them to keep their hands away from the lockout bar and the underside of the mechanism to avoid getting their hands caught in the mechanism by accident.

## Project Plan

The team’s schedule for the last 5 weeks of the semester was reflected in Figure 35 below in the form of a Gantt chart.



**Project Planner : Team 28 - Motorcycle Lift Mechanism**

Current Week: 13

Planned Duration | % Complete | In Progress

| ACTIVITY | PLAN START | PLAN DURATION | ACTUAL START | ACTUAL DURATION | PERCENT COMPLETE |
|---|---|---|---|---|---|
| Develop Scaled-Down Prototype | 12 | 3 | 13 | 2 | 50% |
| Validation and Verification of Prototype | 12 | 2 | 13 | 2 | 0% |
| Validation and Verification of CAD Model | 10 | 3 | 11 | 3 | 66% |
| Design Review 3 Report | 10 | 3 | 12 | 2 | 100% |
| Research Materials for Damage Resistance | 10 | 2 | 11 | 4 | 75% |
| Research Casters | 10 | 2 | 11 | 4 | 75% |
| Alter Design Based on Validation and Verification Results | 13 | 2 | 13 | 2 | 50% |
| Final Validation and Verification Tasks | 13 | 2 | 13 | 2 | 50% |
| Design Expo Poster | 12 | 4 | | | |
| Prepare Materials for Design Expo Presentation | 12 | 4 | | | |
| Design Expo Presentation | 15 | 1 | | | |
| Bill of Materials for Final Design | 15 | 3 | | | |
| Manufacturing Plan for Final Design | 15 | 3 | | | |
| Final Report | 14 | 4 | | | |



**Figure 35:** The Gantt chart in this figure maps out the duration of the final portion of the project, highlighting the individual tasks along with their projected duration/completion on the left side of the chart. The blue blocks indicate the planned duration of each activity, the red blocks represent the percentage of completion of the task, and the orange blocks show which tasks are still in progress.

Following the completion of Design Review 3, the team's next immediate tasks were to finish the remaining verification tasks listed in the "Remaining Verification Tasks" section then move onto validation plans listed under "Individual Specification Validation Plans". Many of the remaining verification tasks required us to develop a physical scaled-down model. Since our prototype worked properly and we are satisfied with the results of our validation and verification, SPARK may choose to construct the full-scale mechanism. We worked to prepare our deliverables for the design expo in week 15 and made a completed bill of materials and rough manufacturing plan for the final design to incorporate into the final report before the end of the semester, which corresponded to the end of week 17.

Throughout the remainder of the project timeline, the team continued to meet with our sponsor biweekly to inform them of the team's progress, ask for their opinions on our progress, set up times to meet in person if needed, and ensure our team satisfied all of their wants from the designed lifting mechanism. Having a specific timeline for the start and completion of the tasks reflected in the Gantt chart in Figure 35 allowed the team to organize and delegate tasks in order to ensure we were staying on track for the completion of the project before the end of the term.

### *Individual Roles and Responsibilities*

Each of the five members of the design team were assigned a role in which they are in charge of for the duration of the semester. The roles cover all areas of the project from team logistics to specializations in diverse technical fields and are assigned as follows:

- *Communications*: Our communications lead is Becca Cuomo. The main responsibilities of this role are:
    - Draft outgoing team communications for further approval by the team
    - Set up meetings and Google Calendar invites
    - Serve as liaison between team and sponsor
- *Documentation:* Our documentation lead is Sarah Dressing. The main responsibilities of this role are:
    - Set up documents for team usage
    - Ensure weekly links in class document are uploaded by Monday evening
    - Keep all team documents organized and easily accessible
- *Manufacturing and Embodiment:* Our manufacturing and embodiment lead is Dustin Fletcher. Becca Cuomo will assist as necessary. The main responsibilities of this role are:
    - CAD modeling
    - Prototyping delegation
    - Overhead production of machined parts
    - Ensure machined parts meet specifications and quality standards
- *Modeling and Analysis:* Our modeling and analysis lead is Emma Pickett. The main responsibilities of this role are:
    - Manage mathematical models and delegation thereof
    - Ensure mathematical models align with experimental data
    - Lead the FEA of models
- *Budget and Finances:* Our budget and finances lead is Grant Robertson. The main responsibilities of these roles are:
    - Submit purchase orders under this section associated with Barton for our project
    - Have a strong understanding of what the budget is
    - Manage research into pricing of outsourced items, pricing of benchmarking
    - Budget Negotiations (if applicable)

## Discussion

Our team did everything within our power to create a thorough and robust design to satisfy the needs of the UM SPARK Racing Team. Our design has many strong aspects to it, however as with any design, it is not without its shortcomings. This section will be a complete critique of our design and design processes.

### *Problem Definition*

A large portion of the semester focused on creating as complete of a picture as possible for the problem definition, which allowed our team to more clearly understand the scope of the project. Even with this emphasis on problem generation, the nature of ME 450's short timeline did not allow for a perfect understanding. If given more time and resources, our team would plan to implement several sources for collecting information. We had attempted to survey the UM SPARK Racing team through an online Google Form, however we did not receive any responses. Thus, with more time, we would plan to survey members of the team in person, asking the participants what they like in the current design, what they don't like, what they want the new design to have, what they NEED the new design to have, and any other questions/concerns/comments. Asking these guided open-ended questions is important to gain perspective of what the real problem is, as the real problem could lie elsewhere than the original design request. As a hypothetical example, the main issue with SPARK's current setup could have been with how the bike is lifted onto the table surface, rather than the lack of table adjustability, and could have changed the scope of the design entirely. Further, in a typical design process, the problem definition is re-evaluated after creating a "final prototype" that is then presented to the focus groups. With direct feedback from the focus group, the design team may or may not need to revisit the original problem definition to create a more precise set of requirements and specifications, such that the design ultimately satisfies the wants and needs of the users. If given the opportunity to present a prototype, our team would explore the following questions:

- How easily is our lift transported into the trailer?
- How does our lift perform on uneven terrain?
- How accessible is this lift for team members in wheelchairs or with other forms of disabilities?
- Are there any features our team missed that UM SPARK would like to have? Any features that are unnecessary?

### *Design Critique*

Our team's final design has many strengths. We were able to meet almost every functional requirement that was defined in the problem statement. Most importantly, our lift is sturdy and can withstand incredibly heavy loads, ensuring the safety of the users. The hydraulics allow for continuous adjustability, allowing for far more adjustability than the minimum specifications required. The lift was sturdy, requiring over 450 lbs of force applied laterally on the table surface in order to tip, is simple to operate, and contains an additional fail-safe mechanism. However, to further improve these strengths, some additional explorations should occur. One such exploration would be analyzing the scissor geometry to minimize the forces required by the hydraulics in order to operate the lift. Further, optimizing the hydraulic connection to minimize deviations in the amount of force required to operate the lift, which would reduce the fatigue ratio on the hydraulic axle and increase the overall lifespan. Another area of exploration focuses on the locking teeth for the fail-safe mechanism. Due to the geometry of a scissor lift, equidistant teeth do not translate to equidistant height settings for the table surface. Thus, design considerations could be made to make the stop heights equidistant rather than the teeth. Lastly, the current design could have some interference between the slider axle and the teeth of the locking mechanism. To circumvent this issue, the slot and pin support holes could be made lower in the lift base and the height of the slab under the locking teeth can be reduced. This would allow the teeth to be welded onto the base such that the bottom of the slab is above the slots.

Currently, the main weakness in our design is the weight. With our material choices, the mechanism totals approximately 1550 lbs. This could prove to be an issue when transporting the lift into a trailer, as it may be difficult and/or dangerous to push up a ramp. Some potential solutions to mitigate this issue would be considering other materials, such as carbon fiber for the table surface and less dense metals for the mechanism body, or possibly attaching a winch to the mechanism and a hook on the trailer, allowing the scissor lift to be loaded into the trailer using a winch system.

### *Risks*

Our team encountered several challenges during this design process that have implications for the final design. One such challenge was finding a way to model the metal safety grating surface that was planned to be used for the table surface. SolidWORKS was unable to form a mesh when this design was implemented in the CAD model, and thus a stress analysis could not be performed specifically on a surface with grates. In an attempt to model this while mitigating potential adverse effects, our team modeled the table surface as a whole slab of metal rather than a grated metal slab, and added an additional safety factor of 500 lbs to the maximum load. Empirical testing of the safety grating surface is recommended. Another challenge encountered was performing fatigue analysis testing on the mechanism. Under all of the conditions tested, the CAD output stated that “All values were below the S-N curve at all times”, which would theoretically mean that the mechanism would never fail due to fatigue. However, as we have never used this software before, we could not be certain that this was not a faulty result. Testing with much larger values yielded the same results, and thus we could not validate the lifespan of the mechanism. Therefore, we recommend moving forward that the final design is assessed in an FEA software such as Abaqus to ensure that the design will operate safely during the 10 year span. With the current analysis, a potential risk of operation is cyclical failure during a 10 year mechanism lifespan.

Other general risks associated with the final design are pinching points around the scissor joints, exposed corners that users could hit their heads on, tipping of the mechanism if the lift is operated on steep angles, and general misuse of the lift while in operation.

## Reflection

There were many factors that influenced our project and how we went about defining our problem and brainstorming solutions, including public safety and welfare, and social and economic impacts. Public safety was extremely relevant to our project since we wanted to come up with a solution that would reduce the risk of injury for users while working on their motorcycle by creating a mechanism that would reduce the amount of human-labor required to access certain areas of the bike. We also held the overall welfare of SPARK in mind since we believed that easier access for bike maintenance and repairs could lead to better team morale. As SPARK moves forward with manufacturing our design, we want to make sure that we are keeping the welfare of any manufacturing workers involved in the process. We do not want to create any negative social impacts by sourcing materials from companies that participate in harmful labor practices or contribute negatively to public welfare in the form of pollution or other environmental damage.

We also understand that our project has a direct economic impact on the College of Engineering, as well as SPARK and their sponsors since our design could improve team performance which could bring in more money for SPARK and the College of Engineering. Since SPARK plans on using resources available through the College of Engineering for manufacturing our design, our project is directly impacted by the resources provided by the University to student project teams and will have a direct economic impact on the companies who provide those resources to the University, since they provide the materials and machinery necessary for the manufacturing processes.

The global context of our project, however, was not at the forefront of our minds throughout the design process since our project was intended to be for private use by SPARK. Since there are many products similar to our design in the global marketplace, however, if we wanted to move forward with commercializing our design, we would have to figure out how to make our design unique enough to really be of benefit in a global marketplace. Overall, we found our stakeholder map to be a helpful tool in understanding the broader impact of our design beyond SPARK which informed our design process in general.

Although the members of our team all come from different backgrounds with different privileges associated with either gender identity or socioeconomic status, we quickly discovered that we all placed an importance on communication and independence in group work, which we worked to maintain with each other as we completed individual tasks throughout the design process. Sharing similar values allowed us to effectively communicate with each other about dividing work and asking each other for help when needed. When it came to communicating with our sponsor, we understood that he was more experienced in working in project teams and was much more knowledgeable about motorcycles and SPARK's needs in general, so we used his knowledge to our advantage and ran all of our decisions by him, seeking his advice on major design decisions and verification methods.

Throughout our design process, there existed a power dynamic between the members of our team and also in our relationships with our sponsor and other stakeholders. Our sponsor, being a member of SPARK, was more knowledgeable about motorcycles and SPARK's needs so he had the power to influence our overall design, but we also have power over his safety as a potential user. Most of our other stakeholders were related to the University of Michigan (the Mechanical Engineering Department, College of Engineering, the ME 450 instructional staff, etc.) and, therefore, had the power to determine what resources we had access to over the course of our project, but the success of our project could also have a direct impact on their reputation and ability to acquire resources for future students. Between members of our team, we had different levels of knowledge and experience in different subjects within mechanical engineering, so we tended to take the lead on things that applied to our interests or specialties and became the source of knowledge on those topics within the team.

When deciding between different viewpoints in design decisions, we weighed the pros and cons of each option and discussed the situation with our sponsor. He was then able to guide us in making a decision that the whole team was comfortable with and would also suit his needs. When it came to balancing whose ideas were selected, we prioritized the ideas of our sponsor because we were working directly for SPARK's benefit and wanted them to be happy with our final design, but we also listened to guidance from our professor to determine how to go about fulfilling our sponsor's needs. As a group, we had more cultural similarities than differences which allowed for easier communication between members of the group throughout the design process and any cultural differences that would have an impact on the project such as holidays and family obligations were handled with responsible and honest communication whenever they arose. We were not heavily impacted by cultural differences with our sponsor either, so we were able to easily communicate with him as well.

Our group ran into an ethical dilemma when faced with the choice to include the lockout bars in our design. We discovered that we needed to have a plan for ensuring the safety of the mechanism in the case of hydraulic failure and our team agreed that the lockout bars would be the best fail safe. Including them in the design, however, would add to our list of tasks for validation. As we approached the deadline for DR 3, however, the whole team was suffering from burnout due to other academic and extracurricular responsibilities, so it was tempting to cut corners and avoid performing the analysis on the design including the lockout bars. Ultimately, we all knew that providing our sponsor with proper validation and verification was important since they were very trusting of us in their willingness to implement our design without much modification. As the deadline for verification and validation approached, we communicated as a team and budgeted our time by splitting work so that the members responsible for the analysis could complete it in a reasonable time frame without having to worry about additional work on the report and presentation. Overall, as a team we valued transparency and prioritizing the safety of as many people as possible throughout our design process which aligns with the ethics taught to us by the University of Michigan. If we were working on this project as engineers working in industry, we would still strive to uphold the same values but could potentially run into disagreements with our supervisor if our values of transparency and safety would impact the profits of the company or the public reputation.

## Recommendations

Throughout verification and validation testing as well as a fast approaching deadline, there are a few areas of this project that would benefit from revisions in future iterations. The overall design has had significant modifications since its first alpha design stage due to lack of feasibility or inability to pass validation testing. Some of these recommendations for improvement range from a broader system-level to a finer detailed-level aspect.

### *System-Level Recommendations*

Overall, the system may benefit from the addition of a third hydraulic actuator. This would not significantly change the design of the mechanism as it could go on the same axle as the other two existing actuators. Providing a third hydraulic to this design would reinforce its ability to withstand substantially large loads for this application, as well as ensure a backup actuator in case one of the other hydraulic actuators were to fail.

Another system-level design recommendation our team would have for our sponsor or future teams assigned to this project would be to investigate the use of different materials for both the top surface as well as the bottom base of the mechanism. Lightweighting these materials would reduce the total mass of the design which is beneficial as it would allow the mechanism to effectively be more portable.

Originally, our alpha design included the addition of a stowaway ramp that would rest within the top table surface. However, our team did not have time to successfully incorporate this into our build design within the time frame given for the project. Additionally, introducing a ramp would further increase the weight of the mechanism. A recommendation for the stowaway ramp feature would be to investigate materials that could withstand the weight of the motorcycle as well as minimally increasing the total weight of the design.

### *Detail-Level Recommendations*

Another way to achieve lightweighting the design could be looking into the possibility of designing thru holes in the top table surface where excess material is not needed. This may also be applicable to other areas of the design such as the bottom base. Introducing this to the design could also contribute to significant weight decrease and increased portability of the design. Finally, other than determining how the hydraulics are powered, whether it be through a hosing power source, valves, etc, a final detail-level design recommendation would be to consider the use of bearings for the axles to fit into, and determine whether or not this would impact friction or impede motion of the mechanism.

## Conclusions

From analyzing important contextual factors, we have come to some critical conclusions. First, this project is easily justifiable due to its positive societal impact across the globe. Improved ability for mechanics to work on motorcycles efficiently and safely, improved portability for motorcycle raising mechanisms for potentially stranded drivers, and improved ergonomics for motorcycle mechanics are all benefits that could reach internationally as well as the 126,356 United States Automotive Repair Shops or the 8.6 million registered U.S. motorcycle owners (IIHS, 2021) (SICCODE, 2023).

