2-Axis Electric Off-Road Bucket Seat Bases

Final Design Report

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Abstract

Off-road vehicle bucket seats are currently restricted to a single position relative to the floor of the vehicle. Drivers and riders desire the ability to adjust their seat position to increase comfort and allow for a greater size range of riders to fit safely within the cabin or roll cage. To develop a viable solution, the team has gone through an extensive design process and has constructed a functioning prototype. This Final Design Report encapsulates the entire design process and concludes with recommendations for changes we would make looking both back in review as well as moving forward with further iterations of the product.

1.0 Introduction

One of our group members, Alex, is currently rebuilding a 1992 Jeep Wrangler for off-roading purposes. While deciding how to mount his aftermarket bucket seats, he noticed that his especially tall roommate was not able to fit in the passenger seat. With the seats at a comfortable position for Alex, taller passengers would contact the roll cage with their head. Knowing that bucket seats are usually mounted with zero adjustment, the challenge became clear: design a seat mount that can quickly adjust the seat position. The general function, shown in Figure 1, is for the seat to be adjustable forward, backwards, upwards, and downwards. The scissor lift is shown to describe function and is not to be misinterpreted as an initial design. A stiff back off road bucket seat is pictured from Mastercraft in Figure 2 (Mastercraft Safety).

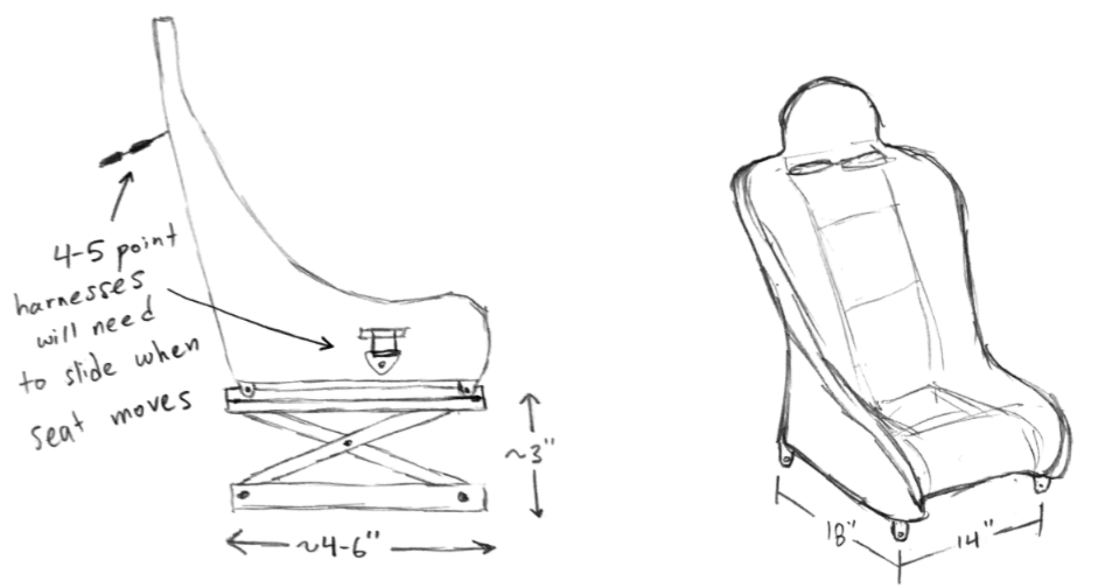


Figure 1. General Idea, Dimensions, and Desired Motion Range for Seat Base

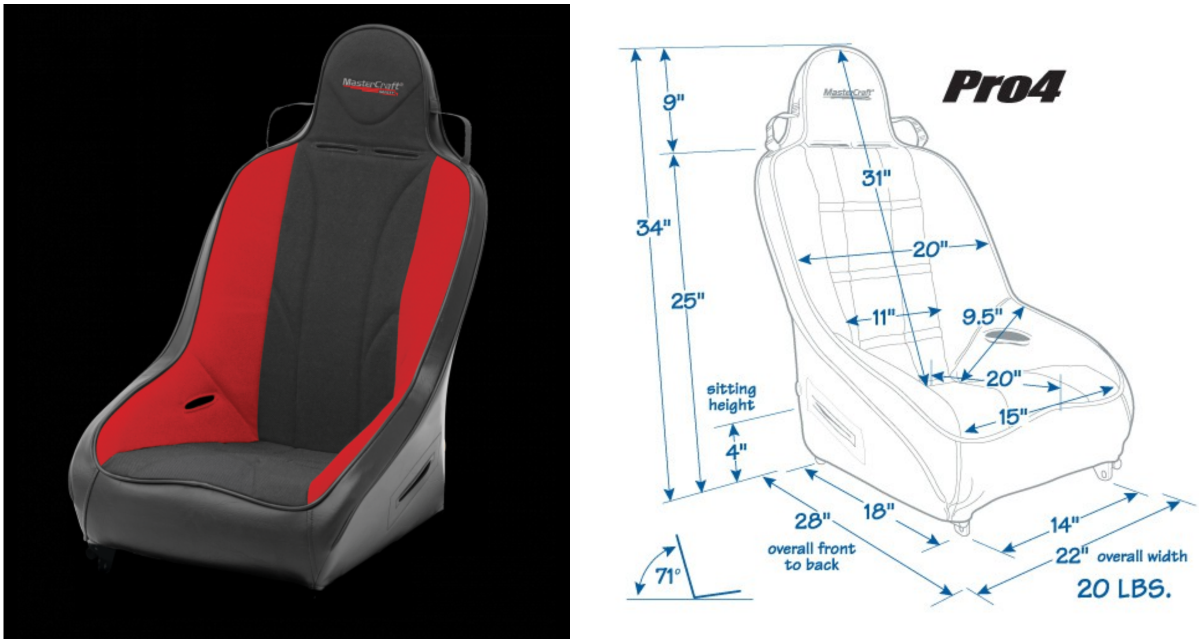


Figure 2. Mastercraft Pro4 Bucket Seat Image and Dimensions [1]

After touring Alex's garage and the Jeep reconstruction project, we discovered the floorboard attachment points are not flat, and, in this case, have one bolt hole on the transmission tunnel. A picture of the Jeep floorboards can be seen in Figure 3. The stock seat bracket mounting holes are circled in red. The seats are currently mounted to the rigid frame also visible in Figure 3. This frame will ultimately be removed and replaced with the electric bases. The 5-point harnesses would be mounted to tabs on the roll cage, separate from the seat base for safety purposes. This requires that the harnesses will have to slip through the slots in the seat for the seat to move. Adjusting the seat while the harness is tight will likely not be possible.

Figure 3. Floorboard Image Displaying the Uneven Design and Bolt Location

The custom roll cage is lower than the stock roll bar resulting in less head room available to the rider. For taller passengers to fit, the lowest vertical setting would ideally place the seat just above the floorboards. This leaves little space between the floor and bottom of the seat for the base to fit. Space constraint is one of the expected challenges of the design. A picture of the Jeep along with the lowered cage and installed bucket seats that provided us inspiration for this project are shown in Figure 4 below.

Figure 4. Alex's Jeep YJ with Lowered Cage and Bucket Seats

We began our ideation with the thought that other off-road enthusiasts would be interested in the product we were intending to build. We were aiming for the design to be compatible with a variety of off-road vehicles. For this to be possible, our design would need to be modular and allow for customization of floorboard mounts. Additionally, we considered a design allowing for an electric seat base to attach to manual seats. The YJ may be a test vehicle for the seat bases, but the intention was to expand this product to other vehicles and make our design as universal as possible. The next sections capture the results of the initial project definition process, preliminary and intermediate designs, and the following steps of the project.

In the end, a functioning prototype was fabricated. This prototype struggled to meet the performance and safety needs that are required to install the seats in the jeep. The prototype, however, is fully working. Electrical component selection and tighter tolerances while fabricating would need to both be considered in order for the seat base to become a truly viable solution in the future of this project. This document records the steps taken up to the point that we tested our final prototype, and suggests future action for off-road use of the product in the future.

2.0 Background

The Jeep was designed for rock crawling and speed in the desert. These driving conditions produce large and unpredictable accelerations of the sprung weight. The seat needs to support riders during fast off-camber transitions, bottoming out in the desert, and high-speed rollovers. As rider safety was a main concern, quantifying these forces was essential to understanding the design challenge. Finally, space efficiency would be an important element of the design, for limiting the space for the rider would be counterproductive to the project. A visual representation for spatial concerns can be seen in Figure 5. These challenges are further discussed in future sections of this report.

Figure 5: Interior view of Jeep showing spatial limitations.

During our design research, we found numerous customers wants, product limitations, and existing designs. Our original customer is Alex Croteau, but we needed to expand our customer market since Alex is also a group member within the project. We turned to outside sources to gain a better understanding of what is important to off-road riders in the market for an aftermarket seat base designed for bucket seats. We looked for insight from two sources: Poly Performance, a local off-road parts supplier, and the Poly Goats, the off-road club at Cal Poly. These casual interviews netted the same opinions. Mounting bucket seats is not trivial and electric adjustability would be a great additional upgrade. We shared these opinions, so the next step was to dig further into what already exists to mount seats in a vehicle.

It is important to note here that while the inspiration for this project is Alex's Jeep, the primary customer is the public off-road market. After talking with potential customers, this need had not been met by the aftermarket and we see a potential to break into the off-road world as a potential company. The test vehicles we would use during this project were for prototyping purposes, but we were hoping to expand this product to be universal after this initial phase of the project concludes.

2.1 Existing Solutions

Mounting a seat is not a new concept, but the four tabs on the bottom of bucket seats are usually always different than stock seat bolt patterns. This application is specific to bucket seats, and we researched the existing ways to mount a bucket seat into a vehicle. The solutions are outlined below.

2.1.1 Rigid Mounting

The first alternative solution, and what is currently being used, is to rigidly mount the seats to a non-adjustable frame. It is most common to tie the base frame into the roll cage as it provides an easy solid mounting point. This solution is typically sturdy as there are no moving parts or hinges. On the current Jeep, the base frame is tied into the cage and the floorboard. This method is relatively cheap, but requires custom fabrication, cutting, and welding. Once the seat position is set, there would be no way to adjust the seat position unless the brackets have multiple bolt holes. Due to non-adjustability, rigid mounting is the method we were aiming to replace while maintaining the benefits of safety and rigidity.

2.1.2 Modifying Stock Seat Bases

It is also possible to adapt the stock seat bases for bucket seat mounting. This method retains the adjustability of the stock seats and does not require as much fabrication as rigid mounting. Tabs are needed to mount the bucket seat to the stock base. While this can be an easy solution, many older jeeps and off-road vehicles have no vertical adjustability and the longitudinal adjustment is manual. This is not a viable solution for our project as vertical adjustment is essential, and the stock bases would place the bucket seat too high for taller riders to fit underneath the roll cage.

Additionally, stock seat bases are challenging to buy as they are no longer produced for older model Jeeps. Junkyards do not have seat sliders readily available and they are hard to acquire. Figure 6 below shows stock seat sliders that represents the lack of appropriate mounts for bucket seats.

Figure 6. Stock Seat Slider with No Features for Different Seat Mounting [2]

2.1.3 Aftermarket Bucket Seat Mounts

Another way of installing bucket seats is to purchase aftermarket bucket seat mounts. While promising in theory, these mounts require more work than custom rigid mounting because the aftermarket bracket mounts are not specific for off-road applications. The mounting hole locations are designed for street cars. Because every vehicle has unique mounting holes for seat bases, these parts were not helpful to the project. Figure 7 below shows a mounting solution made by Sparco for flat mounting.

Figure 7. Existing Bucket Seat Mount with No Adjustment and Poor Mounting Adaptability [3]

2.1.4 Powered 6-way Van Seat

Powered seats are a convenience for modern car owners. (shop4seats.com) These are expensive, starting at $320, and we only found one from a company called Adnik￼The unit is shown below in Figure 8.

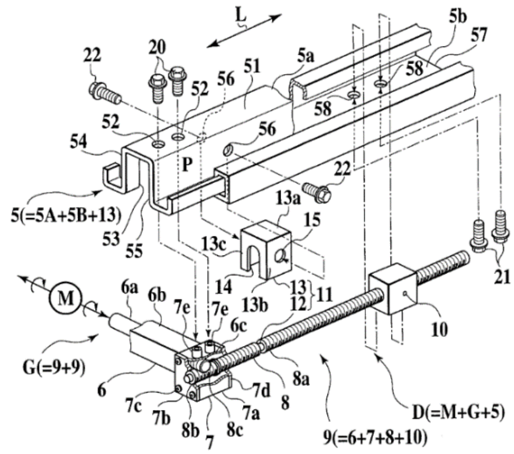
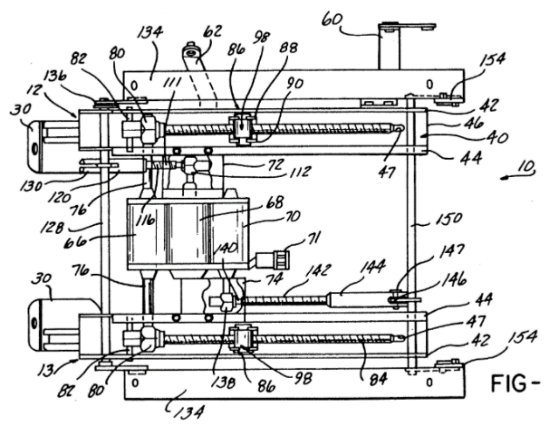
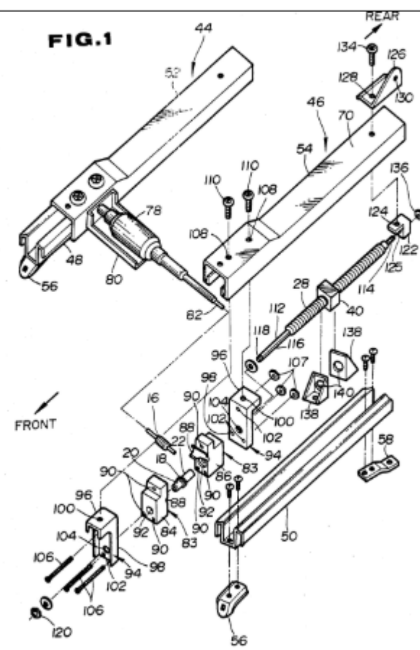
Figure 8. Aftermarket 6 Way Power Seat for Vans and RVs [4]

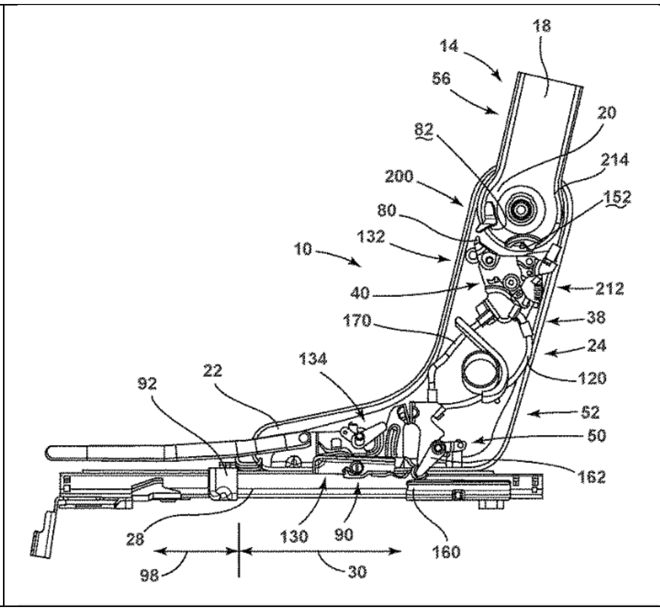
While this is not low profile or adaptable enough to either fit out floorboard or seats, there are some important takeaways from this product. First, aftermarket powered seat bases exist. Secondly, aftermarket seat bases like this pass Department of Transportation standards for street legal vehicles. These were standards we had to meet to market our seat bases as a street legal product. More specifically, the design must pass Department of Transportation Federal Motor Vehicle Safety Standards tests. DOT S71.207 lists a variety of tests that will need to be passed for our seat base to be considered safe to ride.

2.2 Patent Searches

Patent searches for seat bases, both mechanical and powered, yield the following results shown in Table 1 below.

Table 1. Patent Search Results for Similar Products

Patent Number	Patent Title	Description	Drawing
US6244660B1	Power seat for Vehicles	This is Nissan Motor’s 1999 patent for a powered seat, consisting of a lead screw activated seat rail system with a fixed lower rail and a moving upper rail	
US5292164A	Power seat adjuster with horizontal slot drive	Powered seat base with horizontally mounted motors to save space and be more low profile than other powered seat bases like it	
US5150872A	Power seat slide device	Seat slider with a motor mounted on the movable rail driving a lead screw to adjust movable rail position	

US9868369B1	Tip and slide system for a vehicle seat	Rear seat slider and pivoting mechanism for seatback and seat location adjustments	

The takeaway from this patent research was that there are different ways of adjusting seat position, and many existing patents on the topic. Most powered seat bases use a system of lead screws and motors to adjust the seats; most manual seat bases use a locking system either with cams or slots to allow for positioning with a lever and solid locking into position. Going forward, we expected to look further into each of these options to see what would be best for our application and design, and how we can adapt and change current designs to fit the needs of our customer.

2.3 Journal Article Research

First, we found an article in the Journal of Tribology [5] explaining the mechanisms of lead screws and how they are best utilized. Based on previous solutions to on road vehicles, we expected lead screws to be an optimal option for lateral movement of our seat. Next, an article in ScienceDirect [6] described the general weight distribution of a rider in an automotive seat. This information was helpful to use when calculating our static and dynamic forces used in FMEA. We also found an article in The Journal of the Acoustical Society of America [7] which researched the comfort of seats in automobiles. This directly applied to our objectives of the product as comfort for the rider is an important customer want. In preparation for calculating the forces for vehicle roll, we found two articles which describe the state of the vehicle in such state. The first article was called "State estimation in roll dynamics for commercial vehicles" [8] and the second was called "Real-Time Estimation of Center of Gravity Position for Lightweight Vehicles" [9]. Together, these two articles helped us make predictions about what loads our seat mover needed to be able to withstand.

3.0 Objectives

Custom off-road vehicle owners looking to change driver and passenger seats have been historically limited in their choice of seats and seat position due to the lack of aftermarket and OEM support for rigid seat mounts. Designing new modular seat brackets that allow any bucket seat to be mounted to various floorboard patterns while maintaining familiar seat adjustment would let drivers and passengers ride comfortably and safely.

For our design to be successful, it must be able to fit in the space described, easily move a seat in the vertical and longitudinal directions and be durable enough to handle a rollover. Our initial goal was for six inches of travel forward/backwards and three inches of vertical travel. These numbers compare to measurements take from seat movers in other vehicles; the distances are short enough to maintain rigidity and reduce deflection. The lowest vertical position needed to lower the seat to nearly touch the transmission tunnel. To achieve this, the seat tabs and lifting and sliding components would need to fold beside each other into a single plane beneath the seat. A rough boundary sketch of our design is shown below in Figure 9.

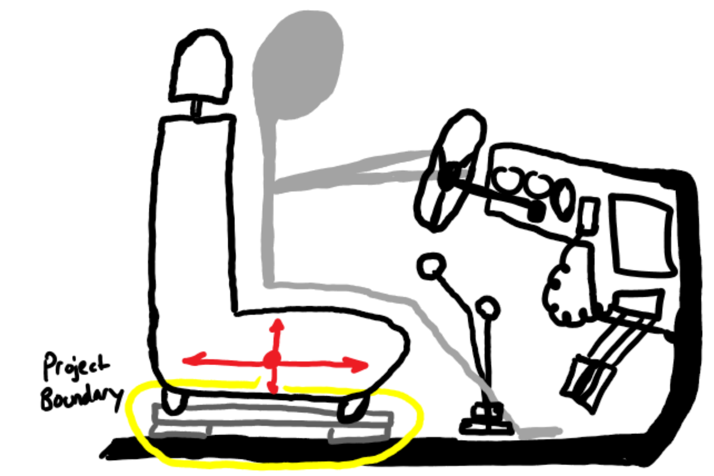


Figure 9. Project Boundary Sketch

Table 2 below lists the customer needs and wants. Since we were designing for Alex’s Jeep Wrangler, it was essential that our design would fit well and would not interfere with the floorboard and other components. It must also mount a bucket seat with a standard 14” x 18” tab pattern. Bucket seats are intended to keep riders safe and in place, thus making it necessary for the base to support the seat in the worst-case scenario of a roll over. Longitudinal and vertical adjustment were required. Designing for reclining was unnecessary as bucket seats are fixed back. Meeting the DOT standards is required for use on the street.

Table 2. List of Needs and Wants

Needs	Wants
Fits in Alex's Jeep YJ	Fast and smooth travel
Mount a seat with a 14" x 18" tab pattern	Lightweight
Support the rider during a rollover	Minimal deflection in frame
Easy 2-axis adjustability	Easy to use
Lower as close to floor as possible	Adaptable to other vehicles
Meets DOT standard	Cheap to manufacture

We decided that if all needs were met, we would work on optimization to meet the customer wants. These features were not essential but would make the product more desirable if taken to market. Fast and smooth travel would make someone using the seat feel as though they were in a modern car. A lightweight product is always beneficial, but this came second to strength and safety. Minimal deflection of the seat during operation would also give the rider confidence in the design. The commands for adjustment needed to be intuitive and easy to operate for all riders. Locating the switch panel in a similar location to regular cars would add familiarity for users.

To help get an idea of how current products meet our design needs and customer wants and to explore how to test the needs and wants are satisfied, a Quality Function Deployment was used to create a House of Quality, shown in Appendix A. This process began with listing the customers and their needs and wants. We then compared their respective level of importance to different customers. Next, we listed current products and quantify how well the current products meet each need. From this, we outlined potential specifications, considered how those specifications related to each other and defined how important each test should be for those specifications and the desired results. Although complex, this process gave us an idea of how we should specify our product based on preliminary research. The House of Quality gave us a goal to work towards during the design phase of this project.

The specification goals were developed from industry experience, customer interviews and personal goals. Keeping the deflection of the seat low will keep the rider confident in the strength of the product. We decided to measure deflection at the head rest as it best describes the effect seat adjustment has on the rider. Cost to manufacture would be important because an underlying goal was to produce and sell these bases. The travel and speed specifications were determined from measuring vehicles equipped with electric seats, as well as measuring the space available in the YJ. The target specifications are shown below in Table 3.

Table 3. Engineering Specifications Table

Spec #	Parameter	Target	Tolerance	Importance	Risk
1	Deflection at max force	2 Inches	MAX	High	High
2	Cost to Manufacture	$250	MAX	Medium	Medium
3	Longitudinal Travel	6 Inches	MIN	Medium	Low
4	Vertical Travel	3 Inches	MIN	High	Low
5	Meets DOT standard	Section S71.207	MIN	High	Medium
6	Speed to Adjust	7 Seconds End to End	MAX	Low	Low

An explanation of each of these parameters is as follows:

1. For a seat to be stable and comfortable, the base needs to restrict the movement of the seat so that the driver does not experience excessive movement. We defined this as the deflection of the seat at max force needs to be less than two inches, the highest point on the seat. This would be tested by loading the base and measuring the deflection.
2. The lower the cost of manufacturing, the lower the selling price of the seat can be, and the more customers we can reach. This would be determined by the material and manufacturing cost of the seat base.
3. The longitudinal travel (front and back) of the seat needs to be at least 6 inches for satisfactory adjustment in the seat. We will test this by measuring the travel of the seat once fully assembled.
4. The vertical travel (up and down) needs to be at least 3 inches for satisfactory adjustment in the seat. We will test this by measuring the travel of the seat once fully assembled.
5. There is a DOT standard (Department of Transportation) for the rigidity and safety of a seat base, and our seat base must pass this standard to be road legal. This will eventually be tested to the proper DOT specification; however, we do not expect for this to be viable with any prototypes due to the cost of equipment to test.
6. The speed to adjust should be under 7 seconds from end to end on either axis for satisfactory adjustment in the seat. We will test this by timing the speed of adjustment once fully assembled.

The highest expected risk specifications were deflection at maximum force and vertical travel. Deflection at maximum force is a combination of seat and mounting rigidity, as well as the tolerance on parts to fit together well. This was a challenging specification to meet, as current car seats move significantly under low force. The vertical travel was challenging to meet as the adjustment for this motion was difficult to implement. The last high-risk item is meeting the DOT standard. This is expensive and challenging to test, but we would need to find a way to do so for the product to be road legal.

4.0 Concept Design

With our specifications defined and background research providing enough of a base to progress, it was at this stage when we decided to begin ideation for possible solutions we could use in our designs. This section details the process we used to go from our defined specifications to a concept model, and the steps we progressed with until our final prototype was complete.

4.1 Initial Stages of Design

We began with our research of how other seat devices achieved vertical and horizontal movement. With this background in mind, we hosted a handful of ideation techniques amongst the group. Ideation sessions were performed both individually as well as in the presence of other group members to capture the benefits of each ideation method. These techniques included brain writing, brainstorming, and a scamper session (See Appendix D for samples of ideation results). Through these methods, we developed a sufficiently broad spectrum of ideas to achieve both vertical and horizontal movement, as well as mechanisms that ensure rider safety.

Our process of determining the top concepts started by eliminating the most unrealistic ideas. Then, we sorted through the list and highlighted our most feasible ideas. During this phase, we thoroughly considered the expected safety, ease of manufacturing, and the space efficiency of each design. Some models we used to create ideas are shown below.

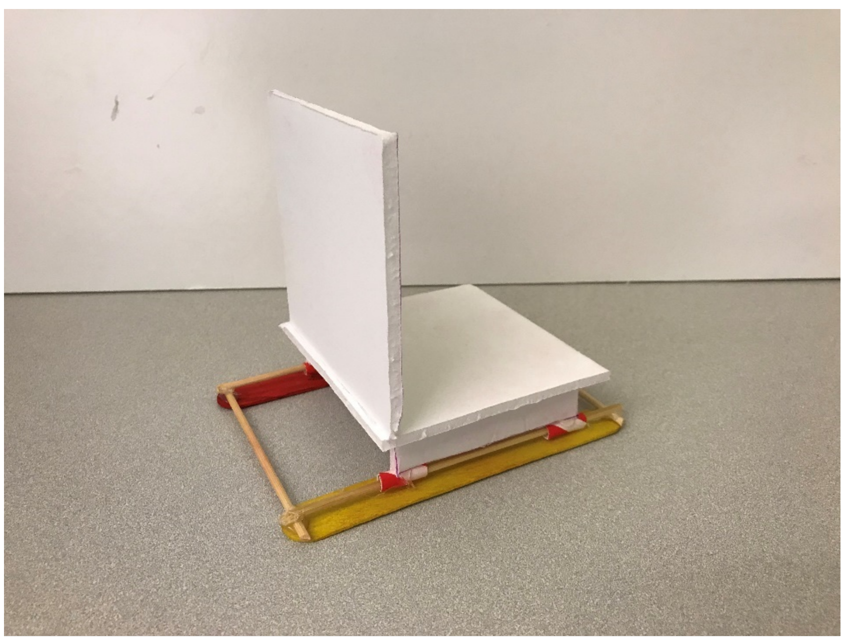


Figure 10: Fore/Aft Initial Concept

Figure 10 represents an early concept for fore/aft movement. This motion can be achieved by the previously decided motion options of either a lead screw, linear actuator, or even a rack and pinion system using a motor.

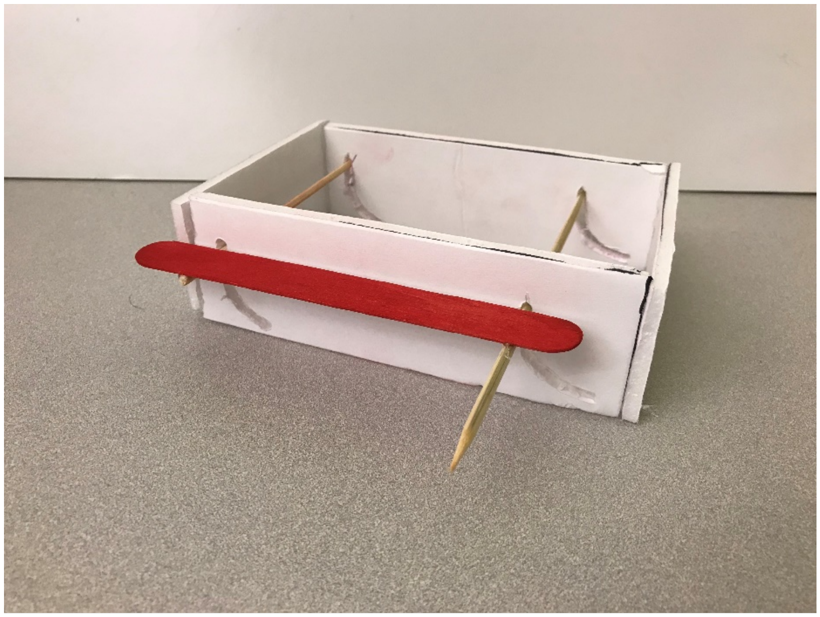


Figure 11: Initial vertical concept using curved lift tracks

This concept model utilizes quarter circle guide slots to achieve vertical movement. The shafts could be driven by a linear actuator forcing movement up the guide. While this is a simple method, the seat will also move forward as it moves upward. Other concept models were created during this concept design session, but as they were more feasible to move forward with, they are included in the next section.