Our stakeholder analysis aided us in determining where to focus our efforts. Many individuals and groups are attached to this project in some way, but our primary stakeholders are the most important to consider when making design decisions. The most prominent motivation among our primary stakeholders is classified as social. Both the SPARK team and the Mechanical Engineering Department benefit heavily from an increase in SPARK's success in competition and reputation as an organization. Improving the motorcycle lift's safety and efficiency will ultimately cause the competitive and reputational success that our stakeholders strive for.

In order to find a clear path moving forward, we thoroughly considered the requirements and specifications for this project. With the contextual motivation of this project in mind, the requirements of reliability, adjustability, ability to support a heavy load, and portability have been emphasized as absolutely critical. Their specifications are heavily detailed to ensure these key requirements are fulfilled entirely and quantifiably.

After conducting initial brainstorming and concept generation, our team sorted through solutions via processes such as individual concept-generation, iterated individual concept-generation through the use of morphological charts or design heuristics, gut checking and functional decomposition, and finally a group concept-generation session. These processes allowed the remaining solutions to be sorted into design features which would then be scored against their respective Pugh Charts which served as a formal down-selection process in which the best features of generated solutions were selected and morphed into an Alpha Design. Runner-ups from the charts were separately labeled as beta elements. Beta elements served as contingency plans so that if moving forward with the Alpha Design in the design process did not turn out how the team had hoped, there would be backups in place to fall back on. However, after discussion with our sponsor of our design, our team felt confident moving forward with our chosen Alpha Design plans.

Additionally, our team developed and executed a plan to analyze and validate each of the engineering specifications. The validation tests that posed the largest challenges were for the main four requirements of “Support a heavy load” due to material and safety constraints, “Portable” and “Reliable” due to potential bottlenecking from running multiple long tests, and “Sturdy” due to variability in applied loads when testing. Since these four posed the largest challenge and were considered our most important requirements, we decided to focus our validation and verification on those requirements and their corresponding specifications. We employed a static analysis of the CAD model using the CAD software to ensure the design could endure the loading conditions and we relied on inspection of the CAD model for the remaining 3 requirements. We also developed a scaled-down physical model for validating and verifying other requirements and specifications.

Using feedback from our sponsor along with feedback we received from DR 3 and the design expo, we were able to finalize our design and create a manufacturing plan and bill of materials for the final design. Following the completion of this report, our team will hand off our bill of materials and manufacturing plans to SPARK so they can work on building our final design in their off-season in order to use it for the next competition season. We believe that we have fulfilled SPARK’s needs in providing them with a safe, adjustable, reliable, and portable design that will improve morale among the team along with performance at competitions. We also believe that our design could be applied to other student project teams and could serve to benefit motorcycle owners and racers all around.

## Acknowledgements

We would like to thank our sponsor, SPARK, along with the ME 450 Instructional Team for their guidance throughout the design process and ensuring our success with our project. We would also like to thank librarian, Paul Grochowski, for his guidance in our research for the front-end of our design process.

## References


"1910.147 - The Control of Hazardous Energy (Lockout/Tagout). | Occupational Safety and Health Administration." n.d. Accessed February 1, 2023. https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.147.

23, posted on: Sunday September. "An Explanation of Force and Labor Power." Load Movers INC, September 24, 2012. https://www.loadmoverinc.com/force-labor-power/#:~:text=person%20with%20good%20upper%20body,steel%20may%20be%20300%20lbs.

"ANSI/ALI ALOIM – A New Standard | Automotive Lift Institute." n.d. Accessed February 1, 2023. https://www.autolift.org/history/1994/.

*ASME Standards Collection - ASME PASE 2019*. n.d. Accessed February 1, 2023. http://asmestandardscollection.org.proxy.lib.umich.edu/GetDoc.aspx?doc=ASME%20PASE%202019.

"Auxx-One - Lifter for Hard Top, Motorcycle, Rooftop Tent, Fifth Wheels – Auxx-Lift Store." n.d. Accessed February 1, 2023. https://auxx-lift.com/products/auxx-one?variant=40041984524464&currency=USD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&gclid=CjwKCAiAoL6eBhA3EiwAXDom5nQLRodr5p3GFyuIdqcYW3nxNDkDrkzgUECvXXXlS56StqnRmHRlBBoCBVUQAvD_BwE.

Balls of Steel. 2022. "Deadlift Jack, All Products.". Accessed February 15, 2023. https://www.bellsofsteel.us/all-products/strength-equipment/strength-training/deadlift-jack/

"Black Widow ProLift Heavy-Duty Air/Hydraulic Motorcycle Lift Table - 1,500 Lbs. | Discount Ramps." n.d. Accessed February 1, 2023. https://www.discountramps.com/motorcycle-lift-tables/p/BW-PROLIFT-HD/?gclid=Cj0KCQiA_bieBhDSARIsADU4zLepsw-X24nZVZexj3mT9qSqI236Y_oRZFMdyDOpIiequTnimm6QpGUaAtMXEALw_wcB.

Convergence Tech, Inc. n.d. “Frequently Asked Questions (FAQs).” Accessed February 15, 2023. https://www.econvergence.net/category-s/1817.htm.

Cooper, Heather L. 2020. “ME Capstone Design Process Framework.” University of Michigan- Ann Arbor. https://umich.instructure.com/courses/606189/pages/me-capstone-design-process-framework?module_item_id=2712887.

Design Heuristics, LLC. 2009. “Design Heuristics.” Accessed February 15, 2023. https://www.designheuristics.com/the-cards/.

Dugan et al. n.d. “Concept Exploration Overview: ME 450 Learning Blocks WN 2023.” Accessed February 15, 2023. https://umich.instructure.com/courses/606189/pages/concept-exploration-overview?module_item_id=2713004.

Eoslift USA. n.d. “I10 - -I15D, I10, I15DE,I10E/I15E - Eoslift United States.” Eoslift USA. Accessed February 24, 2023. https://www.eoslift.us/index.php?m=content&c=index&a=show&catid=85&id=41.

“Ergonomics Back Injury Prevention, UVA-EHS.” n.d. Accessed February 1, 2023. https://ehs.virginia.edu/Ergonomics-BIP.html.

G. E. Totten and N. V. J. de, *Handbook of Hydraulic Fluid Technology*. Boca Raton etc.: CRC Press/Taylor & Francis Group, 2017.

Industrial Quick Search. n.d. “Scissor Lifts: Types, Applications, Benefits, and Components.” Editorial. Industrial Quick Search Articles. Accessed February 24, 2023. https://www.iqsdirectory.com/articles/hydraulic-lift/scissor-lift.html.

Khan, Mustafa, 2023. 2/23/2023 Mustafa Meeting Notes. https://docs.google.com/document/d/1-Q59XE8RGHX1-ltGGLCbO4aTYuw202aWzTgN2WpK-b8/edit.

Khan, Mustafa. 2023. "RE:[Powered Motorcycle Lift Mechanism] Hi from Your New ME 450 Team!," January 13, 2023. https://mail.google.com/mail/u/0/?tab=rm&ogbl#search/mustafa/FMfcgzGrbvKrRcbKrWQZhGPrwXwGnHpn.

Khan, Mustafa. 2023. Initial Sponsor Interview- ME450 Team 28. https://drive.google.com/drive/folders/19aKMBjL8ese_TIrV0fpLErP0bp8K_1fx?usp=share_link.

Khan, Mustafa. 2023. Letter to ME 450 Team 28. "Notes from Design Review," January 26, 2023. https://mightymichiga-1yn3284.slack.com/archives/C04K4NLTR6F/p1674762401561079.

Magister Hydraulics. 2019. "1.5 Bore x 8 Stroke Hydraulic Cylinder, Welded Cross Tube Double Acting Cylinder." Magister Hydraulics. July 5, 2019. https://www.magisterhyd.com/product/1-5inch-bore-x-8inch-stroke-cross-tube-hydraulic-cylinder/.

"Material properties database," *MakeItFrom.com: Material Properties Database*. [Online]. Available: https://www.makeitfrom.com/. [Accessed: 28-Mar-2023].

ME 450 Team 28. 2023. "Notes from Librarian (Paul Grochowski) Meeting 1/30 - Google Docs." January 30, 2023. https://docs.google.com/document/d/16xCOahxJ9qtjysJTERFhBRQlpYYojKGn0PqeOFzFqo0/edit.

Mills, N.J. 2007. "Hip Protector Case Study." In *Polymer Foams Handbook*, 403–24. Elsevier. https://doi.org/10.1016/B978-075068069-1/50018-0.

"Motorcycle Lift Table, 1000 Lb. Capacity." n.d. Accessed February 1, 2023. https://www.harborfreight.com/1000-lb-steel-motorcycle-lift-68892.html?utm_source=google&utm_medium=cpc&utm_campaign=12144811130&campaignid=12144811130&utm_content=117789303998&adsetid=117789303998&product=68892&store=210&

gclid=Cj0KCQiA_bieBhDSARIsADU4zLdPMIdc964Xs9AdaILwiXqUPKubUL82Qt-12af4qkA4mX6ouJIiMZkaAiXTEALw_wcB.

"Motorcycle Maintenance Checklist - Nationwide." n.d. Accessed February 1, 2023. https://www.nationwide.com/lc/resources/powersports/articles/motorcycle-maintenance-checklist.

"MSF Releases Motorcycle Pre-Ride Inspection How-To Video New T-CLOCS Video Shows How Costly Repairs and Injuries Can Be Avoided – Motorcycle Safety Foundation." n.d. Accessed February 1, 2023. https://msf-usa.org/msf-releases-motorcycle-pre-ride-inspection-how-to-video-new-t-clocs-video-shows-how-costly-repairs-and-injuries-can-be-avoided/.

"Pit Bull - Spooled Rear, Motorcycle Stand [F0003-000]." n.d. Accessed February 1, 2023. https://www.pit-bull.com/motorcycle-stands/spooled-rear-motorcycle-stand-f0003-000.

Sarum Hydraulics. 2018. "Single Acting and Double Acting Hydraulic Cylinders: What's the Difference? - YouTube." November 6, 2018. https://www.youtube.com/watch?v=O_2BZs3WiQY.

Service Caster Corp. n.d. "6'' Swivel Caster with Brake - Polyurethane Tread on Metal Wheel - 1,200 Lbs Cap." Www.Servicecaster.Com. Accessed March 30, 2023. https://shop.servicecaster.com/product-p/scc-30cs620-pur-tlb-rs.htm.

"SIC Code 7538 - General Automotive Repair Shops." n.d. Accessed February 1, 2023. https://siccode.com/sic-code/7538/automotive-repair-shops.

"Spark - Mighty Michigan Motorcycle Meche Maniacs - Slack." n.d. Accessed February 1, 2023. https://app.slack.com/client/T04JRM55P52/C04K4NLTR6F.

"Sponsors." n.d. Accessed February 1, 2023. https://spark.engin.umich.edu/Sponsors.html.

Teoh, Eric R. 2021. "Motorcycles Registered in the United States, 2002–2021." *New York*, March.

"TT Fact Zone - Iomtt.Com: The World's #1 TT Website." n.d. Accessed February 1, 2023. https://www.iomtt.com/tt-database.

Vestil Manufacturing Corp. n.d. "Pneumatic Scissor Lift Table (AT) - Product Family Page." Vestil. Accessed February 24, 2023. https://www.vestil.com/product.php?FID=300.

Wilson Student Team Project Center. n.d. "Wilson Student Team Project Center Safety Training." Accessed February 2, 2023. https://docs.google.com/presentation/d/1ntmvR7pxq02SbA8Rp87un5W3ZA1qwceN0xNr7Yv_hGw/present?slide=id.g2437252466_3_431.

# Appendix

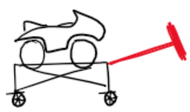
## *Appendix A:Individual Concept Generation*

### *Becca*

1. omnidirectional wheels → wheels that rotate 360° (VEX Robotics)

2. Adjust height with inflatable air-bladder-like device (sphygmomanometer)


3. Handle bar → like a wagon



4. Battery operated


5. Gurney style mechanism


6. Carry bike to trailer (man power)

7. Teleport bike to competition

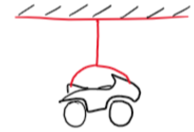
8. Autonomous motorcycle drives itself to competition

9. Make the Wilson center staff hold the bike higher when needed

10. Use a crane to lift the bike onto table

11. Hoist motorcycle with pulley system

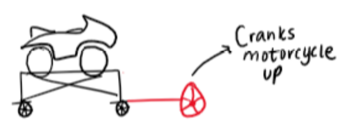
12. Suspend motorcycle from ceiling



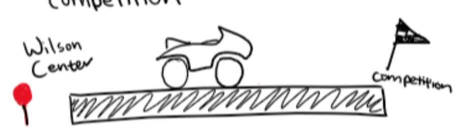
13. Suspend bike in jello block

14. Change motorcycle design to make it taller (doesn't need to be raised anymore)


15. Vise-type mechanism




16. Motorcycle conveyer belt to get to competition




17. Pull bike with rope

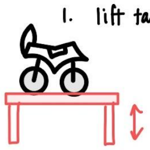
18. Hire private company to transport bike

19. Hydraulic-type mechanism

20. Put bike on private plane to get to competition

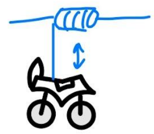
<u>*Sarah*</u>

1. lift table



2. wheel stands

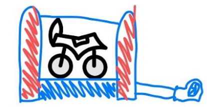

3. overhead hoists



4. Seesaw lifter

probably needs some sort of locking mechanism as well.

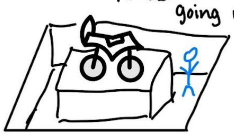
5. Inflatable bounce house



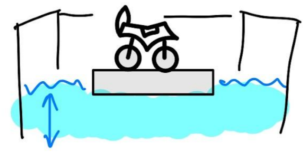
- portable bc everybody rents their bouncy houses
- weight bearing capacity
- washable because kids at parties are not clean.