4.2 Selecting Top Designs

After reducing our list, we landed on three methods for vertical lift. The first method is a scissor jack. These designs are quite common and easy to design and assemble and are known to be able to withstand exceptionally high loads. Additionally, a clever design would allow the jack to fold in on itself which gives this design a space efficiency advantage. Our next idea involved vertically oriented linear actuators. This design would be simple to implement and would have a high safety expectation. A potential downside to the design came with the size. For a linear actuator to lift three inches, the collapsed length would be greater than three inches. This does not allow for compact packaging. Our last model for vertical lift involved rotating linkages. This design would likely incorporate a rotary motor and would have the advantage of eliminating a separate system for horizontal movement as the design could be manipulated to adjust the seat position both horizontally and vertically. Visualizations of the designs can be seen in Figure 12, Figure 13, and Figure 14 shown below.

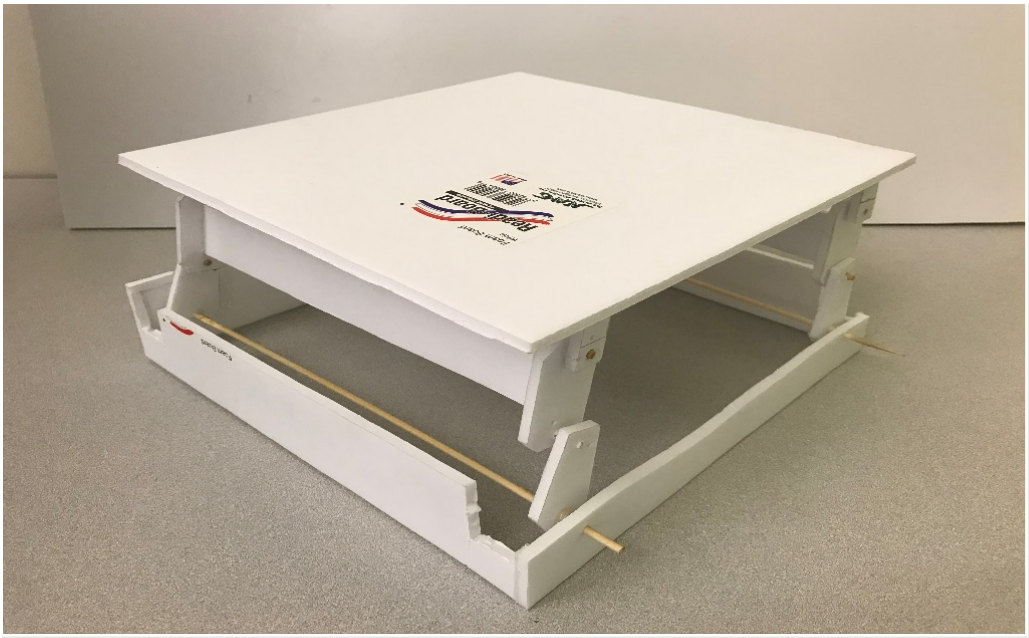


Figure 12. Double Hinge Concept Model

This double-hinge design incorporated vertical and horizontal movement into a single mechanism. The links could be driven in different ways to achieve either horizontal movement, vertical movement, or both. Physically manipulating the prototype revealed that fixing the rotation of one hinge would make the control system simpler. This change is shown in the single hinge concept model.

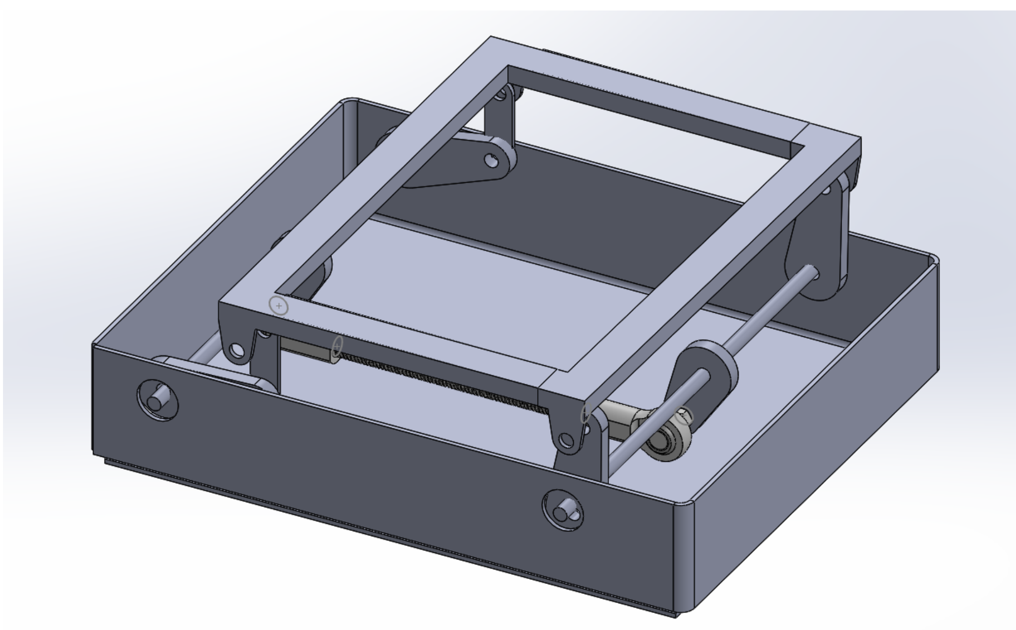


Figure 13. Single Hinge Concept Model

This single hinge is another potential use of the pivoting link design that we came up with. The hinge idea changes to a single hinge rather than a double, which creates an arc like motion. This would allow the base to be raised vertically by twisting the pins that the links are connected to.

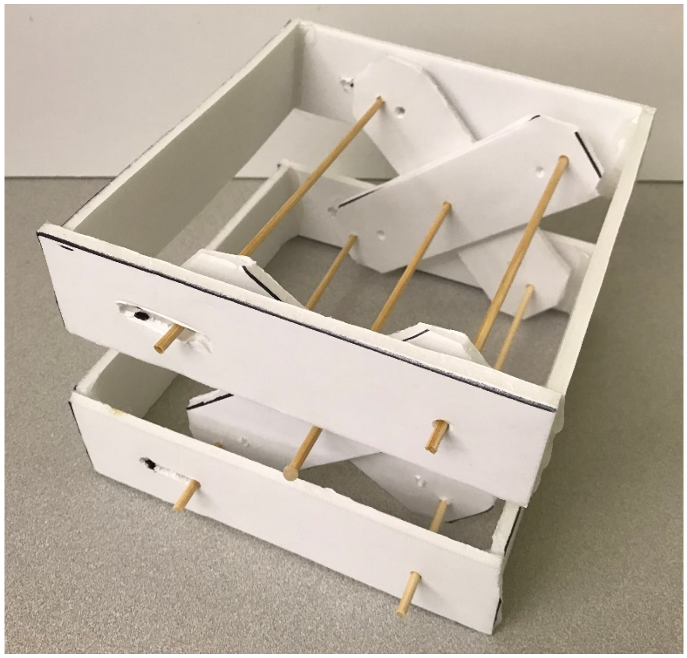


Figure 14: Scissor Lift Concept Model

Finally, the scissor lift and slider concept isolated the two movements and allowed the system to fold into itself, much like the hinge concepts. However, it was a much simpler idea that we thought would be easier to implement.

The three options all seemed feasible, but the single best idea was still difficult to select. The ideas are summarized in the morphological matrix shown in Figure 15 below and analyzed to choose the idea to progress with in the next section.

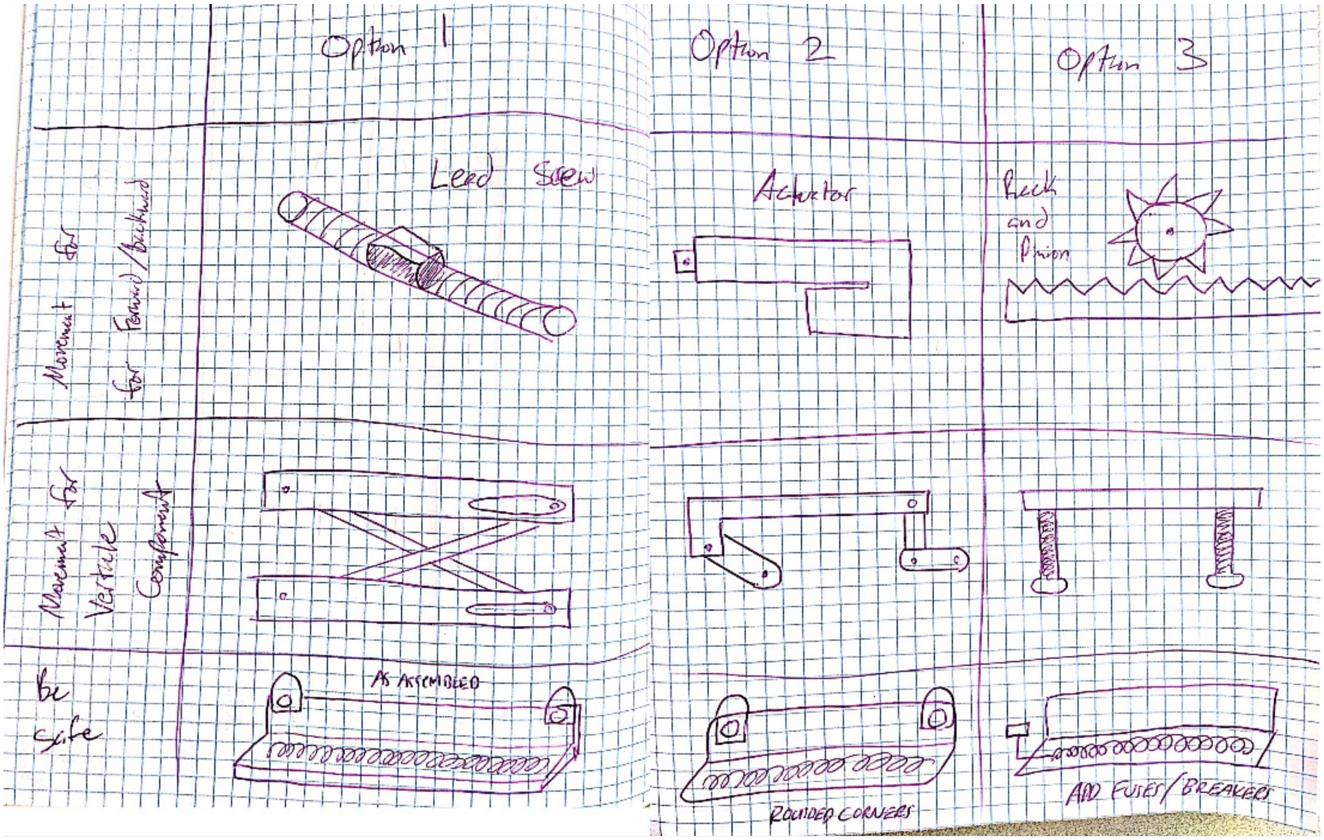


Figure 15. Morphological Matrix Including Best Ideas for Each Function

4.3 Chosen Design

After performing controlled convergence with a Pugh Matrix and a Weighted Decision Matrix, shown in Figure 16 below, we chose to move forward with a design that includes two independent systems. The vertical lift component would be accomplished with a scissor jack while the horizontal movement would be driven with a lead screw. Special safety precautions would be taken at pinch points and all sharp edges would be shielded with protective materials as the team sees fit. This design would be able to accomplish the project goals of six inches of horizontal range and three inches of vertical range without sacrificing safety or space efficiency.

Full system level concepts

option 1 – scissor and lead screw and rubber pinch points

option 2 – scissor and rack and pinion and rounded corners

option 3 – double hinge and lead screw and rubber pinch point

option 4 – double hinge and rack and pinion rounded corners

option 5 – double hinge and actuator and rounded corners

criteria	weighting	option 1		option 2		option3		option 4		option 5	
weight	1	5	5	1	1	4	4	2	2	3	3
complexity	2	5	10	4	8	2	4	1	2	3	6
cost to make	3	5	15	3	9	4	12	2	6	1	3
ease to make	4	2	8	1	4	5	20	3	12	4	16
travel	3	5	15	4	12	3	9	2	6	1	3
sum			53		34		49		28		31

Figure 16: Weighted Decision Matrix

Photos of an initial proof of concept can be seen in

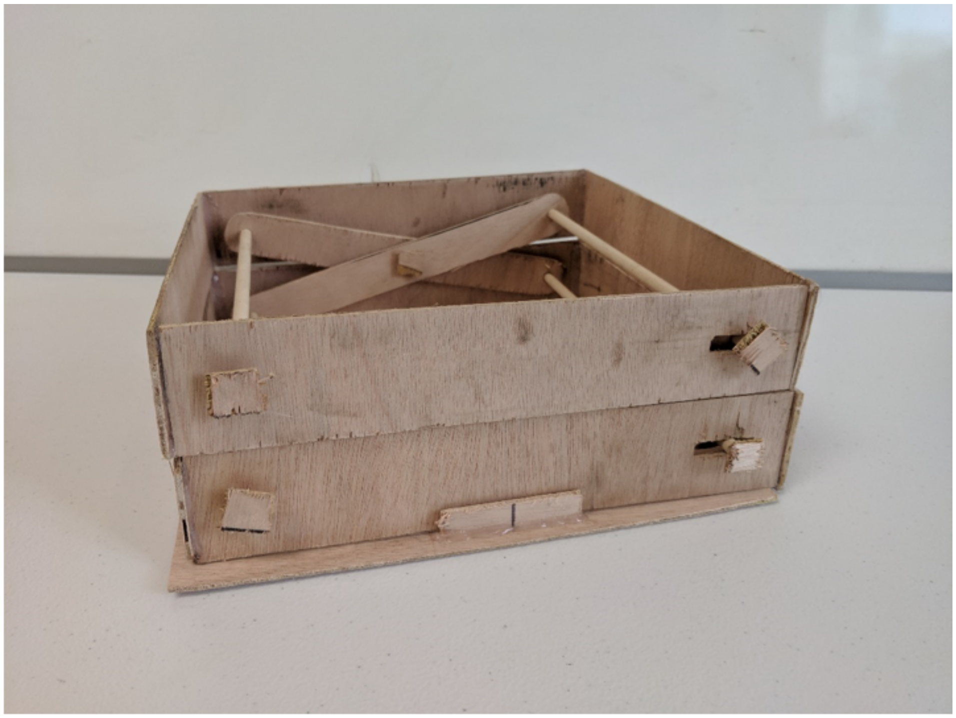


Figure 17 and Figure 18 below. Our prototype does not show the ability for the scissor jack to fold in on itself. This concept was developed as our design was refined and more specific dimensions were defined. The bottom plate is meant to signify the implementation of a lead screw. Since the system for vertical lift is independent from the system for horizontal movement, the prototype can simply be mounted on a rail system and nut driven by a lead screw.