Inflatable bounce house

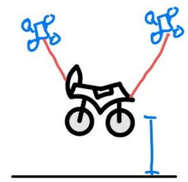
6. build a moat
- the people go down rather than bike going up



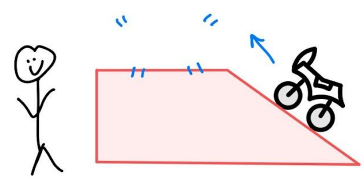
7. bike raft in locks → raise and lower water level



8. Drones



9. Ramp + block



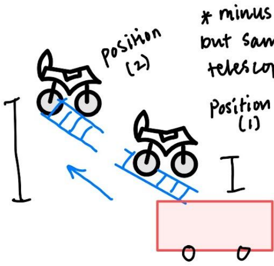
10. baby walker

- portable
- can install other actuators to raise

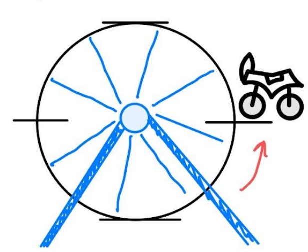
bike is supported in seat like baby would be

11. Fire ladder

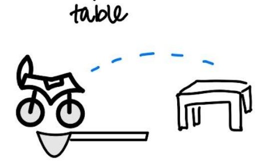
* minus firetruck, but same telescoping ladder



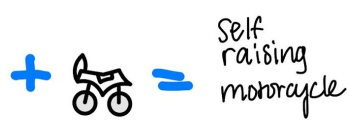

12. Ferris wheel



17. catapault onto table



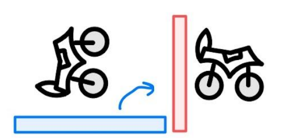
13. lowrider hydraulics on motorcycle



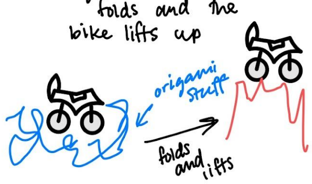

14. magnet

15. Treehouse bike elevator but with motorcycle power

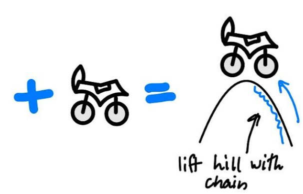
16. strap to wall mount and raise wall



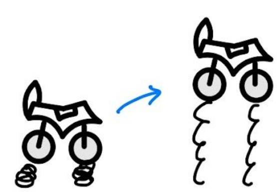
18. origami table that folds and the bike lifts up




19. mini rollercoaster hill for bike



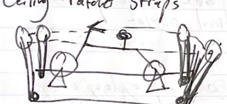

20. springs



## ***Dustin***

- Power screw for adjustability
- Worm Screw? Unsure if different

- Ceiling ratchet straps



~~Connect bikes~~ top spools through rope so synchronous raise; Saw this in a cider mill

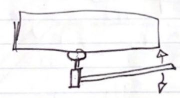
- Team of ~~[illegible]~~ Dedicated Motorcycle Lifters to mount/unmount/hold @ different heights
- Portability → Modular
  - be able to piece together
  - Folding
- Large wheels that can transition to casters or to ground.

off road tire

casters for smooth concrete

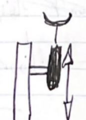
Rotates like a microscope or something

- Bridge-Truss-style to increase strength + decrease weight
- Tungsten surface
- Hydraulic Pump to lift (car jack style)



Hydraulic Press (Manual)

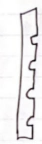
- Fluidized bed of sand
  - supports bike + acts as buoyant fluid
- Forklift style lift



Front view

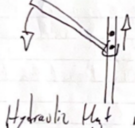
Potentially Double-sided to eliminate Moment

- Gasoline or Diesel generator to power electric lift
- Nuclear Powered lift - no need to refuel
- Powerlifting Rack style

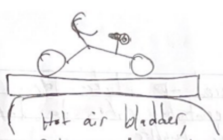


Insert in pegs to set on top

- Combo rack - Long lever arm see powerlifting



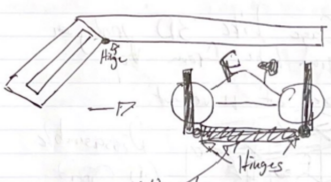
- Hydraulic that moves up but won't come down until pressure release valve ~~[illegible]~~ (Desk chair)
- Hot air balloon



Hot air bladder, fills like hot air balloon

Similarly Fill Bladder with liquid (Hydrostatic die stamping type-beat)

Ramp that also acts as wheel chock (Front + Back)



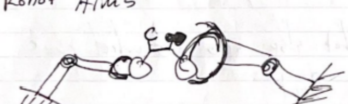
Hinge

Hinges

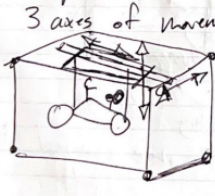
Table Thing

Design would be more compact than current

- Yeast Powered → Makes Bread rise, change concentration ratios to determine adjustable heights
- Hoist Crank with ~~[illegible]~~ very ~~[illegible]~~ low gear ratio
- Robot Arms



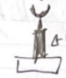
- Modular Case like 3D printing or
  - Suspend bike from top
  - 3 axes of movement



Dissasemble @ Joint Nodes

Single Elevated Stand + adjustable raise/lower stands for students

Front view



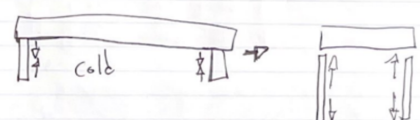
wheel (of motorcycle)

Stand raises to lower to account for heights. Less weight to move.

Similar Concept → multiple discrete ladder sizes w/ fixed motorcycle height

Virtual Reality Controlled Assembly Robot arms assemble bike in remote location

Liquid Cooling ~~/~~ Heating for thermal expansion of stands

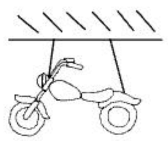


cold

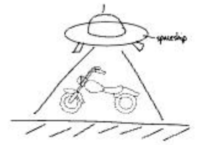
large α value

## Emma

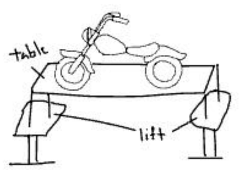
1. Hang motorcycle from ceiling



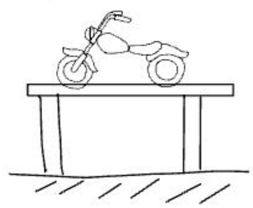
2. Levitate motorcycle



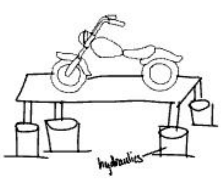

3. Table lifted from floor



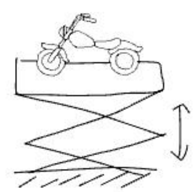

4. Bike on tall table



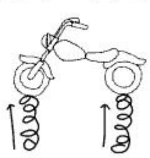
5. Hydraulic lift



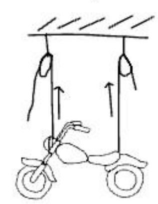

6. Scissor Lift



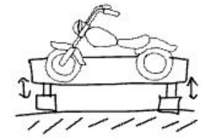
7. Bounce Bike up w/ springs



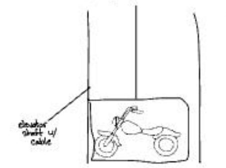
8. Pulley system



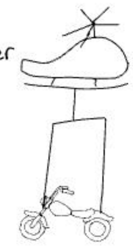
9. Desk w/ adjustable height



10. Elevator

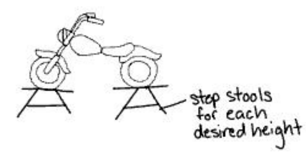



11. Helicopter

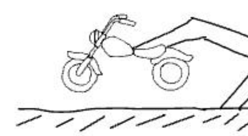


12. Door lift from Monsters Inc.

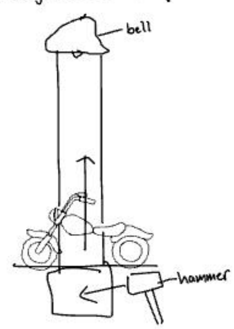
13. Step stools under wheels



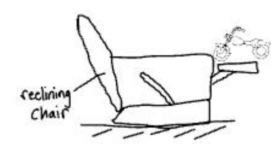

14. Hydraulic arm



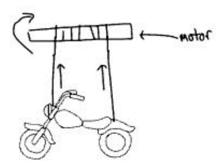
15. Strong man carnival game



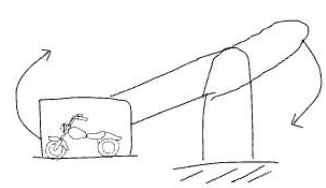

16. Recliner w/ lever



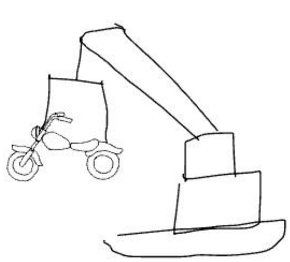

17. Motorized hanging lift



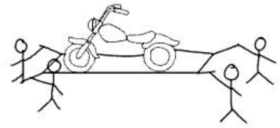

18. Carnival Lift Ride



19. Crane

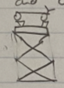


20. Human throne lift

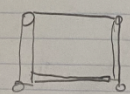


## *Grant*

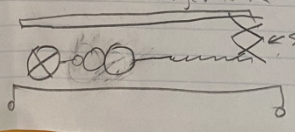
1. Scissor Lift, keep other aspects the same - simple concept. Keep current table and chocks. Use scissor lift w/discrete height settings.



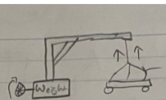
2. Portable Winch System



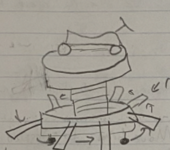

3. Side lead screw w/gear train



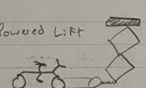

Portable
9 Crane System




"Pirate-Ship Style" Corkscrew Lift

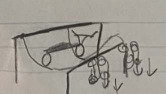



Bike Powered Lift



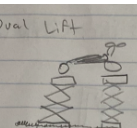
Bike powered scissor lift, could make the process easy and rely on legs (stronger than arms)

Tension Based Lift



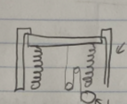
Pull down on ropes until at desired height. Pulley system could reduce weight/force required.

13 Dual Lift

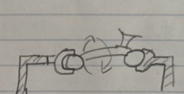


Dual Scissor lift connected w/same lead screw leaves room to access undercarriage

14 Spring loaded Lifting device, Pulley system for lowering

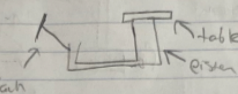



15 Gyroscopic Motorcycle Holder to change bike orientation so bike can be reached easily from any angle



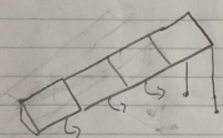
Sets at various orientations

4 Car Jack Style Lift



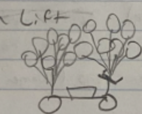

5 Scissor Lift w/ Helium Inserts. Same design as Scissor lift except w/ helium balloons holding in place underneath to reduce load.

6 Incline Plane w/ latches and hole in middle, they fold down



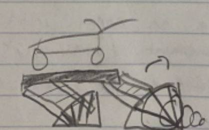
Move bike to desired height then remove middle hatch.

7 Balloon Lift



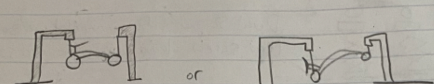
Remove balloons as needed. Can combine with another lifting mechanism to reduce load.

8 Workout Bench-Style Lift (Push from side to various points/notches, use reverse weights to make easier to move)



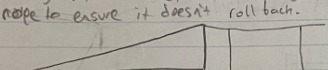
Locks at various tick marks, uses gear train system to make movement easier

(16) Dual Crane Lift w/various heights for either crane

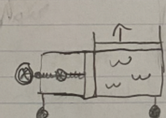



allows for bike to be angled

(17) Not a joke, a long, small angled ramp. With rails and rope to ensure it doesn't roll back.

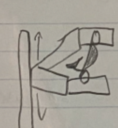


18)



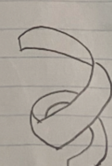
hydraulic piston lift

19)



elevator lift style

20)



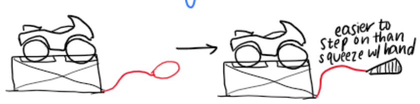
Flat, spiral incline plane lift

## *Appendix B: Iterated Individual Concept Generation*

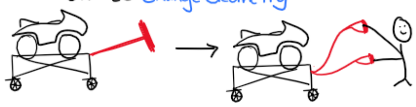
### Becca

1. Built-in housing for wheels
DH#48 Nest

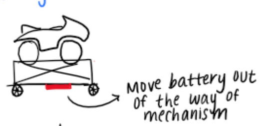

2. Turn inflatable air-bladder into pedal
DH #60 Simplify




3. Turn handle bar into individual hand straps
DH #20 Change Geometry



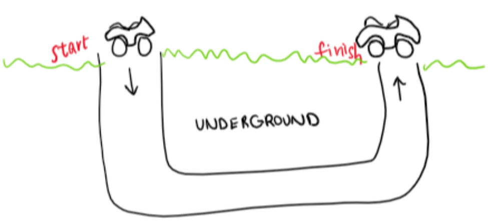
4. Move battery pack to underneath
DH# 18 Change direction of access




5. Work with recycled hospital Gurney
DH #74 Repurposed materials

6. Carry bike on flat surface
DH # 68 Use common base

7. Teleport bike using underground tube system
DH #29 Create system

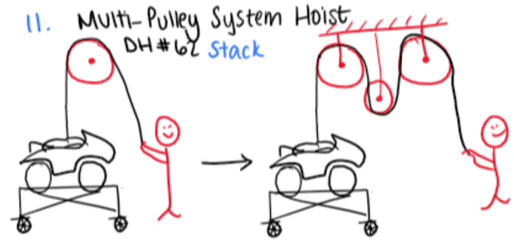



8. Manually drive bike to destinations
DH # 71 Human Power

9. Get staircase to reach new desired heights of bike
DH # 40 User Input

10. Change material to make motorcycle lighter
DH #22 Change Properties

11. Multi-Pulley System Hoist
DH #62 Stack



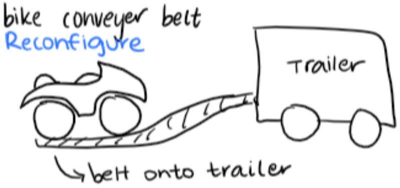
12. Suspend and transport from ceiling hoist
DH # 43 Multifunctional

13. Half jello → expose half of bike
DH # 33 Expose interior

14. Make motorcycle itself height-adjustable
DH# 4 Add to existing product

15. Automatic vise
DH# 70 Different energy source
→ vise won't have to be man-powered

16. Portable bike conveyer belt
DH # 51 Reconfigure




17. Multi-orientation rope harness
DH # 11 Allow user to reorient

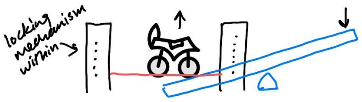
18. Handles for company to hold
DH# 17 Build user community

19. Lightweight hydraulic system
DH# 53 Reduce material

20. Add storage for all team tools
DH# 4 Add to existing product

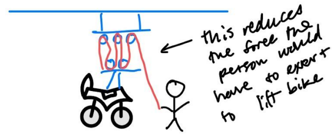
## Sarah

1. seesaw lever w/ frame w/ fall catch




- everytime you seesaw up a bit, the tracks lock at highest position
- combines 1. and 4. from Part 1.
  table seesaw

2. Snatch block hoist



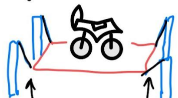

- based loosely on 4. and 19. from part 1.

Functional decomposition

morphological ideas

| lift weight | hold weight off ground | secure bike |
|---|---|---|
| pulley | table | ropes |
| ramp | hanger | wheel chocks |
| lever | stilts | kickstand |
| | moon shoes | wheel holder |
| | salmon ladder/ peg board | bike stand |

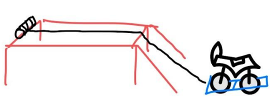
3. Hammock, but you can adjust tension to raise it




- based loosely on 4. from part 1.

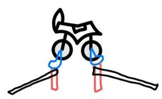
4. tie rod jack platform

5. Ramp + hanger onto table with pulley



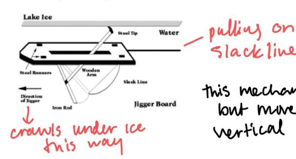
- motor cycle is put on sled, sled is winched up onto ramp with tracks and onto table

6. lever stilt chock stand



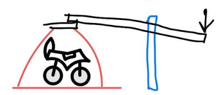
- start on ground with bike on chocks.
- push lever to get bike off the ground and then the stilts come into position and hold bike up.