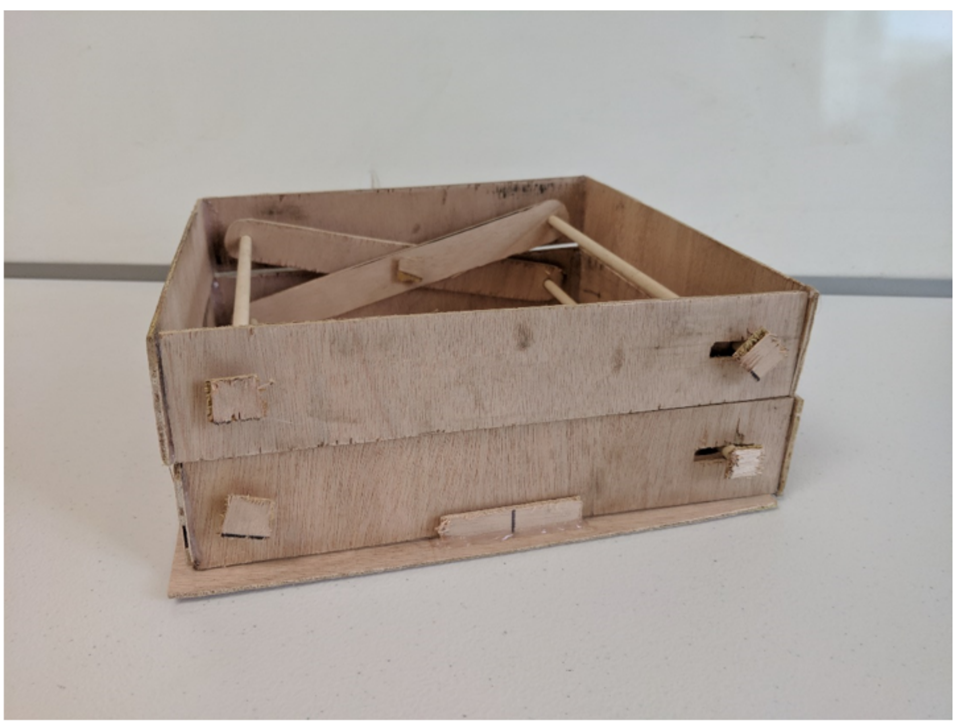


Figure 17: Side View of the Proof-of-Concept Prototype

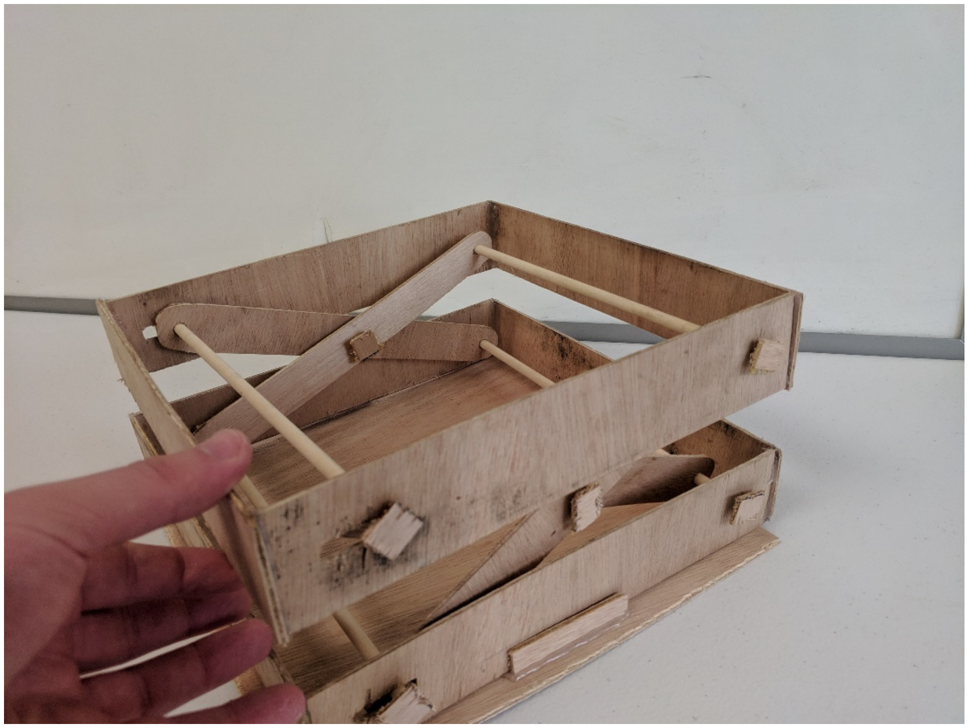


Figure 18: Isometric View of the Proof-of-Concept Prototype

From this prototype, an initial CAD model was created to further explore the locations of things like pivot points, arm locations, support locations, and the possible mounting points for lead screws and actuators. The initial model is shown below in Figure 19.

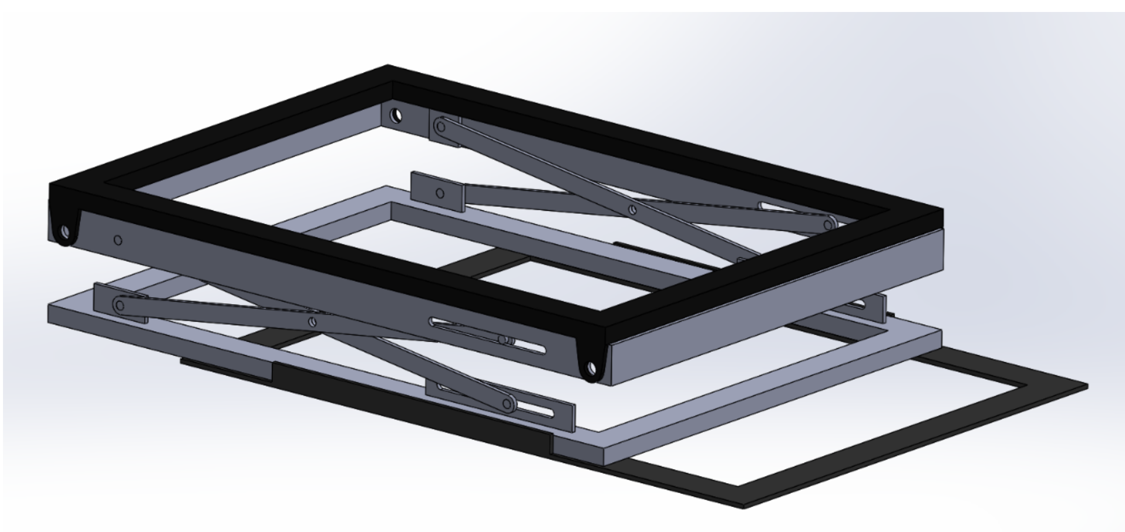


Figure 19: Initial CAD model

Though no decisions were made on materials, hardware, exact geometries, dimensions, or electrical components, the foundation of the design has been selected. The next steps included component refinement paired with a detailed CAD design.

4.4 Initial Design Risks, Concerns, and Future Challenges

The main concern for our design was safety. Due to the rough nature of off-road driving, the seats would have to withstand many differing dynamic loads. The seat base failing during operation would be unacceptable and, therefore, significant testing would be required before completion of the final design. The analysis of expected acceleration during a rollover should also be taken into consideration.

A simulation was performed on scissor arms with a 1.25 by 0.375-inch cross-section. The load case was a 300-pound rider at 5 G's. This included a safety factor on iPhone accelerometer data collected while driving the Jeep. The test is intended to demonstrate that the scissor lift components can handle the forces without being unreasonably thick. The results of the FEA are shown in Figure 20, there was a maximum stress of 32 KSI. Assuming the material is mild steel this would not cause a failure.

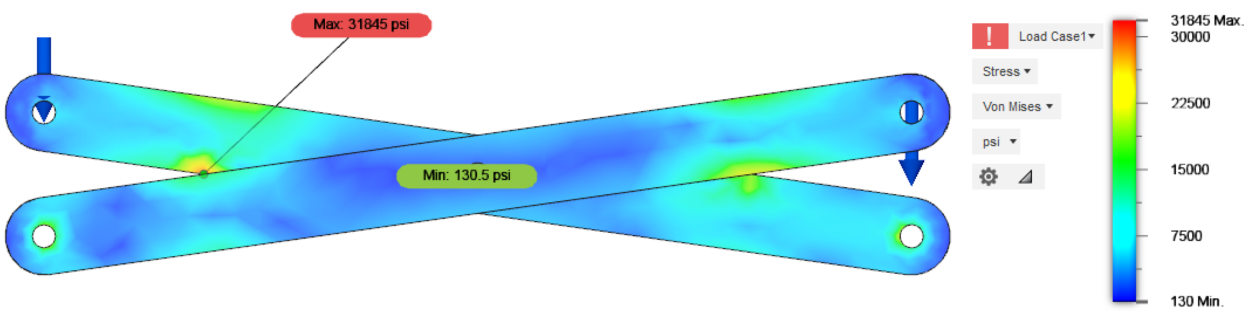


Figure 20. Initial Scissor FEA results

Our next safety concern within the design involves pinch points. These areas require protective attention as large forces would be converging at singularities. Cover plates would be required to keep stray fingers and personal belongings from getting inside the scissor arms. These covers will need to extend the full range of possible seat locations. We will also need to integrate a way to protect the motors from stalling when the seat motion is impeded at the positional limits. Breakers on the electrical system may work well. Refer to the design hazard checklist included in Appendix C for more on these concerns.

Another challenge was designing guide rails that were both cost effective and long-lasting. The forward/back motion and the scissor sliders both require a guide system. Integrating the sliders into the sheet metal frame would be optimal as it reduces the number of components required. We believed a wear-resistant plastic would meet our cost efficiency goal, but more testing would need to be performed to see if a plastic could meet the primary safety goal. Tight tolerances will also be required to reduce unwanted rattling of the seat during operation. (See Appendix C for full Design Hazard Checklist and corresponding resolutions.)

To further focus on safety in the design of this system, a failure modes effects and analysis report has been created. This report, seen in appendix L. This allowed us to focus on the main risks that are associated with the mechanical and electrical components of our design. Actions have been taken according to this report in the final design and the fabrication of our prototypes. Another stress on safety that we carried out was going through a full DesignSafe report for our design. This report can be seen in appendix K. Again, this gave us clarity on what to focus on in our design to make the prototype safe to use. When dealing with motors, electrical wiring, heavy objects, and pinch points all while off-roading; safety is a necessity, not just a priority.

5.0 Final Design

With an initial design in mind, detailed analysis of each of the components of the assembly was done. Additionally, we created a full CAD model of the system to gain a better understanding of the spatial relationships that each component would have. Extensive analysis was performed to determine the size requirements of each component. This process is shown in this section of the report.

5.1 Structural Prototype CAD

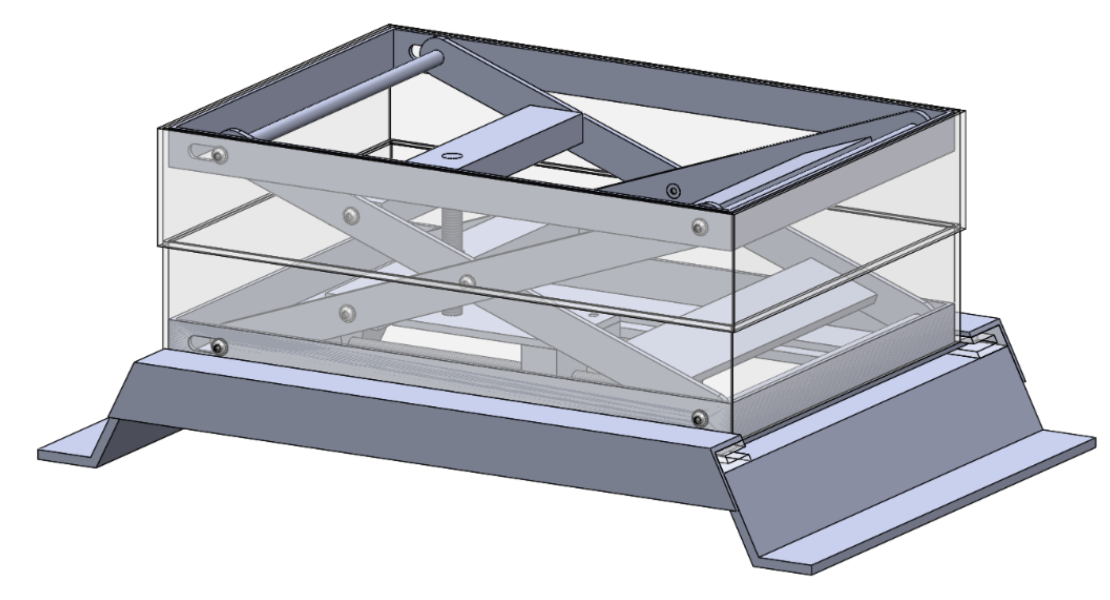


Figure 21: Structural Prototype CAD

A CAD model of our structural prototype can be seen in Figure 21. There are a few noticeable differences from the previous CAD model. First, cross bars were added on the scissor arms to add extra stability and to reduce side to side wobble.