14. under ice shuttle crawler thing but vertical → "ice jigger"



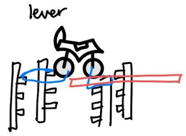

this mechanism but moves vertical

15. lever hanger



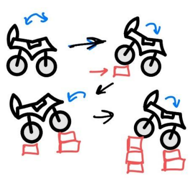
- push down on lever, lift bike in hanger

7. wheel chock-salmon ladder-lever

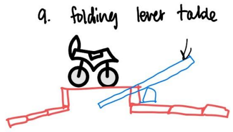


- chock stand rests on salmon ladder rungs
- bike is chock stand

8. rotate lifty thing
- loosely inspired by how people built log cabins



9. folding lever table

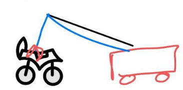


- push down on lever to lift bike
  insert folding segments underneath when current table legs are off ground

16. pulley chocks

oversized chocks that hold bike but you can use pulley to lift bike further - chocks are acting a little bit more like a frame, but they still hold the bike

17. cherry picker with mini crane

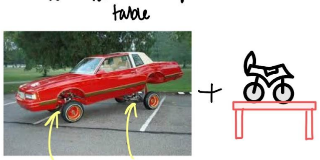


- could be used for a lot of other things too

18. penguin slippery slide thing

- stairs move and penguin climbs up the stairs
- bike is the penguin
- there is no slide

10. lowrider hydraulic table

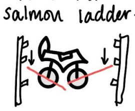


- inspired by 1 and 13 from part 1

11. moon shoe wheels

separate wheels that have blocks that raise them up off the ground

13. Terro motor wheel-salmon ladder-lever



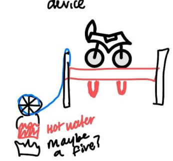
wheels turn levers that let bike move up salmon ladder

act like terro motor

19. levitating table

- no sure how it levitates but it does

20. Sterling engine-pulley powered lift table with magnetic holding device



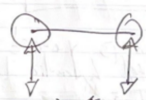

Stirling engine powers pulley lifts bike

12. explosion - blast throws bike onto table

## Dustin

Design Heuristics → - Add to Existing Product
- Allow user to reorient
- Align components around com
- Provide Sensory Feedback
- Redefine Joints
- Simplify

1.) Separate adjusters on each axel so that user may tilt bike

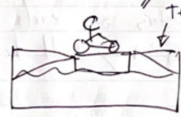



2) Redefine Joints → attach lifting mech to axel instead of table to get rid of chocks to allow free rotation. Drastically reduces area

3.) Attach in center of motorbike mass so it requires single stand

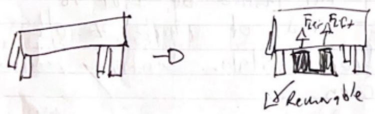
4.) Sensory feedback → adjust to hip height for each individual person

5.) Hydro table (Not necessarily water) that bike floats in on buoyant fluid

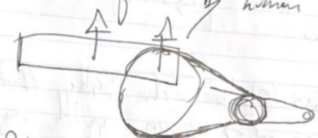



6.) Current Design is raised with a ramp + ~~lift~~ hydraulic lift
~~attachable to it~~

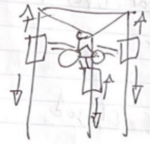
7.) Removable lifting mechanism that transforms regular table into lift




8.) Pulley system with high mechanical advantage powered by human crank



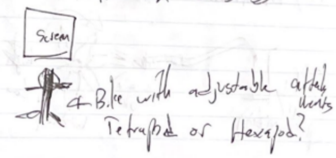
9.) Polar Delta-Printer style mount



10.) Gurney style so humans can use too + (Float)

11.) Suspension mech like in Cars 3

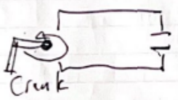
12.)




13.) 2 tall stands with low CoM That have pullys / ropes on the sides

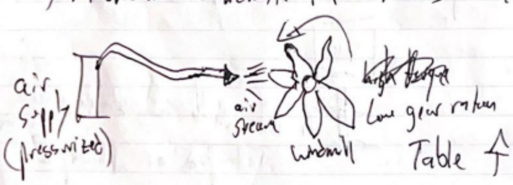
14.) Two Stands with table that moves up & down with motor

15.) Human powered motor like a charge-up flashlight

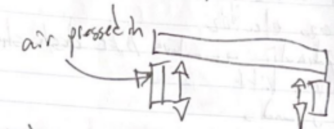



16) Crank power piezo electric system

17.) Pneumatic windmill that raises & lowers

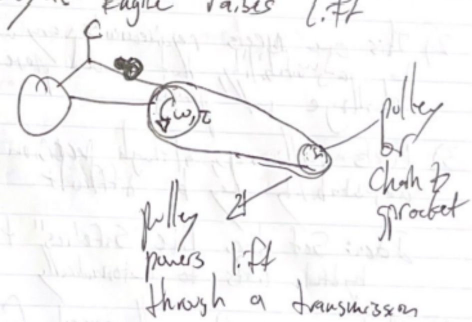



18.) Pneumatic Press



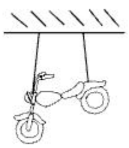

19.) 4 individually pressurized hydraulics under a table that can be individually adjusted or connected through a pressure equalizer

20.) Motorcycle Engine raises lift

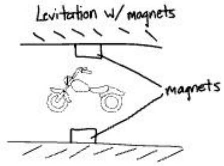


*Emma*

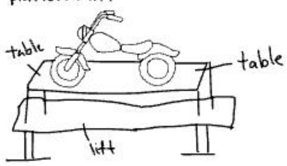
1. Hang motorcycle from ceiling → allow user to reorient → Hanging motorcycle w/ cables of different lengths



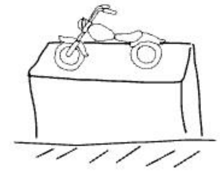
2. Levitate motorcycle → use different energy source → Levitation w/ magnets



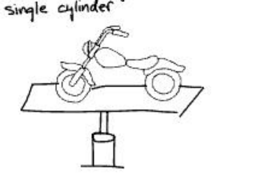

3. Table lifted from floor → extend surface → table lifted w/ single platform lift



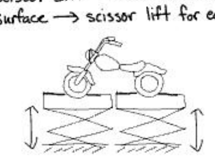

4. Bike on tall table → cover or wrap → bike on solid platform



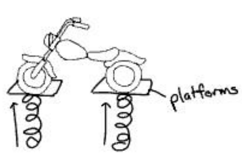
5. Hydraulic lift platform → reduce material → hydraulic platform w/ single cylinder



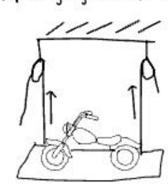
6. Scissor Lift → divide continuous surface → scissor lift for each side



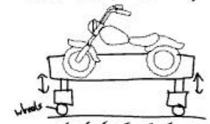
7. Bounce Bike up w/ springs → add to existing product → platforms on springs



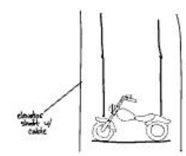

8. Pulley system → make multifunctional → pulley system w/ table



9. Desk w/ adjustable height → allow user to rotate → add wheels to desk w/ adjustable height

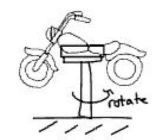



10. Elevator → reduce material → elevator shaft w/ table instead of box

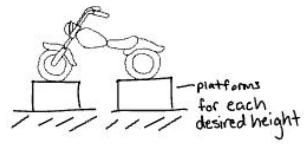



11. Helicopter → use human-generated power → humans holding bike from balcony

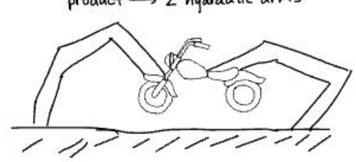

12. Door lift from Monsters Inc. → allow user to rotate → rotatable door lift



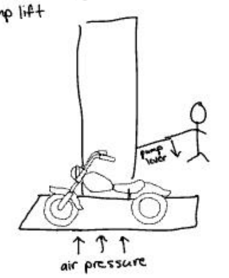

13. Step stools under wheels → cover or wrap → 2 platforms under bike



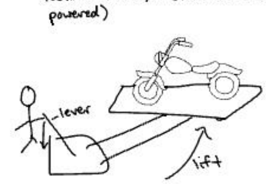

14. Hydraulic arm → add to existing product → 2 hydraulic arms



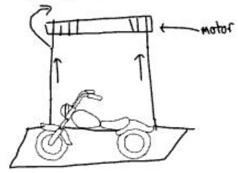
15. Strong man carnival game → use different energy source → human-powered pump lift



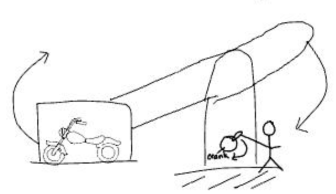

16. Recliner w/ lever → reduce material recliner lift w/o chair (human-powered)



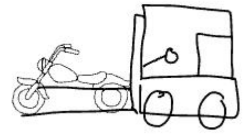

17. Motorized hanging lift → make multifunctional → motorized hanging lift w/ table



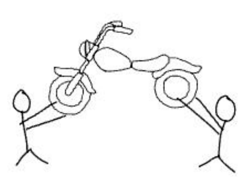

18. Carnival Lift Ride → change energy source → carnival ride w/ crank



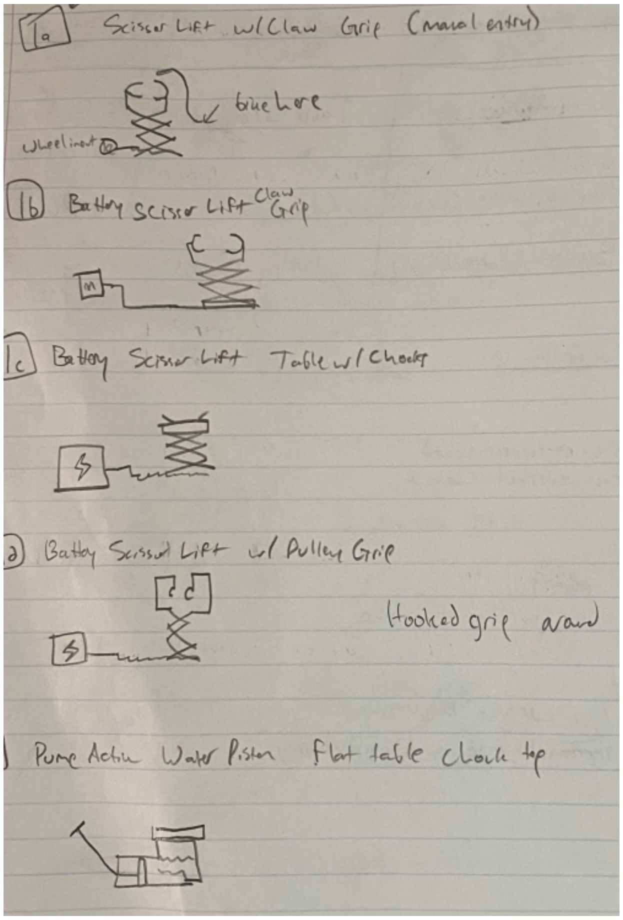

19. Crane → scale down → forklift

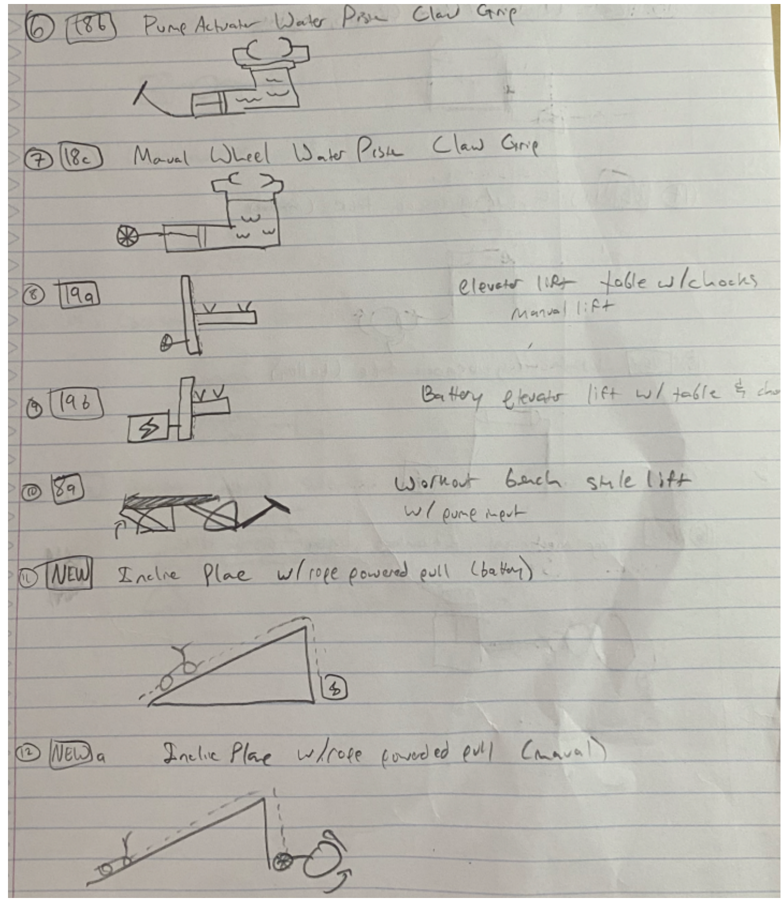


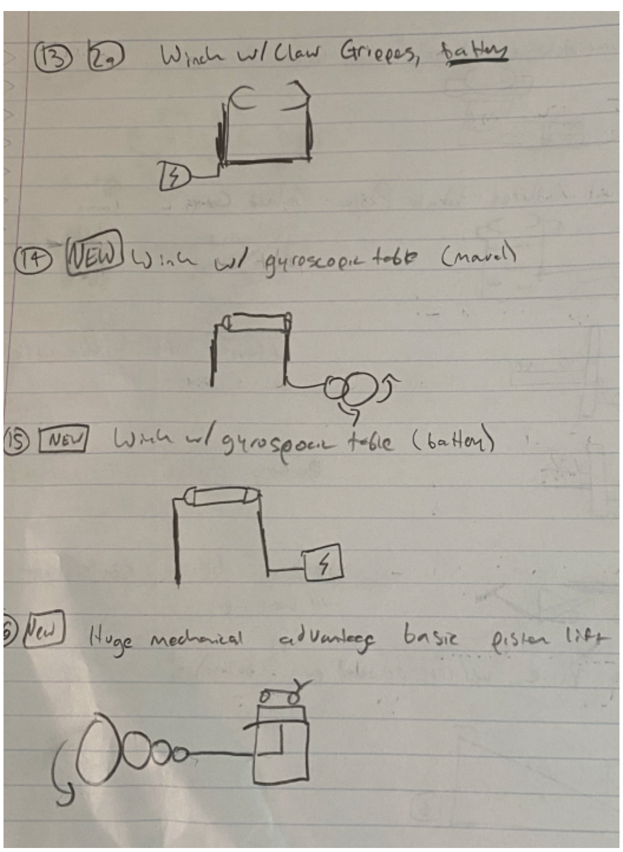
20. Human throne lift → reduce material → Humans holding bike

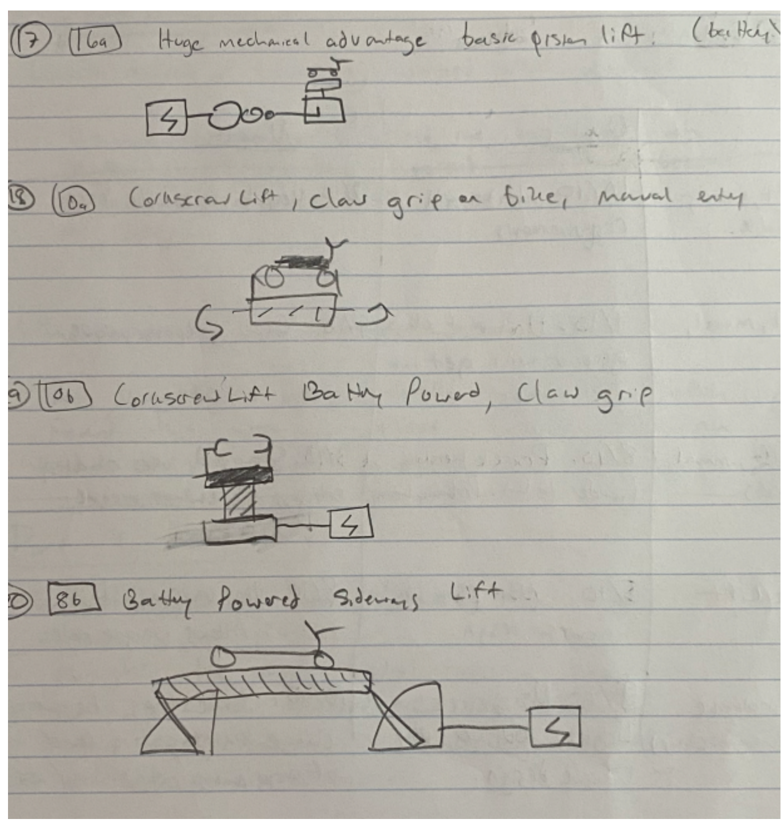


*Grant*


1a Scissor Lift w/ Claw Grip (manual entry)
bike here
wheel input
1b Battery Scissor Lift Claw Grip
1c Battery Scissor Lift Table w/ Chocks
2 Battery Scissor Lift w/ Pulley Grip
Hooked grip around
Pump Action Water Piston Flat table chock top

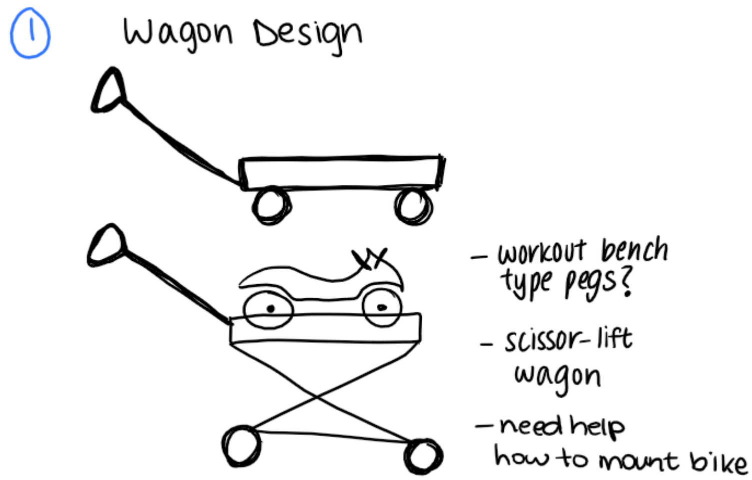

6 18b Pump Actuator Water Piston Claw Grip
7 18c Manual Wheel Water Piston Claw Grip
8 19a elevator lift table w/ chocks
manual lift
9 19b Battery elevator lift w/ table & chocks
10 8a Workout bench style lift
w/ pump input
11 NEW Incline Plane w/ rope powered pull (battery)
12 NEW a Incline Plane w/ rope powered pull (manual)

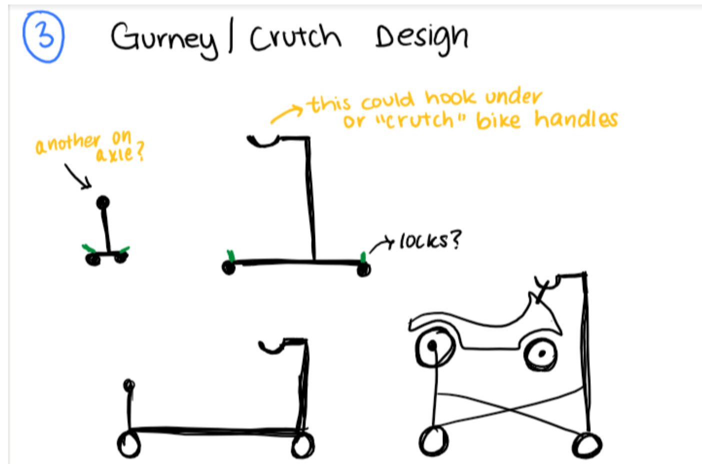

13 2a Winch w/ Claw Grippers, battery
14 NEW Winch w/ gyroscopic table (manual)
15 NEW Winch w/ gyroscopic table (battery)
16 New Huge mechanical advantage basic piston lift

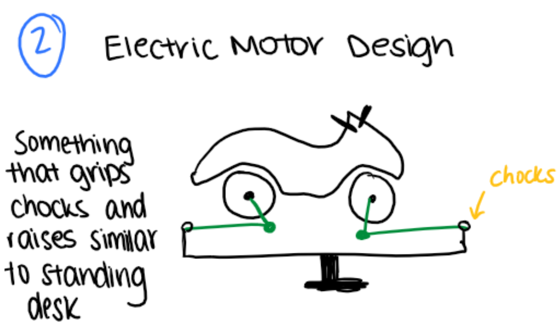

17 16a Huge mechanical advantage basic piston lift (battery)
18 10a Corkscrew Lift, claw grip on bike, manual entry
19 10b Corkscrew Lift Battery Powered, Claw grip
20 8b Battery Powered Sideways Lift

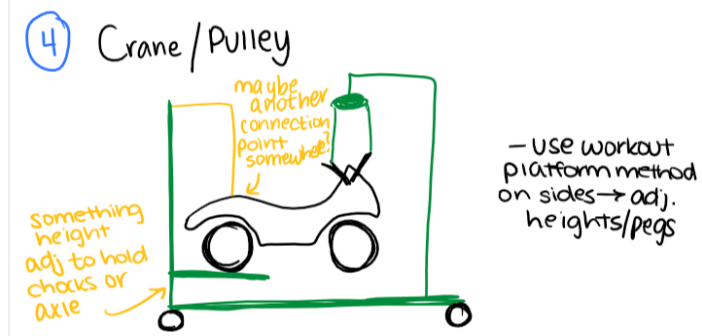
*Appendix C: Ideas After Group Concept Generation*

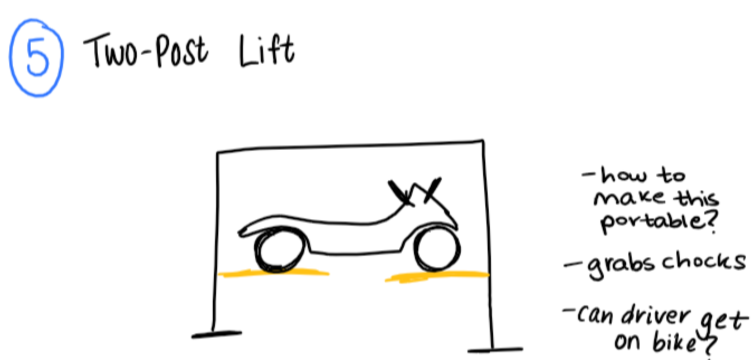
<u>*Becca*</u>



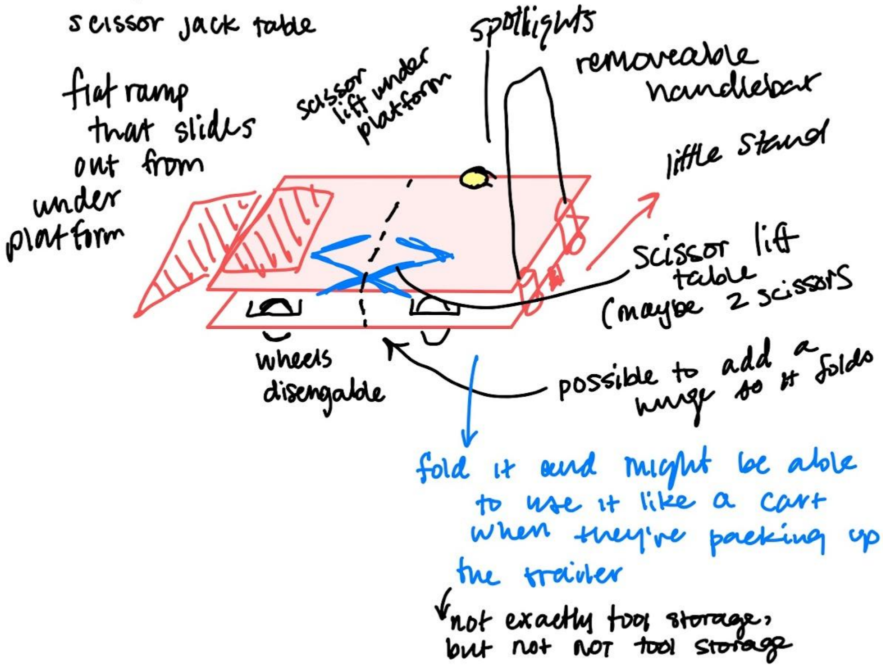



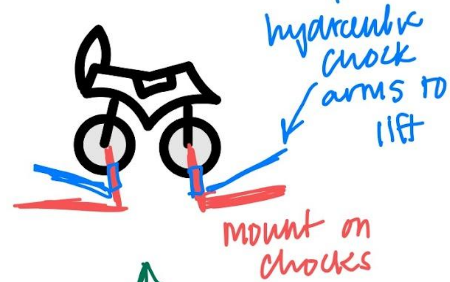



Sarah

1. Ice cream sandwich scissor jack table

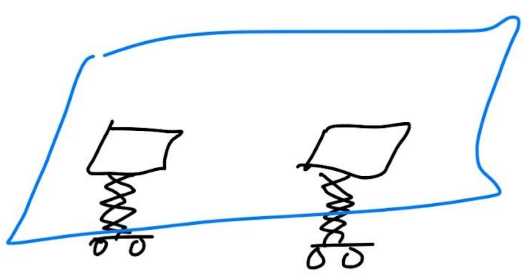



2. Adjustable hydraulic jack chocks

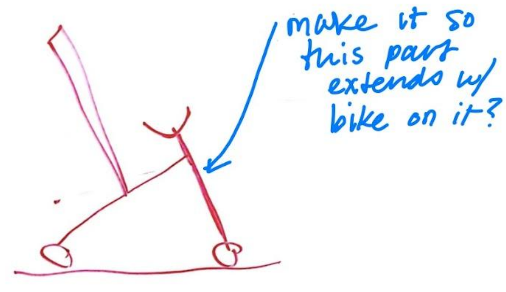



this might be more similar than I realized

3. Buy existing lift stands (2) and put table top on.



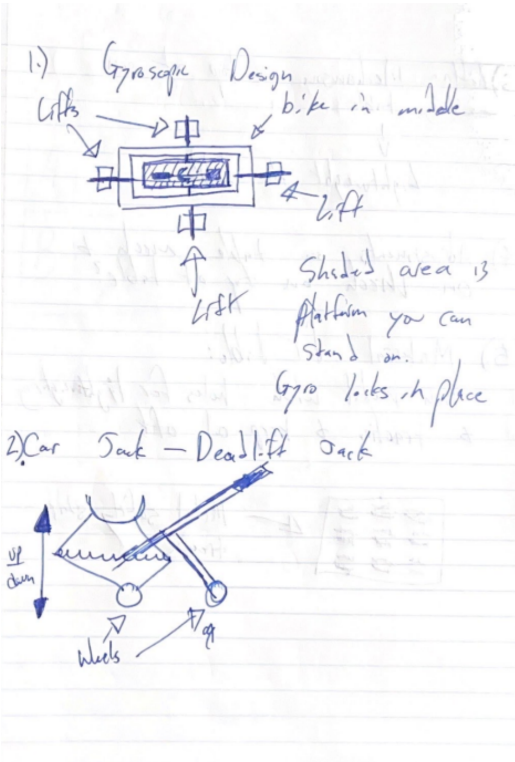
4. It is possible to put pumps or hydraulics onto power lifting lever

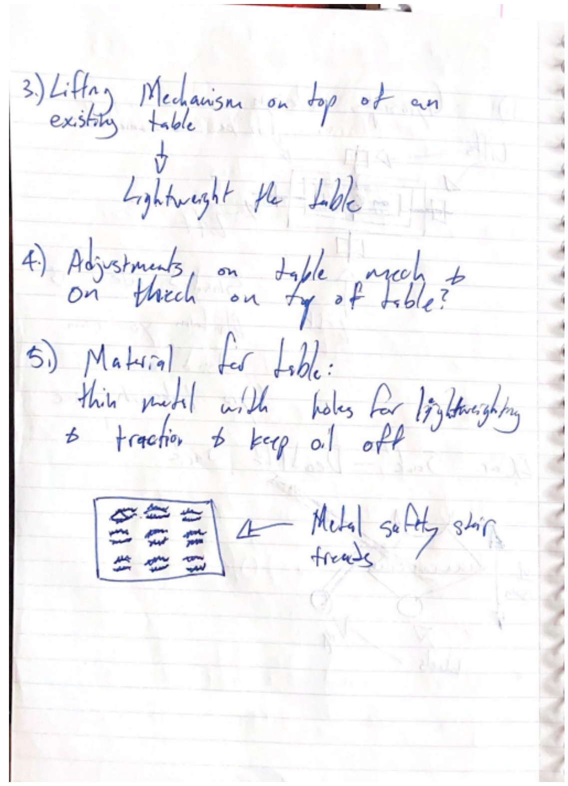


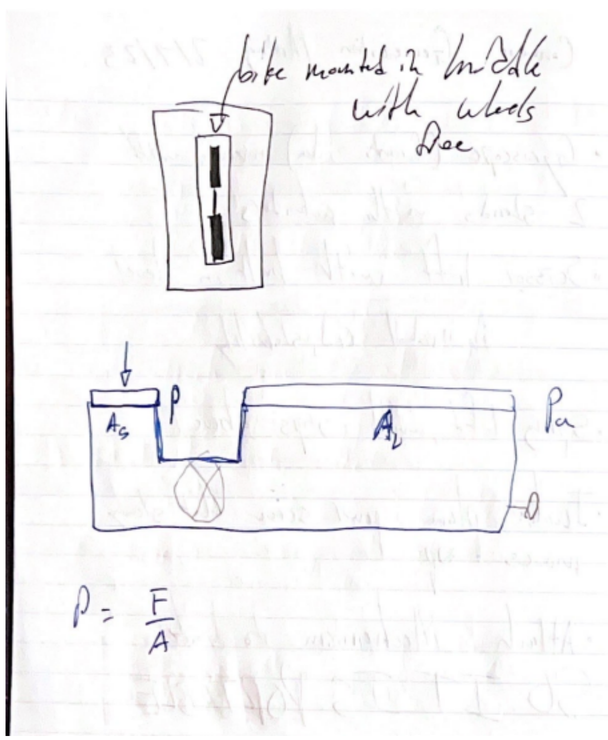

5.

- bike on chocks
- chocks are attached to frame
- raise and lower
- frame folds up
- could use combo rack mechanisms in frame

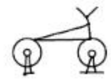
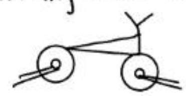
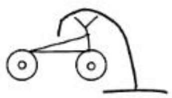
*Dustin*


1.) Gyroscopic Design
Lifts
bike in middle
Lift
Lift
Shaded area is platform you can stand on.
Gyro locks in place
2.) Car Jack — Deadlift Jack
up
down
Wheels