Next, plastic covers were added to increase rider safety. The covers prevent the rider from accidentally placing a finger between the arms when the device is closing. Additionally, steel L-brackets that wrap around the sliding channels made from high density polyethylene were added. These allow for the scissor jack to slide on the lower mounting bracket while maintaining sufficient support and minimizing friction. The sliding motion would be provided by a 12V motor mounted to a nut and lead screw seen in Figure 22.

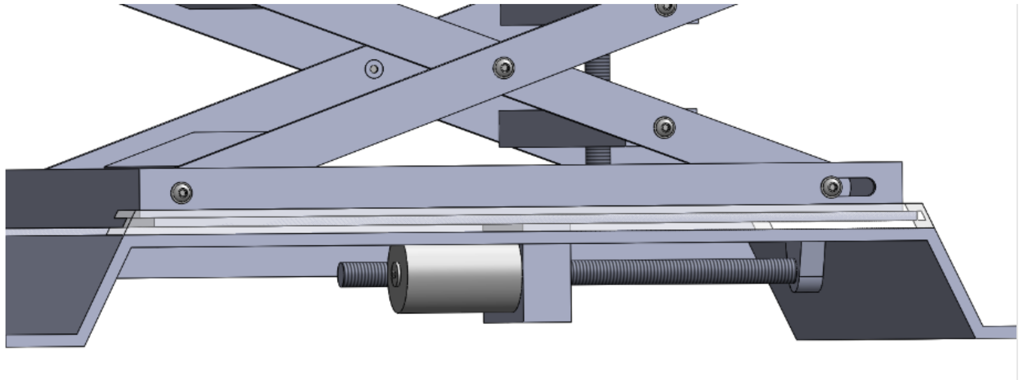


Figure 22: Closer View of Horizontal Motion Showing Sliders and Motor

Similarly, the vertical component is powered with a 12V motor and lead screw. The lead screw would be connected to freely rotating cross bars on the scissor arms. This free rotation design would allow the lead screw to remain vertical as the scissor arms expand and contract. Lastly, the slots for the scissor arm were sized to prevent excessive extension and contraction. Pairing this with limit switches would prevent the motors from mechanical failure when the positional limits are met.

5.2 Design Analysis

Once an initial CAD model was made, the team wanted to push towards creating a physical structure to see the components in action. Prior to manufacturing, we analyzed each component of our assembly and ran all seemingly relevant calculations. To perform these calculations, we needed to find a loading case for the maximum expected load the base would experience. This was done with a phone accelerometer taped to the floorboard of Alex's Grand Cherokee during an off-roading excursion. The worst loading case was found using the maximum acceleration with an additional safety factor; the loading case used for each component assumed 5G downward acceleration. For maximum passenger weight, we chose to use a 300-lb rider as our research showed that this weight was greater than over 99% of the off-road demographic.

Our design process was iterative. We began with using our fabrication experience for selecting the proper materials and sizes. We decided to use mild steel sheet from our local steel yard, as it is readily available in different sizes and thicknesses. It is also easy to machine, easy to weld, strong, and inexpensive. The steel main structure was created in SolidWorks, and the thicknesses and sizes of components were changed based on our findings shown in Appendix E: Design Analysis. In summary, all the components that we designed have respectable factors of safety against the types of failures we expect those components to see.

5.3 Structural Prototype

Using our CAD model, the structural prototype was created and is shown below in Figure 23.

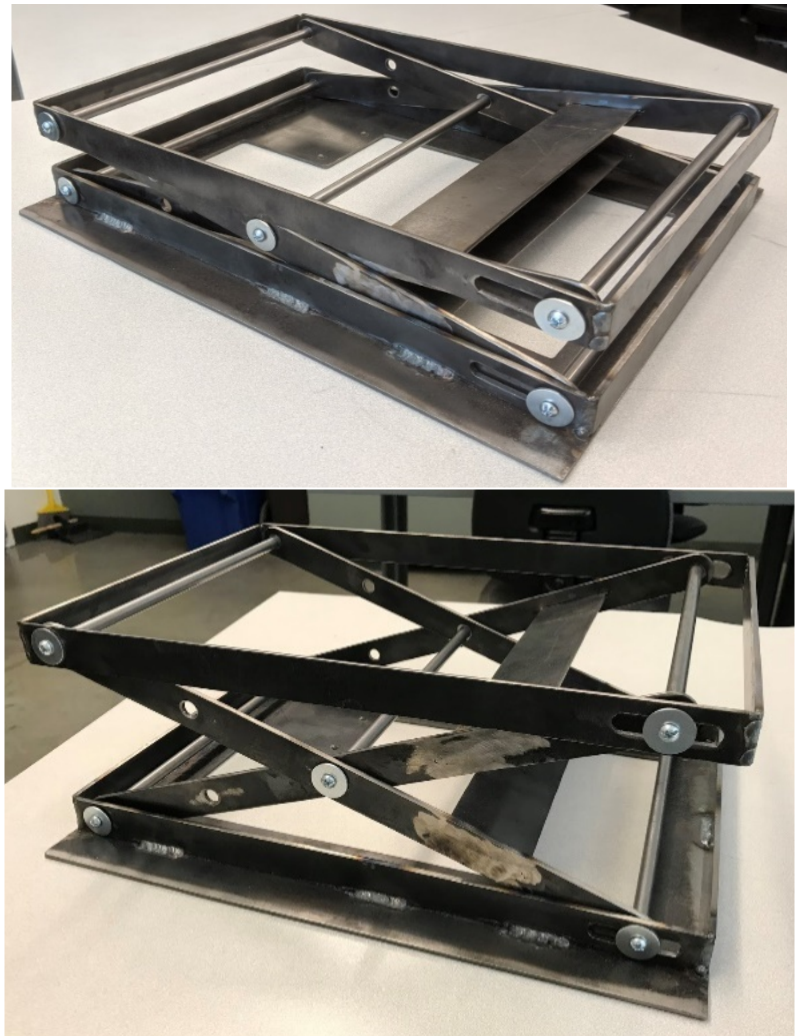


Figure 23: Structural Prototype

This prototype was easily created using a CNC Plasma table, drill press, and manual mill. Our fabrication experience allowed us to create a design that could be easily made which facilitated having such a heavy-duty prototype at this stage. This prototype allowed us to test our motor and lead screw assemblies; we learned from the successes and failures of each piece as they were built.

Our structural prototype confirmed our dimensions and our updated design for vertical and horizontal movement. The joints were smooth, and overall the base felt rigid; however, we learned that the use of spacers between the scissor arms and that brackets were necessary to stabilize the connection of the scissor arms and the 3/8” cross shafts.

5.4 Electrical Systems

Crucial to the project is a functioning electrical system. A simple schematic is shown below in Figure 24 and shows our approach to powering the 12V motors.

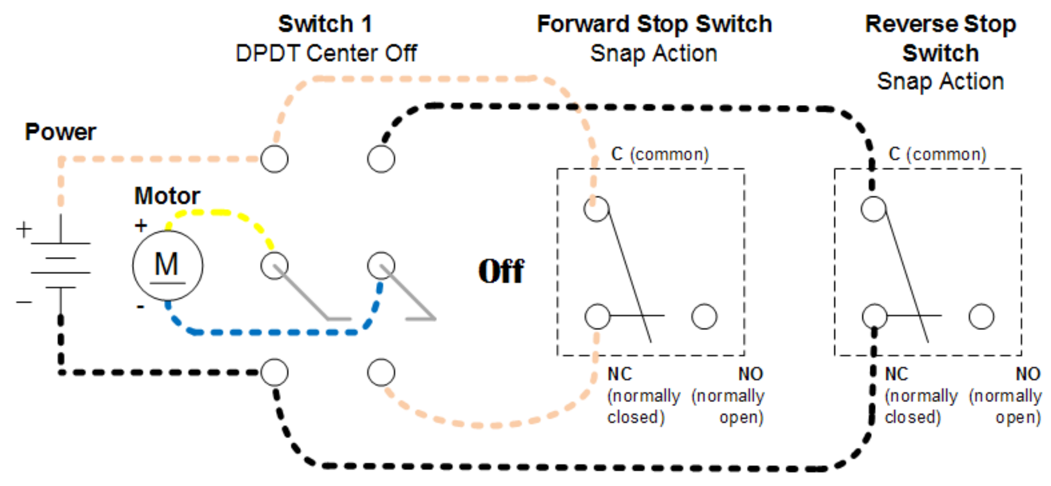


Figure 24: Electrical Diagram

This electrical system comprises of a set of limit switches for each of the axis of motion, 2-way switches for each direction of motion independently, and wires to connect it all. The motor selection calculations can be seen in Appendix E. With the structural prototype constructed, we could order the motors and verify that the sizing calculations were sufficient.

The user of the seat will interact with two separate two way switches, as explained in the owner's manual of appendix I. This signal will connect the 12v source to the motor, but will stop once the limit is reached for the motion that is being commanded. The circuit will then only work in the opposite direction, ensuring that overcurrent does not occur and force a fuse to blow. The 6 pin switches allow us to complete this circuit without using automotive relays as we initially thought we would be forced to. The wiring is seen in the next section.

6.0 Manufacturing

6.1 Part Planning

Figure 25 shows our Bill of Materials necessary for the seat base. For the functional prototype, we will use gearmotors with ratios similar enough to the calculated value. This will save costs on the prototype, for the final product, custom gearboxes would be ordered. Most of the materials were manufactured from stock metal, while most other structural components were purchased from McMaster-Carr. Quantities and costs are listed as well as the vendors used. The individual metal prices were estimated from stock size prices. Links to the purchased parts, or parts similar to what we sourced locally, is shown in appendix J.

Indented Bill of Material (BOM)

Assembly Level	Part Number	Description					Vendor	Qty	Cost	Ttl Cost
		Lvl0	Lvl1	Lvl2	Lvl3	Lvl4				
0	10000	Final Assy					------	------	------	------
1	10100		Top Assembly				------	------	------	------
2	10110			Scissor			------	------	------	------
3	10111				125 inch Scissor arms		Metal Shop	4	20	80
3	10112				Scissor arms		Metal Shop	2		0
3	10113				Extended cross brace		Metal Shop	2		0
3	10114				.75" Rotating Shaft		McMaster	2	10.28	20.56
3	10115				.25" Shaft Pin		McMaster	2	10.28	20.56
2	10120			Top Scissor bracket				------	------	------
3	10121				Outside slider face		Metal Shop	2		0
3	10122				Front slider face		Metal Shop	2		0
2	10130			Bottom Scissor bracket				------	------	------
3	10131				Outside slider face		Metal Shop	2		0
3	10132				Front slider face		Metal Shop	2		0
2	10140			Horizontal Gear Box				------	------	------
3	10141				Housing		Metal Shop	1	20	20
3	10142				12V Motor		Andy Mark	1	35	35
3	10143				ACME Round Nut		McMaster	1	2.68	2.68
3	10144				Load Gear		McMaster	1		0
3	10145				Lead Screw		McMaster	1	5.93	5.93
2	10150			Verticle Gear Box				------	------	------
3	10151				Housing		Metal Shop	1		0
3	10152				12V Motor		Andy Mark	1	35	35
3	10153				ACME Round Nut		McMaster	1	2.68	2.68
3	10154				Load Gear		McMaster	1		0
3	10155				Lead Screw		McMaster	1	5.93	5.93
1	10200		Bottom Assembly					------	------	------
2	10210			Sliding Base				------	------	------
3	10211				Bottom Face		Metal Shop	1		0
3	10212				Floor Mount		Metal Shop	1		0
3	10213				L-brackets		Metal Shop	2		0
1	10300		Electrical					------	------	------
					Switches		Amazon	2	3.98	7.96
					Limit Switches		Amazon	4	2.01	8.04
	Total Parts							40		244.34

Figure 25: Bill of Materials

6.2 Components

As previously stated, the structural prototype was made using a CNC plasma table, manual mill, and drill press. Hand tools like screwdrivers and taps were used as well, but the overall manufacturing of this product was quite simple. With our continued prototypes, we continued to refine the manufacturing and assembly process. We tried to retain the simplicity of flat parts that were cut either using a plasma table or waterjet. For expanded production, all sheet metal parts would be outsourced for laser cutting and bending. For our final prototype, the main sheet metal parts were CNC plasma cut. The remaining parts were hand fabricated for precise fitting of gearboxes and lead screws. To mate the gearboxes to the lead screws, adapters were milled to fit the gearbox shaft and then welded to the screw. Pictures of the CNC plasma table we used and miller MIG welder are shown below in figures 26 and 27.

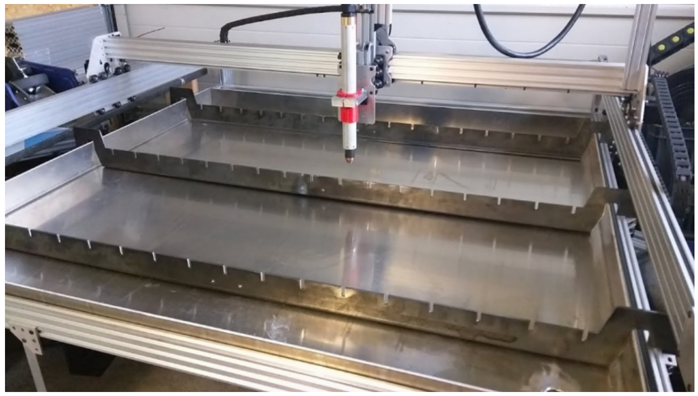


Figure 26: CNC Plasma table ready for steel plate

Figure 27: Miller welder used for this project

Milled UHMW sliders were used in the horizontal movement of the seat. The steel plate base rides in a track lined by this slippery material which allows for relatively low frictional affects while providing good support for the base. These pieces were made using a 1/8-inch end mill and several ¼-inch depth of cut passes. The sliders can be seen in figure 28 below.

Figure 28: UHMW Slider Stock Photo

With all the components plasma cut, machined, and staged, it was time to weld them together. Figure 29 below shows some of this process.