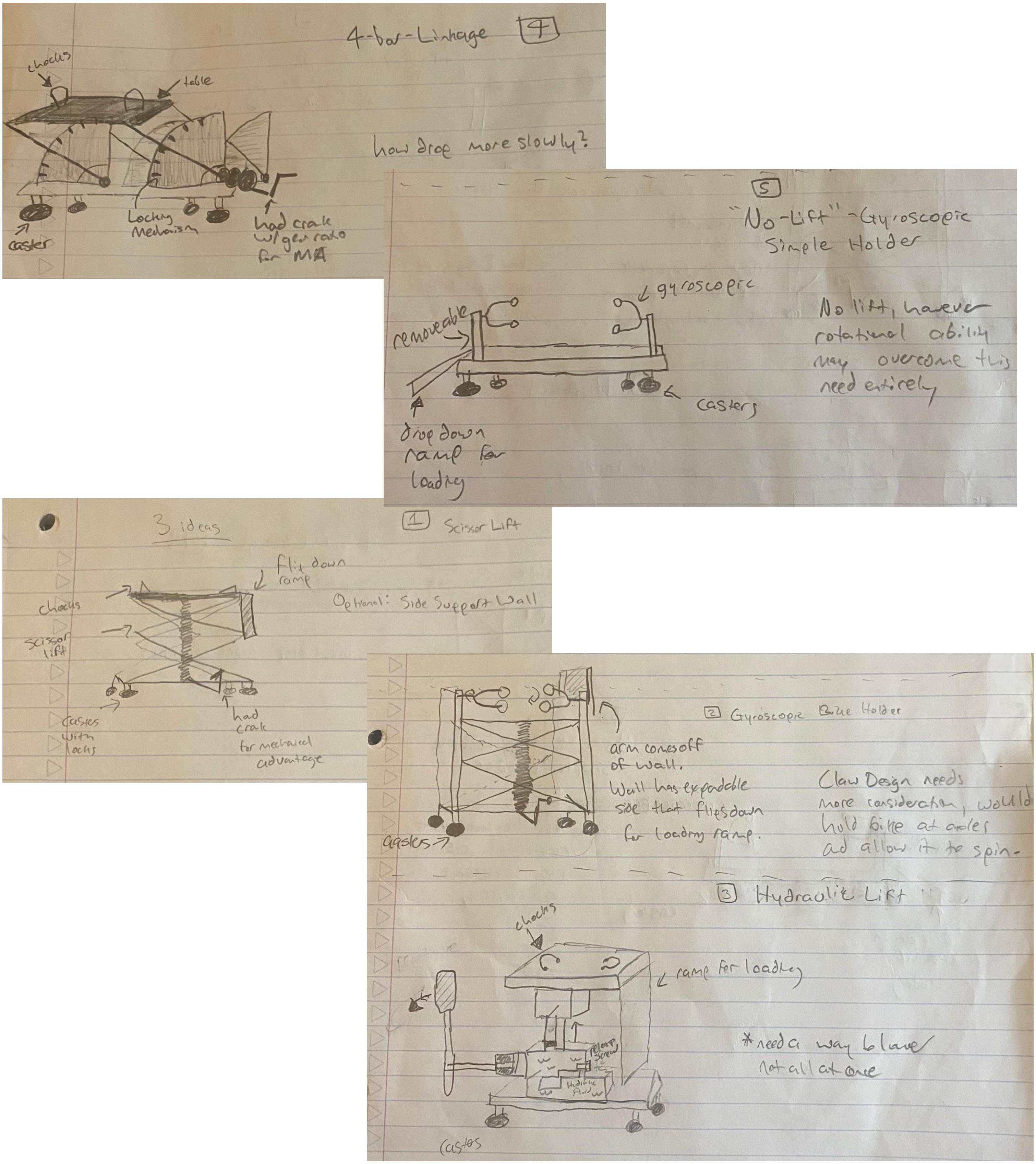

3.) Lifting Mechanism on top of an existing table
Lightweight the table
4.) Adjustments on table mech to on thech on top of table?
5.) Material for table:
thin metal with holes for lightweighting & traction & keep oil off
Metal safety stair treads


bike mounted in middle with wheels free
$A_s$
P
$A_L$
Pa
$P = \frac{F}{A}$

*Emma*

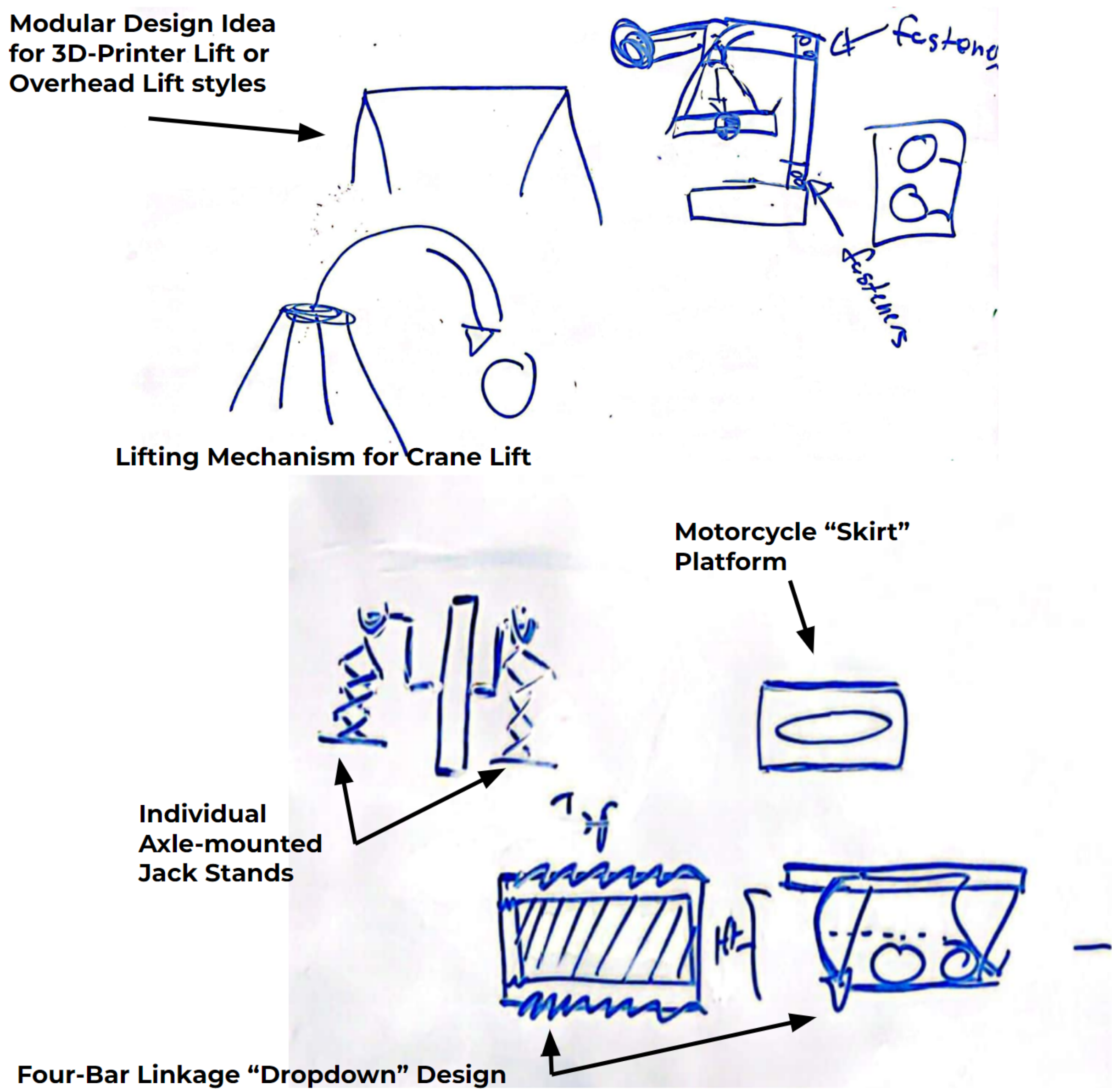
| Frame | Lifting | Portability | Bike Mounting | Extras |
|---|---|---|---|---|
| Guerney<br> | Hydraulics in legs<br>Air pedal<br>Scissor  | Guerney<br> | Chocks <br>Axle mounting within design<br> | Mechanical Stop<br>Lights |
| Banana Hook<br> | Pulley-single <br>snatchblock<br> | Foldable Frame | Frame Mounting  | |

*Grant*

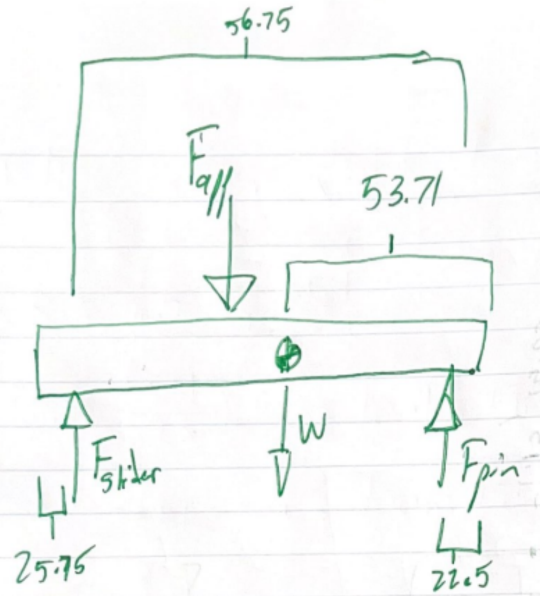


4-bar-Linkage 4
chocks
table
how drop more slowly?
casters
Locking Mechanism
hand crank w/ gear ratio for MA
5
"No-Lift" - Gyroscopic Simple Holder
gyroscopic
removeable
No lift, however rotational ability may overcome this need entirely
casters
drop down ramp for loading
3 ideas
1 Scissor Lift
flip down ramp
Optional: Side Support Wall
chocks
scissor lift
casters with locks
hand crank for mechanical advantage
2 Gyroscopic Bike Holder
arm comes off of wall.
Wall has expandable side that flips down for loading ramp.
Claw Design needs more consideration, would hold bike at axles and allow it to spin.
casters
3 Hydraulic Lift
chocks
ramp for loading
Release Screw
Hydraulic Fluid
*need a way to lower not all at once
casters

## *Appendix D: Beta Designs*



### *Appendix E: Engineering Analysis References*




$$F_{app} + W = F_{slider} + F_{pin}$$

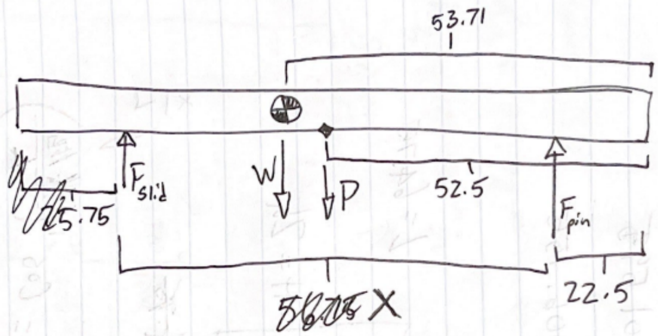
$$\cancel{\sum M_{slider}: 0 = F_{app} \cdot 26.75 +}$$

$$\sum M_{pin}: 0 = -56.75 \cdot F_{slider} + 51.35 \cdot F_{app} + (53.71 - 22.5) \cdot W$$

$$F_{slider} = \frac{51.35 \cdot F_{app} + 31.21 W}{56.75}$$

$$F_{slider} = 1636.5 \text{ lbs}$$

$$F_{pin} =$$




$$\sum M_{pin}:\ 0 = (52.5 - 22.5)P + (53.71 - 22.5)W - \overbrace{56.75}^{x} \cdot F_{slid})$$

Top

$$F_{slid} = \frac{30P + 31.21W}{56.75} = 1072.191$$

$$F_{pin} = 935.558$$

Bottom

$$F_{slid} = \frac{30P + 31.21W}{64.75} = 939.720$$

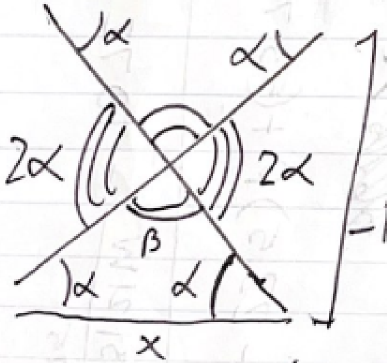
$$F_{pin} = 1068.029$$

Halfway point: $x = \frac{(64.75 - 56.75)}{2} + 56.75$

$x = 60.75$

$F_{slid} = \frac{F_{total} \cdot x_{avg}}{60.75} = 1001.595$

$F_{pin} = F_{total} - F_{slid} = 1006.155$

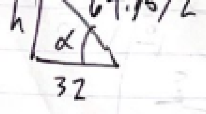



$L = 64.75$

Scenario 1: ~~x = 64.75~~

$x = 64.00$

$\frac{x}{L}$




$\alpha = \cos^{-1}\left(\frac{x}{L}\right)$

$h = L/2 \cdot \sin(\alpha)$

$\alpha_1 = 8.73° = 0.152$

$h_1 = \alpha_1 \cdot \frac{L}{2}$ (small angle theory) $\cong 4.932 = 4.913$

Scenario 2: $x = 60.75$

$\alpha_2 = 0.353$ rad $= 20.24°$

$h_2 = 11.202$ in

Scenario 3: $x = 56.75$

$\alpha_3 = 28.783°$

$h_3 = 15.588$ in $\quad H_3 = 31.176$ in $= 2.6$ ft

| Scenario / Term | 1 | 2 | 3 |
|---|---|---|---|
| $\alpha$ | 8.73° | 20.24° | 28.783° |
| $x$ | ~64.00 | 60.75 | 56.75 |
| $h$ | 4.913 | 11.202 | 15.588 |
| $F_{SLD}$ | 939.720 | 1001.595 | 1072.191 |
| $F_{pin}$ | 1068.079 | 1006.155 | 935.558 |
| $2\alpha$ | 9.827° | 22.405° | 57.56640~~4~~5° |
| Stress OK? | ✓ | ✓ | ✓ |

## *Appendix F: Final Design (Design Review 3 Version [3/28/23])*

### Final Design Description

The Final Design can be separated into easily identifiable subsections, which allows for detailed engineering analysis to be applied, such that the analysis could inform the final design. The subsystems of the lift can be broken down into the Table Surface, Actuation, Lockout Mechanism, and Base. The overall design is pictured in Figure A below.

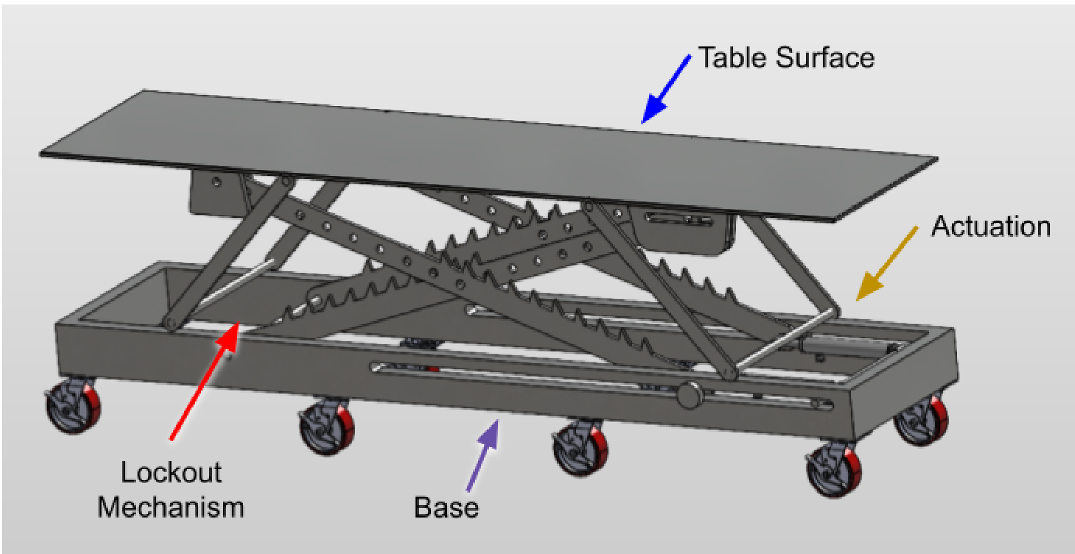



**Figure A:** High level overview of final design. The main subsystems are labeled. More detailed descriptions of each can be found within their various subsections.

### Table Surface Subsystem

The table surface subsystem consists of the table surface itself, a strengthening rib, and the connection fixtures for the lockout bars and scissor arms. This is shown in Figure B below.

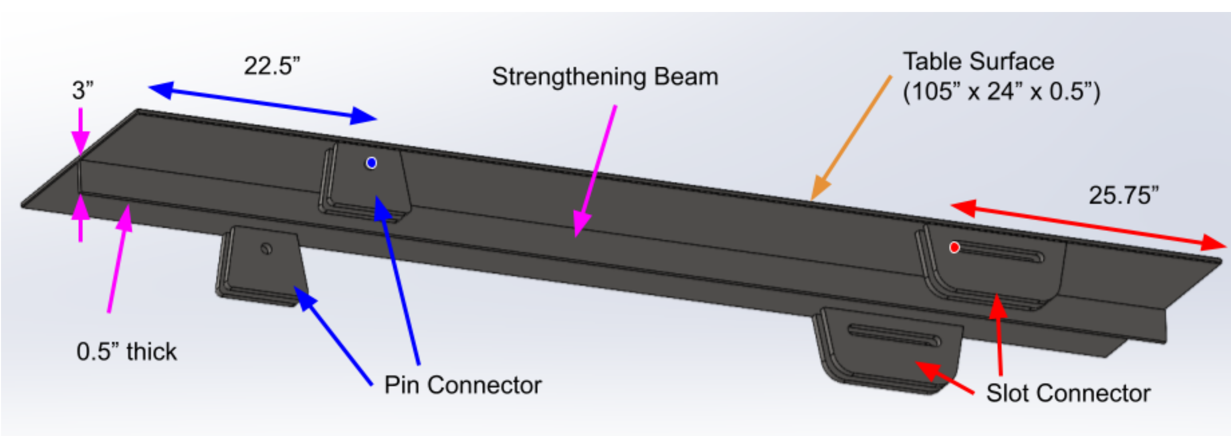



**Figure B:** Table Surface Subsystem. Important components are labeled along some key dimensions and relations. The table has pin connectors on one end and slot connectors on the other end. Omitted from this drawing are the connection fixtures for the lockdown mechanism.