Figure 29: Photo taken of Alex welding components of the frame together

The electrical system is composed of two DPDT switches for control and 4 limit switches to constrain the operation. Spade crimp connectors and 16-gauge wire was used to complete the wiring as described by the electrical schematic. When pressed, the switched control the direction of movement and the limit switches stop movement at the end of safe travel. When an end stop is reached, the switch is still able to actuate the slider in the opposite direction.

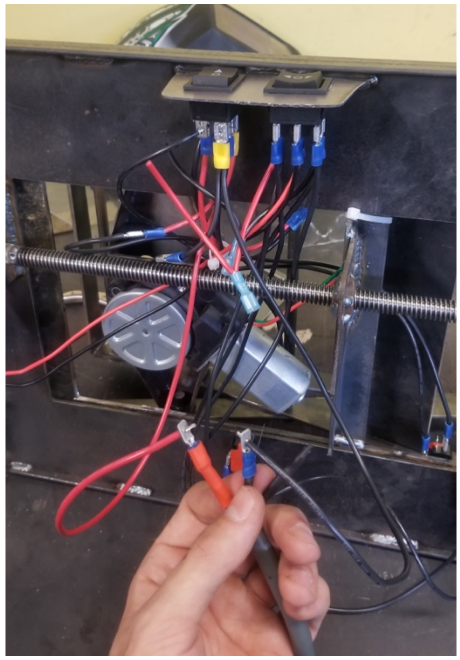


Figure 30: Image Taken During Wiring Phase of Construction

The shielding was made from plexiglass sheeting that was cut using a band saw. There is an upper and lower piece that slide over each other and reduce pinch points. These two pieces needed to have an overlap greater than 3 inches to achieve 3 inches of travel and have no interference issues. The shields are shown below in figure 31.

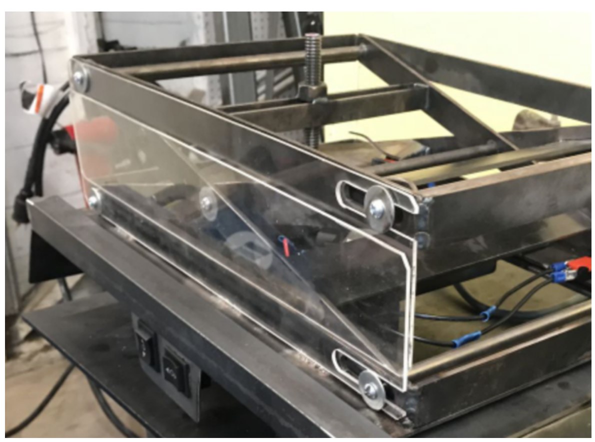


Figure 31: Image Showing Acrylic Shielding to Prevent Pinch Points

6.3 Assembly

As seen in the structural prototype, a challenging manufacturing process was welding the upper and lower brackets and the rigid cross bars onto the scissor arms. Stock metal needed to be cut down to size. For the shafts, this was done with a horizontal band saw, whereas the sheet metal was cut with a CNC plasma cutter. The slot and angled ends of the UHMW plastic were cut on the mill using a square end mill. The L-brackets and plastic runners were mounted to the lower bracket by welding. The shafts were tapped on the ends for 10-24 screws to hold them in place. Our electrical components were wired according to the diagram seen in Figure 25 & Figure 24. Note, during the purchasing of our electrical components, we found it cheaper to use two separate 2-way switches rather than a single 4-way switch. We believed that the cost of a 4-way switch did not outweigh the corresponding benefit. Wiring of the electrical components was nearly identical to the schematics.

6.4 Cost

According to the BOM, we aimed for the price to build our device to be less than $250. The total cost of our prototype was $244.34. We were slightly under budget and our initial estimation was very accurate. Moving forward, we would expect to be able to scale production and produce each device for even cheaper. The most expensive elements of the design were within the scissor arms. The mild steel, shafts, and pins add the most cost to the prototype. Overall, we were satisfied with the finances of the project, and we expect that the costs would only drop moving forward.

6.5 Final Product

After 3 quarters of hard work, the final design is satisfying to see and use. The fabrication is clean, the wiring is tidy, and the prototype is safe to fully use and test. The final product is seen below in figure 32.

Figure 32: Final Prototype

With a bucket seat sat atop the final prototype, it is easy to imagine the next iteration of the design going into a jeep. This view is shown below in figure 33.

Figure 33: Final Prototype Showing Bucket Seat Compatibility

The final prototype was setup to sit on a table rather than bolt into a vehicle. This was for demonstrating the product at senior project expo as well as for testing. The switches are on the right side of the base and they are intended for potential use in the passenger side of the vehicle. Unlike in our CAD model, there is only plastic shielding on the sides of the scissor mechanism. This was done because no main pinch points exist in the front and back of the base. The same gearmotor was used for forward/back as well as up/down to save costs on the prototype. This resulted in slow horizontal movement.

Overall, the final design matches our initial CAD drawing. As seen in Figure 34, the differences are minor. The sizing of the frame and cross members were directly taken from the CAD model, so it is expected that the two images are so similar. Other slight discrepancies include the electrical components and switches.

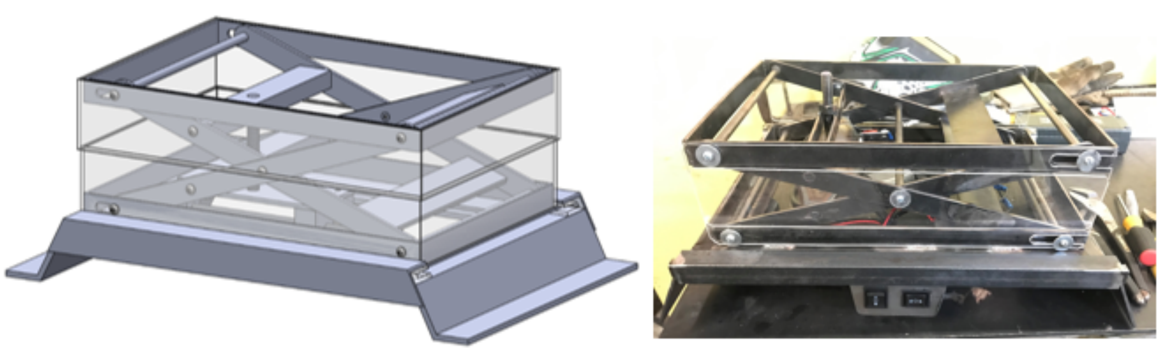


Figure 34: Comparison of CAD Model with Final Prototype

Custom motor mount crossmembers were made for the prototype motors, these can be seen in Figure 35. The boxing on top needed to be added reduce bending in the member. This was an example of slight changes we made to the design while manufacturing. The cover was welded on and eliminated the issue of member bending. The lead screw nuts were also mounted to crossmembers to complete the drivetrain.

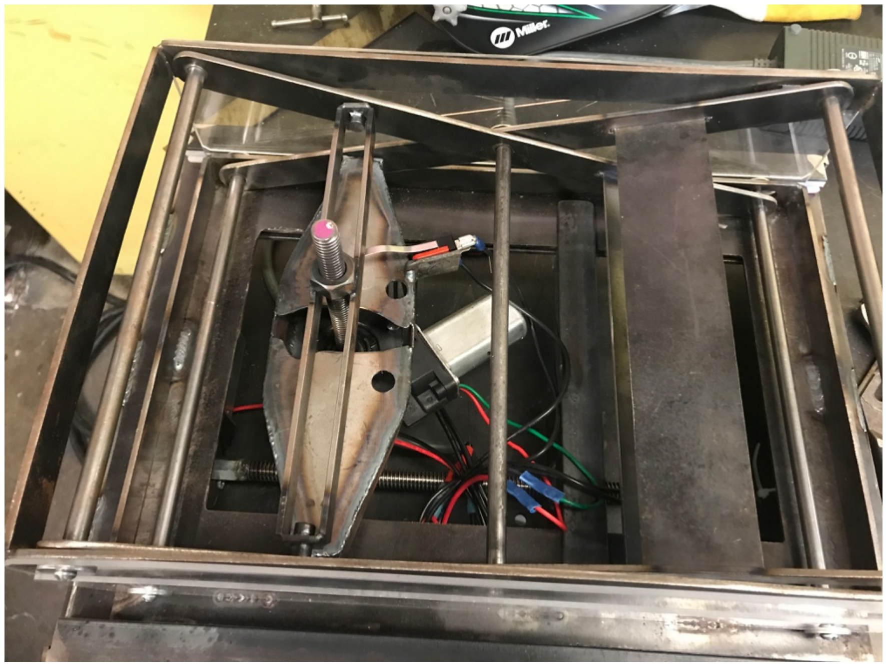


Figure 35: Image Showing Boxing to Add Rigidity to Rotating Cross Arm

With the prototype fully functioning and assembled, it was time to move on to testing.

7.0 Design Verification

7.1 Static Testing

Our static test was performed by taking a measurement of the position of the seat base when the bucket seat has been mounted but with no passenger weight loaded. Then, we loaded the seat with an increasing amount of weight. Our highest measured static load was 180 lbs. Note, we did not want to break our product during static loading, but if we were to expand our product, we would load our seat base until failure.

7.2 Dynamic Testing

We did not complete our dynamic test for safety reasons. Hypothetically, our dynamic test would be performed by rigidly mounting a camera so that it can record the deflection of the seat base. The seat base would be mounted in Alex's Wrangler, and loaded with weight to simulate the force of a rider. A measuring device would be mounted within the camera field of view so that the deflection of the seat can be recorded and measured. Additionally, we would mount an accelerometer to measure the G forces felt with each dynamic load. With the camera recording and the accelerometer taking data, we would apply dynamics loads to the seat by driving the Wrangler. With the data, we would model the deflection of the seat base as a function of the experienced G forces. This model could be used to verify the safety of the design and give us insights on recommended use of the product.

7.3 User Testing

If we felt confident with the performance of our seat base after the static and dynamic tests, we would load the seat base with a rider. We will have the user test the control system to position their seat in their desired location. After driving the vehicle through a mild test course, we will ask the rider to tell us how they felt about the rigidity and usability of the seat base. Consumer reviews and feedback would be invaluable to refining our design.

7.4 DOT Standards Review

The Department of Transportation has tests listed in section S71.207 that are specific to our product. To be compliant, we need a precise way to measure and apply a large axial force. The standards say that the seat base needs to withstand "20 times the mass of the seat in kilograms multiplied by 9.8 applied in a forward [and rearward] longitudinal direction" when the seat is at "any position to which it can be adjusted." This causes challenges. First, we have no way obvious method of applying a measurable force of this magnitude. We researched to find a method to exercise this test to no prevail. With enough resources or the right connections, we could potentially use some automakers testing facility. Additionally, there were seemingly countless different positions the seat base could be positioned in as there are two independent and continuous axes for positioning; this suggests that the necessary testing would be extensive and time consuming.

On top of these challenges, to meet DOT S71.207 we would need to test our seat base with an applied moment. Section S71.207 states that the base must withstand the following: "In its rearmost position - a force that produces a 373 newton meters moment about the seating reference point for each designated seating position that the seat provides, applied to the upper cross-member of the seat back or the upper seat back, in a rearward longitudinal direction" Again, we face the challenge of finding a method for the test, and would again need access to an automakers testing facility.

7.5 Performance testing

Following the DVP&R seen in appendix M, performance testing of the prototype was completed. The results are summarized in table 4 below.

Table 4: Performance Test Results

Parameter	Target	Method	Result	Pass/Fail
Static Load Deflection	2 Inches at Head Rest	Linear Measurement	0.19 inches	Pass
Dynamic Load Deflection	3 Inches at Head Rest	Untested	Untested	Untested
Cost to Manufacture	$250	Sum Costs	$244.34	Pass
Horizontal Travel Distance	6 Inches	Linear Measurement	6.25 inches	Pass
Horizontal Travel Speed	7 seconds	Stopwatch Timer	42.4 seconds	Fail
Vertical Travel Distance	3 Inches	Linear Measurement	2.3 inches	Fail
Vertical Travel Speed	7 seconds	Stopwatch Timer	7.5 seconds	Fail
Meets DOT standard	Section 571.207	Untested	Untested	Untested

Measuring the speed and distance of our base was relatively straight forward as we only needed a stopwatch and measuring tape for the two tests, respectively. The speed tests were done while the full 300-pound load was mounted onto the base. The speed of our motors did not meet the initial specifications. We did calculations to determine the speed of travel before construction so that we would have a vertical lift speed of 7 seconds. However, it was obvious that the motors were considerably slower with the load applied. Additionally, the horizontal speed was further off than the vertical because speed calculations were done for vertical movement and the same 12 motor was used for the horizontal axis for simplicity purposes.

To measure our static deflection, we loaded the seat base with a known amount of weight in small increments. While we were careful not to damage the scissor arms, we were able to load 180 pounds with a deflection at the top of the base of about 0.19 inches. This measurement was done by comparing the height of the top of the base when there was zero loading against the height of the top of the base with the 180-pound load. 0.19 inches of static deflection scores a passing grade.

We did not test the deflection of the dynamic load. This was decided to be too dangerous as we would need to put riders at risk to gain accurate measurements. The process of how testing would be done can be seen in section 7.2 Dynamic Testing. Additionally, we did not perform the DOT testing. The resources needed to complete these tests were outside of the team's means, and at this stage of the process, we did not plan on pursuing a license to make the base street legal. The benefits of S71.207 testing did not outweigh the costs.

Our goal for construction of the base to cost less than $250 was a success. As previously stated, the final cost was $244.34 which is slightly under budget. The most expensive elements of the design were within the scissor arms. The mild steel, shafts, and pins add the most cost to the prototype. Overall, we were satisfied with the finances of the project, and we expect that the costs would only drop moving forward.

8.0 Project Management

The design process was a multistep and iterative process. After the Scope of Work document was sent, the ideation phase began, which led to our decision of which designs we thought were most promising. Decision matrices were utilized, and details of the design were generated via CAD. Information about our optimal design was presented to the sponsor during the Critical Design Review. Next, we gathered feedback from our sponsor and classmates on our CDR. Then, we made necessary adjustments, and continued to ideate, prototype, and learn from the results. We continued to purchase parts as necessary to move forward with our prototype. We continued construction as we were ready to proceed and made slight adjustments to the design often to ease manufacturing while maintaining structural integrity. We always considered our working prototype as if it were the final design and were always expecting it to be fully functional when complete. Fortunately, we never had to reconstruct the mild steel frame or rework any major components. Overall, our manufacturing process went smoothly, and our final product matched our models.