The table surface is 0.5” inches thick plate of plain carbon steel, with a length and width of 105” and 24” respectively. The dimensions of the table are defined by our sponsor who stated that the length and width of their current table were already working well for them (Khan, Initial Interview, 2023). The surface also includes a strengthening beam lengthwise underneath the middle of the surface which measures 0.5” wide and 3” thick. Including this enables us to use a thinner surface and reduce the overall mass of the mechanism.

Various table thicknesses had previously been tested, however, when analyzed under the weight of a 1500 lb load, the surfaces showed unacceptable levels of deformation, even when the slab was 2” thick. Reevaluating the design and seeking methods other than increasing the thickness of the table were used to eventually converge on our current table surface solution.

There are two distinct connection fixtures: a pin and a slot version. Both fixtures have a height of 5.825” in order to function as mechanical stops at the lowest position and allow clearance underneath. This helps to ensure that one, the hydraulic does not come into contact with the table, two, that the scissor arms never reach a fully horizontal position where actuation would be exceedingly difficult, and three, that additional components would not need to be added to serve the purpose of a mechanical stop. The specific geometric features of each fixture type is depicted below in Figure C.

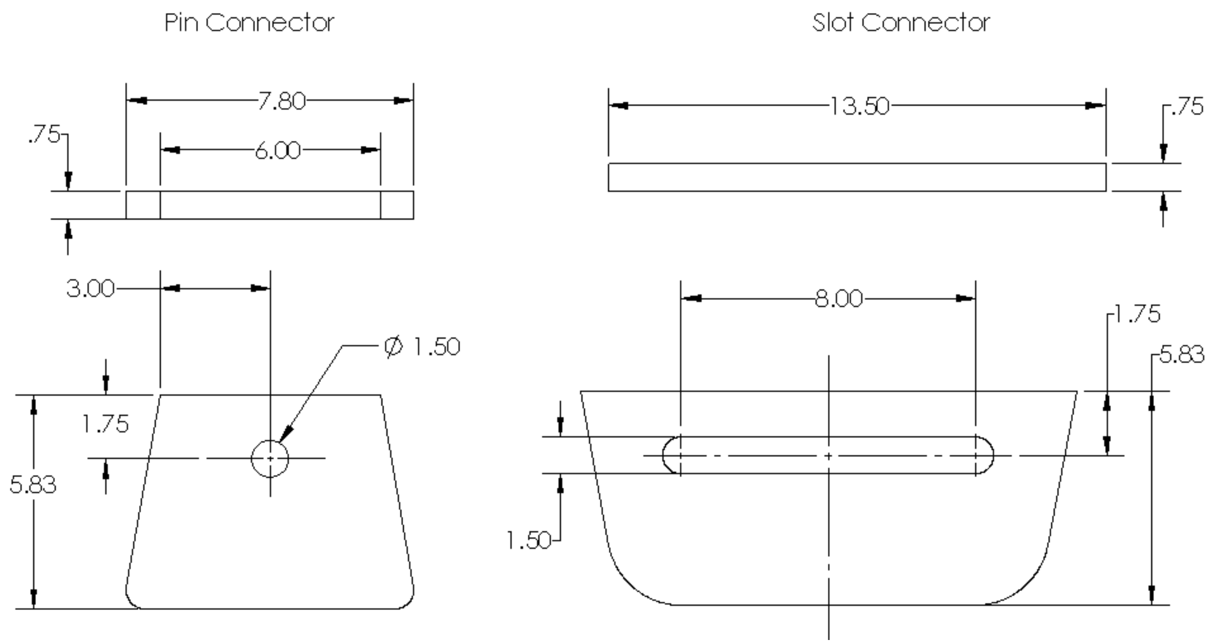



**Figure C:** Various Surface Connection fixtures. On the left is a pin connector used for one set of the scissor arm connections. On the right is a slot connector. This is used for the remaining set of scissor arm connections and allows for more free ranges of motion. Note that the features defined in this drawing are not exhaustive, but rather highlight the more critical dimensions for reference.

All fixtures consist of a channel in which their corresponding connection components will slide into. This ensures that the axles that are connecting the scissor arms and connection fixtures have a moment couple that reduces torque on the scissor arms and distributes the loads through multiple points. The locations of the connectors from the end of the table surface is depicted in

Figure C above. These locations were determined from various iterations of FEA, wherein these locations were altered and the stress and displacement across the length of the table was observed. The dimensions shown in the final design demonstrated that they were positioned in an ideal position such that they helped balance minimizing deflection in between the connection points as well as at the outer edges of the tables. Furthermore, this specific configuration resulted in the reaction forces across the scissor arms being nearly equal which can help with stability.

## Actuation Subsystem

The actuation subsystem consists of the scissors arms, axles, and the hydraulic pistons. There are 4 scissor arms in the final design. As seen in Figure D, they connect at the base, are actuated by the hydraulic pistons, cross at a hinge in the center, and attach to the table surface at their appropriate fixtures. The scissor arms are 3” wide and with a major hole spread of 64.75”. There are 11 holes (1” diameter) in the upper portion of the scissor arm to help in lightweighting the overall mechanism. There are a series of 10 teeth along the bottom portion of the scissor lift to aid the lockout mechanism. The scissor arms are connected horizontally via axles.

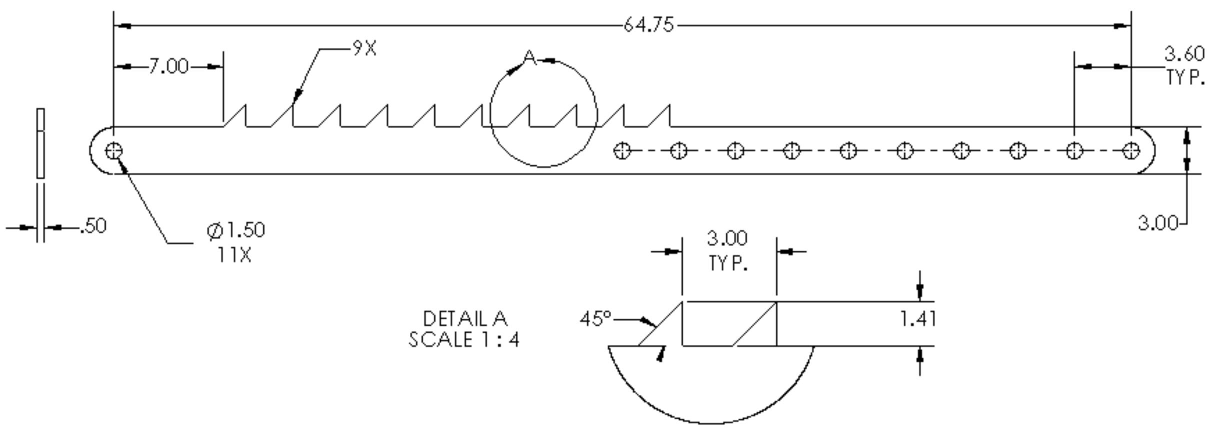



**Figure D:** Scissor Arm Dimensions. The leftmost hole fits into the base while the rightmost hole attaches to the table surface fixtures. The teeth used in conjunction with the lockout mechanism are described by Detail A. Note that the features defined in this drawing are not exhaustive, but rather highlight the more critical dimensions for reference.

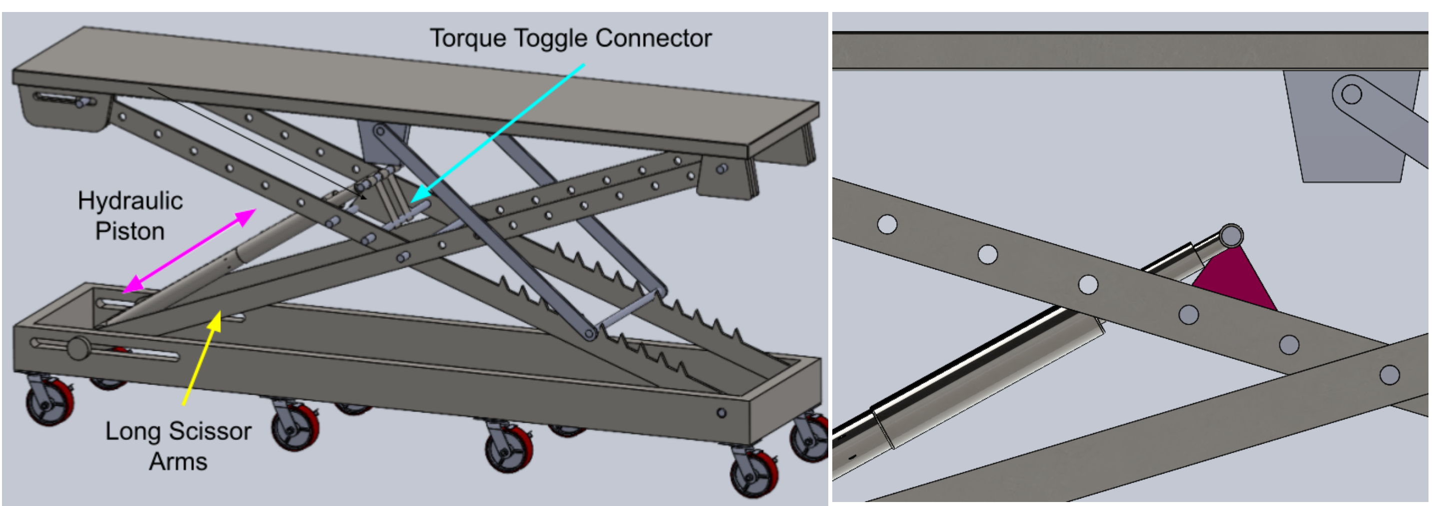
There has been some iteration with regards to the scissor arms. One change that has been made is to shorten the length of the scissor arms (for reference, the previous major hole spread was 97.25”, whereas the current spread is 64.75”). Some benefits to doing this is that it would reduce the overall weight of the mechanism and it would enable us to move the scissor arm connection fixtures closer to the center of the table which helped to mitigate the deflection of the table surface.

There are two horizontally-oriented hydraulic pistons. Using two pistons means that neither piston will have to operate at their maximum capacity constantly, improving their lifespan, and providing a larger factor of safety. The axle that connects the base of the scissor arms to the hydraulics also benefits from the use of two pistons as the force from the hydraulics can be applied nearer to where the forces from the base and the scissor arms are being applied to reduce beam bending within the axle. The lower stresses the axle experiences because of this will improve the longevity of the mechanism as it reduces the potential of a fatigue failure.

Each piston has a stroke length of 8” and is attached to the frame that makes up the base of the mechanism and an axle connecting the bases of the scissor arms. The horizontal displacement of the scissor arm base causes the scissor lift to raise the table surface. The stroke of the piston is equivalent to the maximum horizontal displacement that is needed in the scissor arms to lift the mechanism to our sponsor’s maximum requested height. It is more mechanically advantageous for us to make use of the entire range of motion of the pistons.

Furthermore, the type of hydraulic piston recommended is a double acting cylinder. This means that the hydraulic piston will be capable of actuating in both directions and there will always be a hydraulic force to properly control this, a 4 way directional control valve will be needed (Sarum Hydraulics, 2018). This choice is especially effective as it allows for the design to reach continuous heights rather than discrete due to the constant force from the actuator being the main source of force holding up the lift.

Several changes have been made to the hydraulic actuation during our design process. Previously the hydraulics were oriented such that they remained nearly parallel to the attached scissor arms at all times. In this design, a connection piece we had named a torque toggle connector was needed. This component was somewhat of a liability as it would have been subject to high loading conditions and eliminating this component helps to reduce one point of potential failure of the mechanism. Furthermore, through changing the piston to a more horizontal orientation, there is a greater torque advantage at the higher mechanism heights and less shear in the axles due to a more ideal load distribution.




**(a)** **(b)**

**Figure E:** Previous actuation designs. (a) depicts the previous version of the assembly. Some features of note are the longer scissor arms, the wider scissor arm connection fixtures on the table surface, the angled hydraulic piston, and the torque toggle connector. (b) depicts the now obsolete torque toggle connector, highlighted in red for visibility.

The axles are 1.5” diameter plain carbon steel rods with lengths of 24”. It was determined that this diameter of this material was capable of withstanding the forces of the scissor arm weighing down, the hydraulic actuating, and the base track’s reaction force so long as the scissor arms remained at angles that are >5° as measured from the horizontal direction (design of connection fixtures ensures this).

### Lockout Mechanism Subsystem

As an additional safety precaution to help the hydraulics support the loads the mechanism is expected to withstand and to serve as a failsafe should the hydraulic pistons fail, lockout mechanisms have been added to the design. The lockout mechanism consists of a hanging bar that will be able to move passively upwards as the table surface is raised and will catch on a desired tooth when the mechanism has reached its final height. The hanging bar is connected to the table surface. A demonstration of what this mechanism looks like when in use is shown in Figure F below while a step by step breakdown of how the mechanism works is shown in Figure G below.

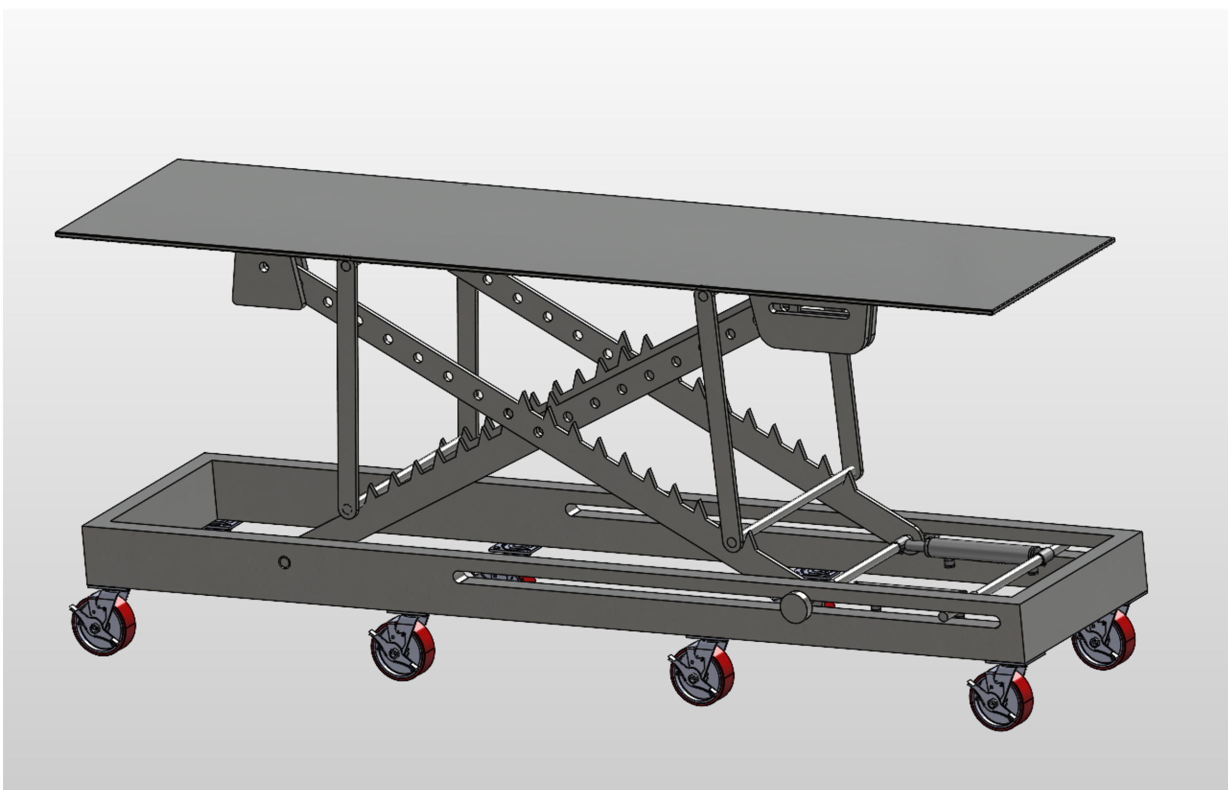


**Figure F:** Example of locking bars in action. As shown above, the dropdown bars rest within the notches on the scissor lift arms.

To lower the lift, the lift must be raised a short distance to disengage the lockout bar from the scissor teeth. The bar is then lifted up and off of the notched scissor arms and the lift is able to be lowered without interference. Due to the potential of injury, before lowering the mechanism, we are advising all users to ensure the hydraulics are actively engaged, all persons and loose items are cleared off the table surface, and the lockout bar is fully disengaged before attempting to lift this bar.

The dimensions of the locking teeth are described in Detail A of Figure 29 above. Previous iterations of our assembly only included a lockout mechanism on one side of the scissor lift. Concerns were raised over whether this would result in uneven support of the mechanism- taking this into account, the design was altered such that the hanging bar lockout mechanism could be used on both sides so that the load would not be supported unevenly. We intend to carry out more thorough analysis on the scissor teeth in the coming weeks.

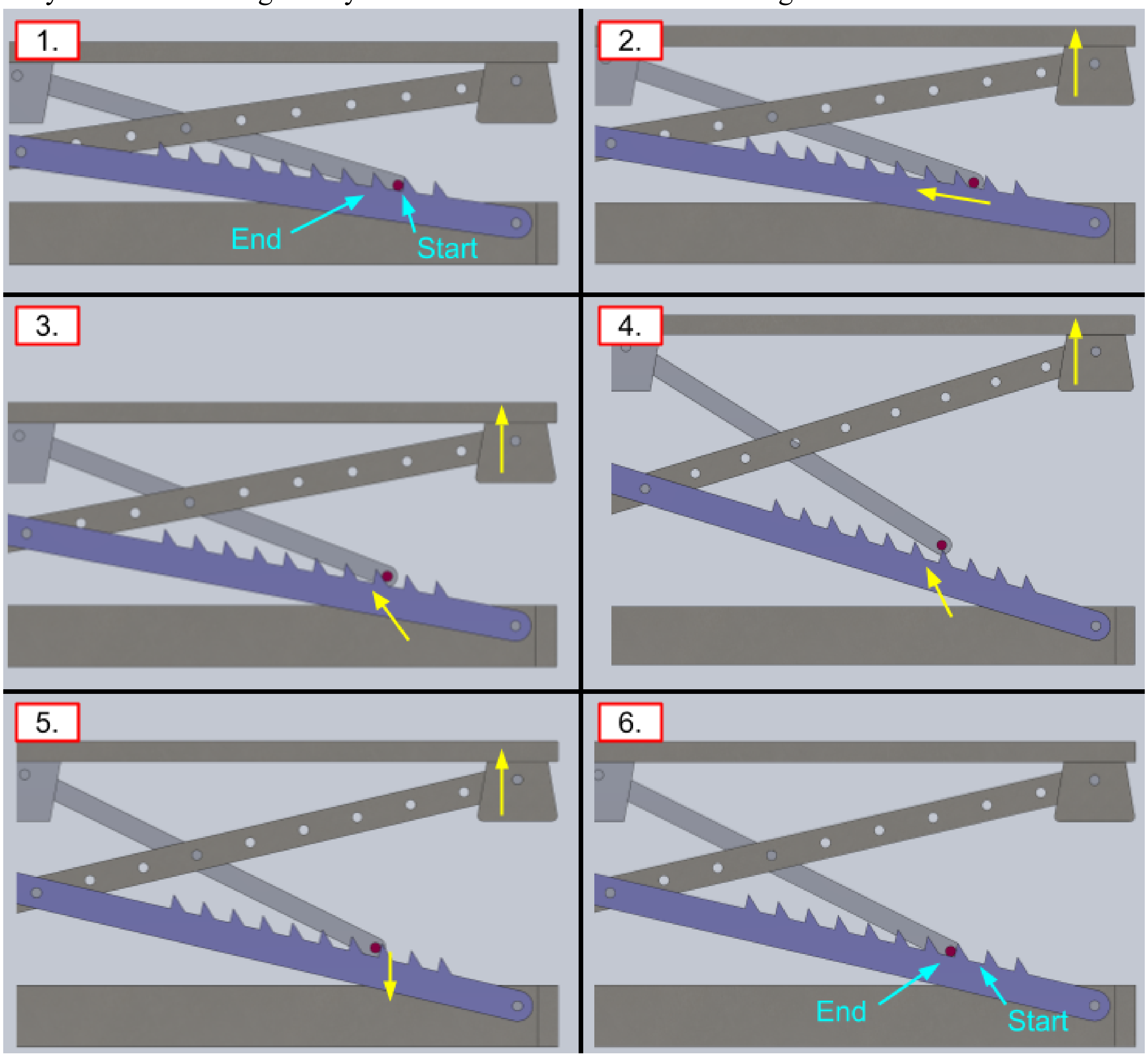



**Figure G:** Demonstrating how the lockout bar works. A section view of the mechanism is pictured with the notched scissor arm in blue while the horizontal portion of the lockout bar is pictured in red for better visibility. As the table surface is raised, the lockout bar is dragged up and over the notches. Once past the peak of the notch, the bar drops down into the notch and prevents further downward motion.

Note: This is our current design for the lockout mechanism. Very recently, as referenced in the engineering analysis section, we have explored the idea of an altered design that changes the location of the teeth from the scissor arm to the bottom frame of the lift. For this report, we will continue to use the currently tested design, however moving forward in the next weeks we will explore the other option.

Base Subsystem

The base subsystem consists of the bottom frame of the mechanism which includes the track the base of the scissor arms glides on and additional fixture points for the other two scissor arms in addition to casters mounted to the underside. A diagram of this subsystem with some key dimensions is pictured in Figure H below.

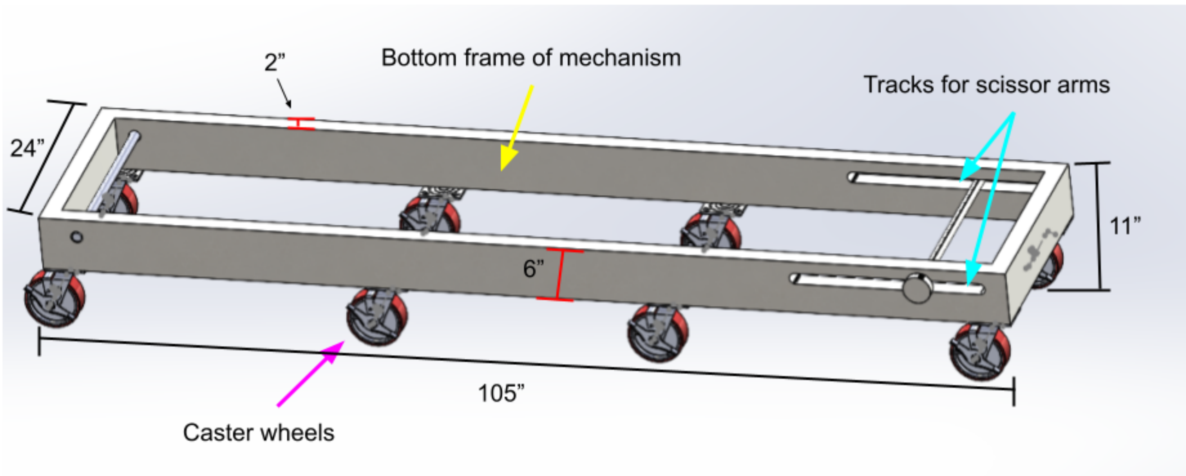



**Figure H:** Overview of Base subsystem. Important components are labeled along some key dimensions and relations. The base frame is depicted along with casters and the tracks that the scissor arms connect to.

The frame is made out of plain carbon steel. Similar to the table surface, it has a length and width of 105" and 24" respectively. Since DR2, the frame has undergone a substantial change in that the bottom plate has been removed. This was initially done as an effort to lightweight the design and resulted in a roughly 700 lb decrease. The structural integrity was not significantly impacted by this loss, as that surface layer was extremely thin, but the resulting weight decrease was a substantial improvement over our previous design.

There are 8 casters, each with a diameter of 6" (Service Caster Corp., n.d.). The casters must be able to support the weight of the entire mechanism and ensure that the mechanism is capable of being pushed and rolled- each individual caster has a weight capacity of 1200 lbs and are capable of supporting our maximum expected loads. All of the casters have breaks to prevent rotation of the wheels while the mechanism is in use. They are separated by even intervals as well to reduce the bending moments felt by the lift base.

It is also important to ensure that there is adequate surface area such that the mechanism stability is not impacted by slight variations in the ground surface. To this end, a recommendation for users is to avoid lifting motorcycles when the mount is on uneven ground- our general guidance is to ensure that all wheels have full contact on the ground.

The last major component of the base subsystem is the scissor arm track. This is similar to the slot connector on the table surface. The purpose of the track is to serve as a guide for the ends of the scissor lift. It restricts the translational motion of the ends of the scissor arm to one direction along the direction of the track.

### *Appendix G: Predicted Information Gaps from DR1 [2/02/23]*

In order to complete this project successfully, our team will need to bridge a few information gaps. First, our team has an overall lack of knowledge regarding motorcycles. None of the team members have worked on motorcycles in the past, let alone performed maintenance on one, and, thus, extensive research will need to transpire to learn more about the culture, challenges, and needs of the motorcycle community. Further, our team lacks experience with navigating patent law, which plays a vital role in the design process. Our design will be limited by patents of current items on the market, as we can not risk any sort of patent infringement. We have already met with the ME 450 Librarian, Paul Grochowski, who has assisted our team in finding the correct resources to navigate current patents (Grochowski, 2023), and we plan to continue meeting with him throughout every stage of the research process. Finally, our team has never manufactured on a large scale before. Therefore, creating a design that is easily manufacturable will prove to have a bit of a learning curve. Our team plans to watch informational videos on manufacturing processes and designing manufacturable products, as well as spend ample time in the Wilson Center becoming familiar with the available resources.

## Team Biographies

**Becca Cuomo**

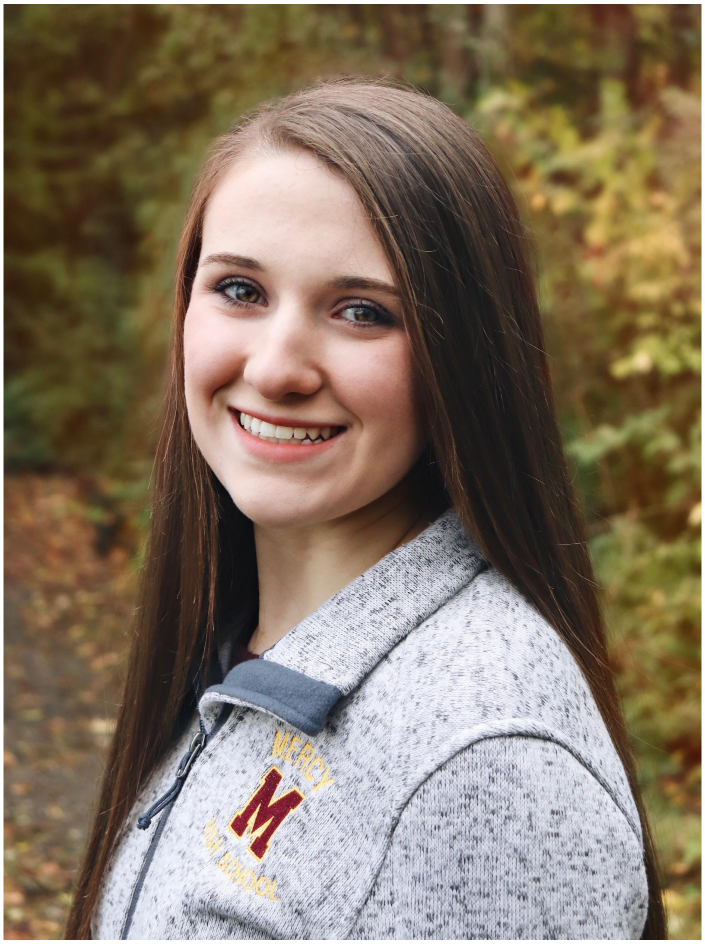
I am a senior studying Mechanical Engineering at the University of Michigan. I am from Long Island, New York and am a proud New York Mets and Islanders fan. I first took an interest in engineering in 8th grade when I took a STEM elective at my middle school. I became more fascinated with the engineering field throughout the rest of middle and high school as I was able to learn 3D modeling on Autodesk Inventor and utilize manufacturing processes such as a laser cutter and CNC milling machine. I decided on Mechanical Engineering after learning the wide range of future career paths it could take me within the engineering discipline. After graduation this spring, I will be moving to Tucson, Arizona to work at Raytheon Missiles and Defense in the System Integration and Testing division. An interesting fact about me is that I have been to 14 out of 30 MLB stadiums in the United States.

**Sarah Dressing**

I am a senior studying Mechanical Engineering, originally from Livonia, Michigan. My interest in engineering stems from always wanting to know how products, infrastructure, and the world around me was made and why. I chose Mechanical Engineering in particular because of the sheer variety of career opportunities and the 'Start here, go anywhere' mentality. Within engineering, I have completed two internships, one of which was at a manufacturing company where I worked in their Quality department approving parts for production, inspecting incoming purchased parts, and checking gauges. My second internship was for a Tier 1 Automotive supplier- my most significant takeaway was getting to help with DFMEAs (Design Failure Mode Effects Analysis) and seeing first hand some of the consideration and documentation that goes into engineering design.  In the future, I hope to continue into a production or quality related career. Outside of engineering, I enjoy bike riding, reading, and anything that has to do with dogs!


**Dustin Fletcher**

I am a 5th year Mechanical Engineering Undergraduate with a minor in Germanic Languages. I am from Midland Michigan, the town where Dow Chemical was founded. I have an interest in Mechanical Engineering because I've always been interested in creating things and understanding how the world around me works, and Mechanical Engineering satisfied both of those functional requirements. My future plans are to attend graduate school here at Michigan in the Robotics or Mechanical Engineering Program, and afterwards plan to go into the field, using my engineering knowledge to invent technology that improves people's lives (e.g. prosthetics). Outside of Academics I am a powerlifter on the Umich Powerlifting team, and I have competed twice at collegiate nationals placing 18th and 19th; with a 687.5kg total between Squat, Bench, and Deadlift. I also am a first year member of the Michigan Marching Band as a senior in college. I play the trumpet and I had the privilege to march in the OSU, TCU, MSU, PSU, Maryland, and Illinois NCAA Football games.



**Emma Pickett**

I am a senior in Mechanical Engineering from Southfield, Michigan who is also minoring in Music. I became interested in Mechanical Engineering because I liked how broad the discipline is and the wide variety of classes available within the major.  Since I graduated from high school, I have spent two summers working at a STEM camp teaching upper elementary and middle school students about STEM concepts such as the engineering design process and supervising projects in rocketry, underwater ROVs, 3D printing, and kinematics. I have also interned at Subaru Research and Development in the Driving Dynamics team within SRD's ADAS and Vehicle Performance Department where I learned a great amount about the automotive industry and vehicle safety technology. After graduation in the spring, I will be staying in the Detroit area to work for General Motors in their Hardware Engineering TRACK program. In my free time, I enjoy singing, exercising, and college football and basketball games. I will also never hesitate to show you a picture of my dog.

**Grant Robertson**

I am a senior in Mechanical Engineering with plans to graduate this semester. I was born and raised in Saint Louis, Missouri. Most of my life has been spent as a student, however I have taken time off of my studies for an internship as well as to substitute teach engineering at my local high school. When I first chose Mechanical Engineering, I did so due to its wide range of applicability in other related fields. As my studies have progressed, I have found myself enjoying tasks that relate to sustainability and innovation. At a recent internship for a local Mechanical Engineering firm, I was given the opportunity to design and maintain a hydroponic lettuce farm. While doing this I rediscovered my passion for unique problem solving and found great satisfaction in the project's completion. I hope to keep this passion alive moving forward by finding more sustainability-related projects to work on in the field.