Our first deliverable was PDR. In our PDR we needed to have considered preexisting solutions to our problem and creating initial prototypes. Important parts of the PDR included the necessity of clarity in what we were trying to design. The customer base we were looking at was surveyed, and performance goals of our end product were created. With these clear wants and desires in mind, we were able to drive forward in the prototyping and research process in order to meet those goals.

The next major deliverable was CDR. Stemming off the initial design ideas of PDR, select designs were further developed that saw promise of successfully meeting the performance goals of the product. Through our analysis, we were able to move forward with one design, the scissor lift idea. The choice to move forward with this one idea came from our decision matrices, initial prototype feasibility studies, and cost projections. We wanted a simple, robust, cheap system that we would be able to make a functioning product to work with. From here, more detailed analysis was completed in order to size the components we were going to be both fabricating and purchasing. This process produced some detailed drawings that we used to fabricate the final prototype, and other guidance that we could lean on to complete the prototype once the major structures were in place.

With the start of fall quarter, the fabrication process began. Components that were not completed for the CDR prototype still needed to be made, and the entirety of the electrical components needed to be installed. The fabrication process went smoothly as is detailed in the manufacturing section of the report. To complete the prototype in a timely manner, the team met Tuesdays and Thursdays in the afternoon to continually complete smaller sections of work throughout the quarter. One last final push was made before expo to wire and install all the safety guards needed to show the prototype off. The build was a success, and both the electrical and mechanical systems work without any issues. From here, more rigorous testing was completed so that the final design report could be created after expo concluded. The major deliverables and timeline of the project is shown below in Table 5.

Table 5. Major Project Deliverables with Timeline

Deliverable	Description	Due Date
Scope of Work	Defines project goals and specifications	February 1st
Preliminary Design Review	Presentation of initial designs and engineering approach	March 8th
Interim Design Review	Reviewed the working stages of product prototyping and design approach	April 11th
Critical Design Review	Review of current prototype and review progress. Report emphasizes safety and future project management	May 3rd
Manufacturing Test and Review	Status of component manufacturing, updated test plan, and updated schedule of project completion	May 31st
Complete Final Prototype	Manufacturing and assembly of design to be completed. Testing and analysis to follow	October 15th
Confirmation Prototype Review	Complete operator's manual detailing all safety hazards, all use cases, and general trouble shooting	October 22nd
Final Design Review	Final prototype, final design report, showcase of the project expo poster	November 26th
Senior Project Expo	Present project and demonstrate product to Cal Poly community and Mechanical Engineering department	November 29th
Wrap Up Paperwork	Finish all final paperwork and hand off all project materials, products, and prototypes	December 5th

The team worked very well together this final quarter and the 2 quarters leading to the fabrication of the prototype. Strengths of individuals were used while teammates carried slack where necessary. We all balanced the workload of senior project well and were not overwhelmed. In the end, we have a functioning prototype, completed design report, and are all still friends.

9.0 Conclusion

Although we have a functional prototype, we do not expect our final design to be implemented in Alex's YJ. Due to the difficultly of performing automotive seat testing, we were unable to conduct the necessary tests to meet DOT S71.207 section testing. Without proper testing, no off-roader should risk using the product in their vehicle. Additionally, the lack of proper testing is the largest factor from the team producing more of our product. We had hopes of selling the product to enthusiasts to improve the off-roading experience, but with graduation quickly approaching, we have decided to put the project to rest.

Looking back at the design process, we would change a few of our steps along the way. We failed to set quality specifications for the seat base. Our requirements about how long it takes for the base to move from boundary to boundary were far less important than safety factors. This failure likely stems from the selection of our specifications being decided without the user fully in mind. Additionally, since our sponsor had no stake in the project other than our team's success, there was no 3rd party clearly listing specifications our product needed to meet. If we were to rewrite our specifications, we would put a greater emphasis on safety requirements, less on speed of travel, and more on space efficiency.

This Final Design Review is meant to be the final update to the sponsor about our design process. The compilation of information, diagrams, tables, drawings and models used in this document are the most complete and up to date. The project has taught the group the benefit of using a structured method of design. Specifically, we have learned about the benefit of using sheet metal to quickly produce a structural prototype. Electrically, we have learned hands-on about the ease of limit switches to set boundaries for moving parts. UHMW proved to be structurally sound while reducing drag, and the process to mill a channel was stress free and straight forward. Perhaps the most important lessons we learned about design and the process is that no design is perfect. There will always be a better iteration or a better method of achieving the project goal. Being able to adapt and overcome minor challenges was invaluable as our best manufacturing ideas came while inside the shop, not while behind engineering paper and a calculator.

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Appendices

Appendix A: QFD House of Quality

Appendix B: Gantt Chart

Appendix C: Design Hazard Checklist

Appendix D: Ideation Results

Appendix E: Design Analysis

Appendix F: Drawing Package

Appendix G: Electrical Schematic

Appendix H: BOM

Appendix I: Owner's Manual

Appendix J: Links to Purchased Parts

Appendix K: Risk Assessment

Appendix L: FMEA

Appendix M: DVP&R

Appendix A: QFD House of Quality

Correlations	
Positive	+
Negative	−
No Correlation	

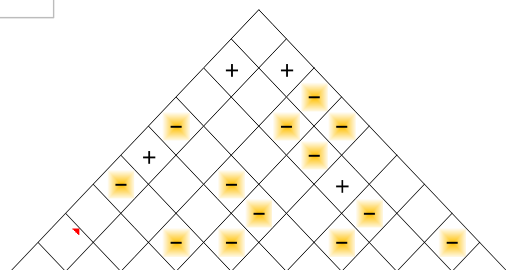
Relationships	
Strong	●
Moderate	○
Weak	

Direction of Improvement	
Maximize	▲
Target	
Minimize	▼

QFD House of Quality

Project: Off Road Seat Base

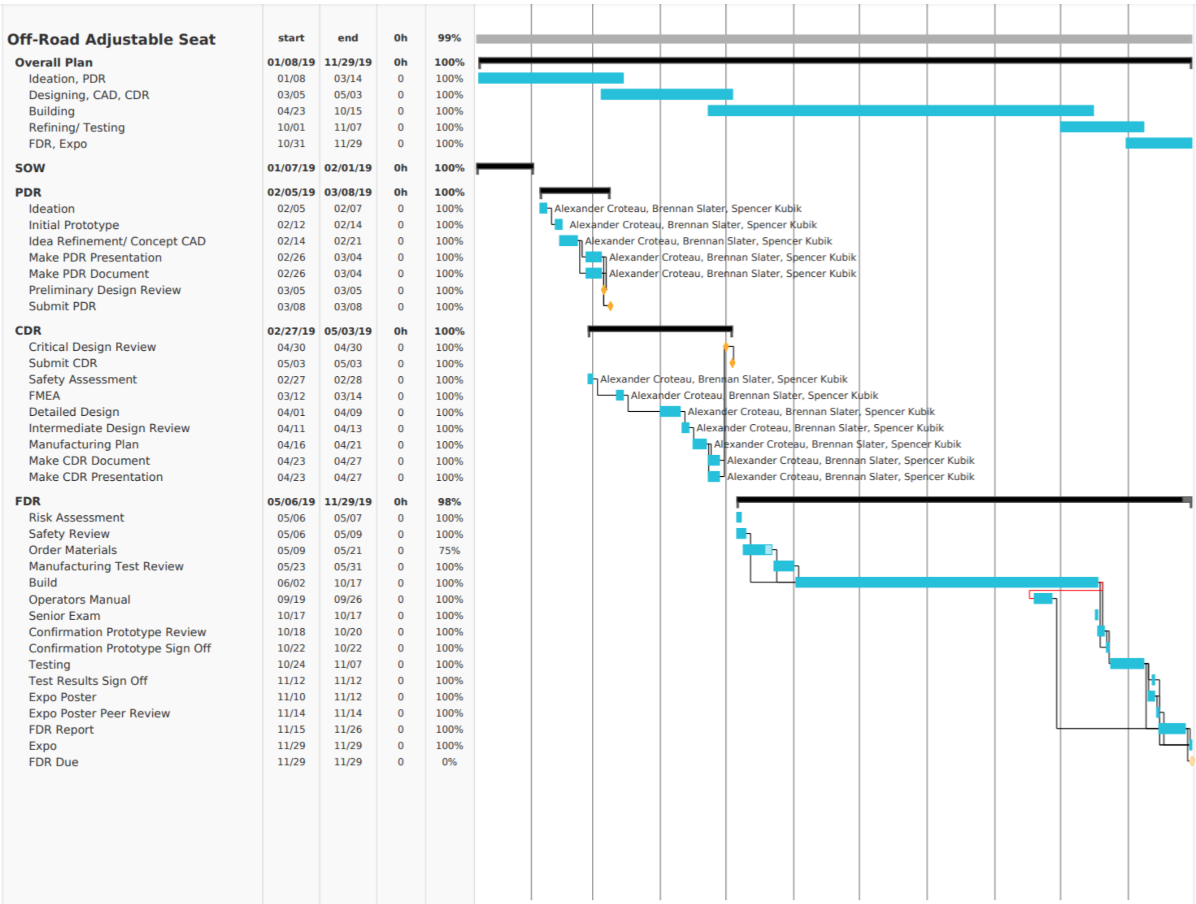
Revision Date: 1/28/16



Row #	Weight Chart	Relative Weight	Buyer/User	Installer	Manufacturer	Seller	Maximum Relationship	WHAT: Customer Requirements (Needs/Wants) / HOW: Engineering Specifications (Tests)	Mount Deflection	Time to install	Time to manufacture	Cost to Manufacture	Weight	Travel	Speed to Adjust	Meet DOT standard	Ease of Adaptability	Rigid Mounting	Stock Seat Sliders	Adapting Power Seat Base	Aftermarket Bucket Seat Moun	6-Way Van Seat	Row #
	WHO: Customers							Column #	1	2	3	4	5	6	7	8	9	NOW: Curr. Products					
								Direction of Improvement	▼	▼	▼	▼	▼	▲	▲		▲						
1		13%	10	4	10	7	9	Reliable	○		○	○	○	●	○	●	○	5	3	2	5	3	1
2		13%	7	6	10	7	9	Safe	●		○	○		○		●	○	5	4	3	4	3	2
3		10%	7	3	5	8	9	Rigid	●		○	○	●	●		●	○	5	2	3	4	1	3
4		9%	7	1	5	9	9	Cheap	○		○	●		○	○		○	4	4	3	2	0	4
5		7%	7	1	3	6	9	Adjustment	○		○	○	○	●	●	○	○	0	3	4	3	5	5
6		9%	8	3	4	6	9	Ease of Use		○	○	○			●		○	1	3	4	3	4	6
7		12%	4	10	5	5	9	Easy to Install		●	○	○					○	0	2	0	3	0	7
8		13%	4	9	7	7	9	Adaptable	○	●	○	○					●	0	0	0	2	0	8
9		5%	1	1	10	1	9	Easy to Make	○		●	●	○	○	○		○	3	1	0	3	0	9
10		7%	5	1	7	4	3	Low Maintenance			○	○						5	4	2	4	2	10

		1	2	3	4	5	6	7	8	9
	HOW MUCH: Target Values	2"	1 hour	6 hours	$75	30 lbs	3" verticle, 6" horizontal	7 seconds	yes	make it happen
	Max Relationship	9	9	9	9	9	9	9	9	9
	Technical Importance Rating	384.5	319	331.6	386.8	232.3	401.4	287.5	410.1	363.9
	Relative Weight	12%	10%	11%	12%	7%	13%	9%	13%	12%
Curr. Products	Rigid Mounting	5	3	2	4	5	0	0	0	1
	Stock Seat Sliders	3	3	4	4	3	2	4	5	4
	Adapting Power Seat Base	2	0	1	3	2	3	3	0	0
	Aftermarket Bucket Seat Mounts	4	4	3	2	4	2	3	1	4
	6-Way Van Seat	2	1	2	1	2	5	3	1	1
	Column #	1	2	3	4	5	6	7	8	9

Appendix B: Gantt Chart



Appendix C: Design Hazard Checklist

DESIGN HAZARD CHECKLIST

Y	N	
☐	X	1. Will the system include hazardous revolving, running, rolling, or mixing actions?
X	☐	2. Will the system include hazardous reciprocating, shearing, punching, pressing, squeezing, drawing, or cutting actions?
☐	X	3. Will any part of the design undergo high accelerations/decelerations?
X	☐	4. Will the system have any large (>5 kg) moving masses or large (>250 N) forces?
☐	X	5. Could the system produce a projectile?
☐	X	6. Could the system fall (due to gravity), creating injury?
☐	X	7. Will a user be exposed to overhanging weights as part of the design?
X	☐	8. Will the system have any burrs, sharp edges, shear points, or pinch points?
☐	X	9. Will any part of the electrical systems not be grounded?
☐	X	10. Will there be any large batteries (over 30 V)?
☐	X	11. Will there be any exposed electrical connections in the system (over 40 V)?
☐	X	12. Will there be any stored energy in the system such as flywheels, hanging weights or pressurized fluids/gases?
☐	X	13. Will there be any explosive or flammable liquids, gases, or small particle fuel as part of the system?
☐	X	14. Will the user be required to exert any abnormal effort or experience any abnormal physical posture during the use of the design?
☐	X	15. Will there be any materials known to be hazardous to humans involved in either the design or its manufacturing?
☐	X	16. Could the system generate high levels (>90 dBA) of noise?
☐	X	17. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, or cold/high temperatures, during normal use?
☐	X	18. Is it possible for the system to be used in an unsafe manner?
☐	X	19. For powered systems, is there an emergency stop button?
☐	X	20. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Sharp edges may exist	Edges would be sanded down or covered with soft cover reducing the danger of the hazard.	May 21, 2019	During Manufacturing
Pinch points will likely exist	Pinch Points would be contained within the seat base making hazardous exposure very unlikely	April 25, 2019	5/1/2019
Large forces would be produced by product	Large forces would be contained by slow velocity of seat. Additionally, the base will have mechanical stops preventing forces from escaping expected seat base boundaries.	April 9, 2019	4/20/2019
Pressing action will be produced by product	The base will have mechanical stops preventing forces from escaping expected seat base boundaries. Additionally, user will have control of the pressing and releasing action	April 9, 2019	4/20/2019

Appendix D: Ideation Results

Up n Down:

- Actuator / Electric Motor / Scissor lift
- Telescoping Actuator
- ~~Sp~~ Striped Actuator / (4) lead screw
- Cam
- Rotating Arms
- Gear track
- Elevator mechanism
- Verticle Sliders
- Forklift-esque mechanism
- Air brake
- Ramp
- 4 post life
- Garage Doors

Scamper — Ideation session 3 (21)

Substitutes
- can be used in other vehicles
- metal — sub frames? (a/wood) — Multiple tabs — more difficult
- hanging bucket seat?

Combine
- 2 dimensional actuator? — will look into further — combine controls into 1 switch — circuits
- objective is to ~~cts~~ seperate

Adapt
- Mechanism on outside of seat
- Other mounting problems
- more mounting options
- more axis — Computers or medical devices

M
- We are trying to minimize
- Ramp System — Different paint
- Arc system — Lube —

P
- Springs / Suspension system
- seat belt mounts
- cup holders — room for speaker?

E
- seat heater / cooler / ventilation
- Movie theater seats / Resturants
- Wheelchair / Powerchair / Executees
- Pilots

R
- Simplicity — Everywhere
  - Failure safety
  - Manufacturing
  - Switches
- Axis of motion / DOT legality

Brainwriting Activity — Spencer Kubik

Choose a Function of our project: electric seat base

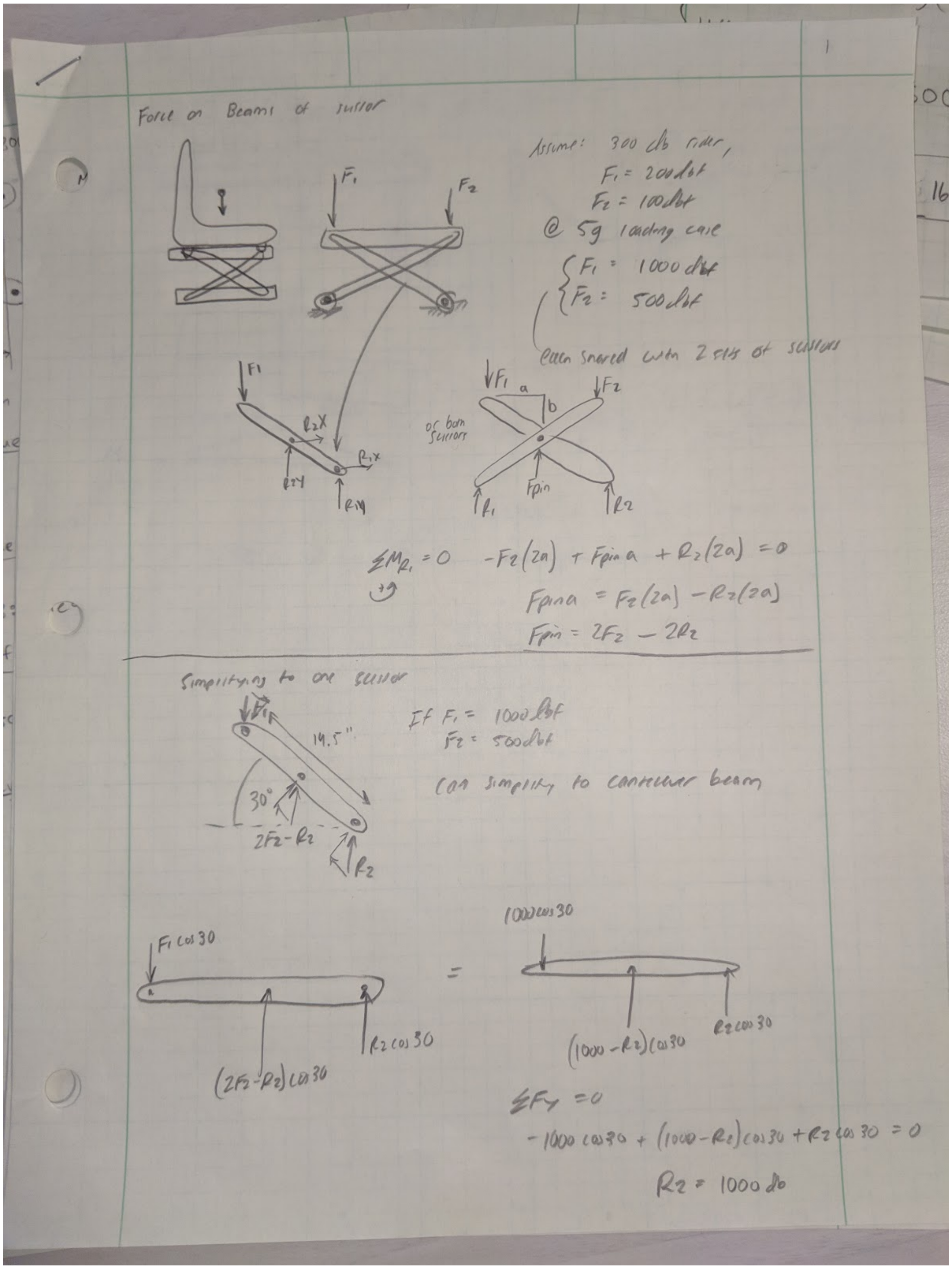
Be Safe ←

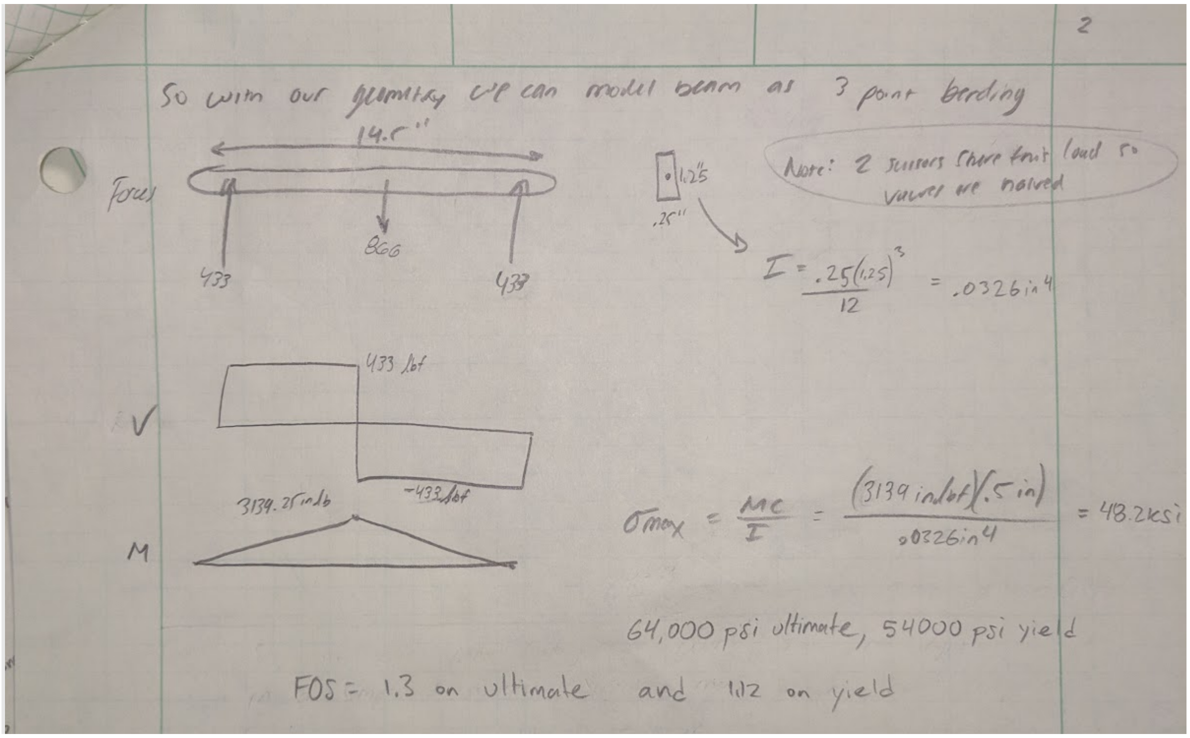
Now develop a list of ideas to do

Put rubber on corners
put pool noodles on corners
no sharp edges
chamfer / fillet everything
no pinch points
use finger guards
make it voice commanded so you don't even have to touch it
use fuses + breakers
failsafe system when motors are maxed out (ISH)
Drive on acceleration, power to not kill battery
make it so there are no sliding parts.
senses ~~fingers~~ skin on metal components and does not
allow motion

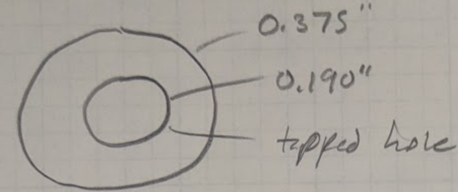
Protective springs
Use squishy material for seat
Preventative measures to limit seat from sliding off mounts
well lubricated
Battery/Cables waterproof, hidden from view of passengers

Appendix E: Design Analysis




2
So with our geometry we can model beam as 3 point bending
14.5''
Forces
866
433
433
.25''
1.25
Note: 2 scissors share fruit load so values are halved
I = .25(1.25)^3 / 12 = .0326 in^4
433 lbf
V
-433 lbf
3139.25 in lb
M
σmax = Mc / I = (3139 in lbf)(.5 in) / .0326 in^4 = 48.2 ksi
64,000 psi ultimate, 54000 psi yield
FOS = 1.3 on ultimate and 1.12 on yield

Tapped 3/8" | Shear Calculation



Assumption
- Worst case loading
- 1 pin takes 100%
- Heaviest rider
- 5 g's

$$\tau_{max} = \frac{4V}{3A}$$

$V = 1,500$ lbf

$$A = \frac{\pi(D_o - D_i)^2}{4}$$

$$= \frac{\pi(0.375 - 0.190)^2}{4}$$

$$= 0.026 \text{ in}^2$$

$$\tau_{max} = \frac{4(1,500 \text{ lbf})}{3(0.026 \text{ in}^2)}$$

$$= 76,923$$

$\tau_{max} \simeq 77$ ksi

$\tau_{allow, steel} = 85$ ksi

85 ksi > 77 ksi

F.S = 1.105

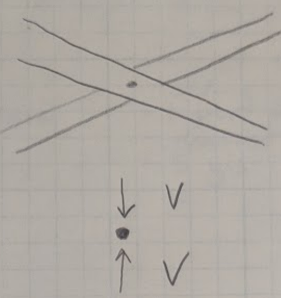
Pin Shear Calculation

$\tau_{max} = \frac{4V}{3A}$

$D = 3/8"$

$A = \frac{\pi D^2}{4}$

$= 0.110 \text{ in}^2$



Assuming

- Full weight of heaviest rider on 1 pin.

$V = 300 \text{ lbf} @ 5g\text{'s}$

$= 1{,}500 \text{ lbf}$

$\tau_{max} = \frac{4(1{,}500 \text{ lbf})}{3(0.110 \text{ in}^2)}$

$= 18{,}181.8 \text{ psi}$

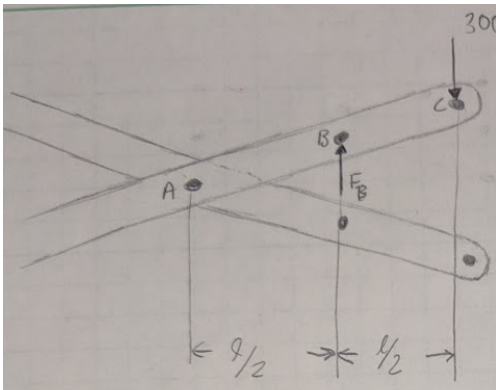
$\approx 18.2 \text{ ksi}$

$\tau_{max} \approx 18.2 \text{ ksi}$

$\tau_{allowable, steel} = 85 \text{ ksi}$ from aerospacespecificationmaterials.asm.matweb.com

$85 > 18.2$

$FoS = 4.67$



$M_A = 0$

$\frac{l}{2} F_B - l(300 lb) = 0$

$F_B = 600$ lbs

→ lifting 600 lbs with a 1/2"-10 lead screw requires
500 oz-in of torque on the nut

→ A planetary gear motor from servo city produces
305 oz-in of torque at 437 RPM

→ Assuming 3:1 reduction from motor to shaft:
915 oz-in of torque at ~146 RPM or 2.4 rev/sec

→ The lead screw moves 0.1" per rev and needs to move 1.5" total so it will take:

$$\left(1.5 \text{ in}\right)\left(\frac{1 \text{ rev}}{0.1'' \text{ in}}\right)\left(\frac{1 \text{ sec}}{2.4 \text{ rev}}\right) = 6.25 \text{ seconds from limits of travel}$$

For Horizontal motor

Static coefficient of friction: 0.1 – 0.2 (Dry steel - UHMW)

$F_f = \mu F_N$

$F_f = 0.2(300\,lbf)$

$F_f = 60\,lbf$

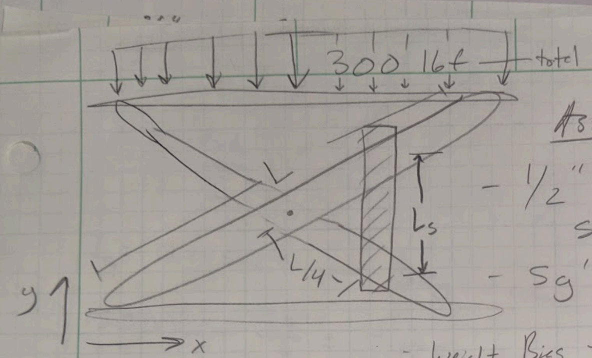
$$RPM = \left(\frac{1\,in}{1\,sec}\right)\left(\frac{1\,rev}{0.1\,in}\right)\left(\frac{60\,sec}{1\,min}\right) = 600\ RPM$$

→ The 600 RPM motor puts out 222 oz-in of torque

→ 222 oz-in of torque on the lead screw nut will result in ~300 lbsf of force

$$FoS = \frac{300\,lbf}{60\,lbf} = 5$$

Buckling Calculation



Assumptions

- 1/2" lead screw (mcmaster
- 5g's
- Weight Bias toward's higher x location (100%)
- L_s = 2 in

From McMaster Carr - 1018 Carbon Steel, 1/2"-10

σ_{UT} = 64,000psi

minimum diameter = 0.4419"

E = 29,000 ksi

Pinned-Pinned $P_{cr} = \frac{\pi^2 E I}{L_s^2}$

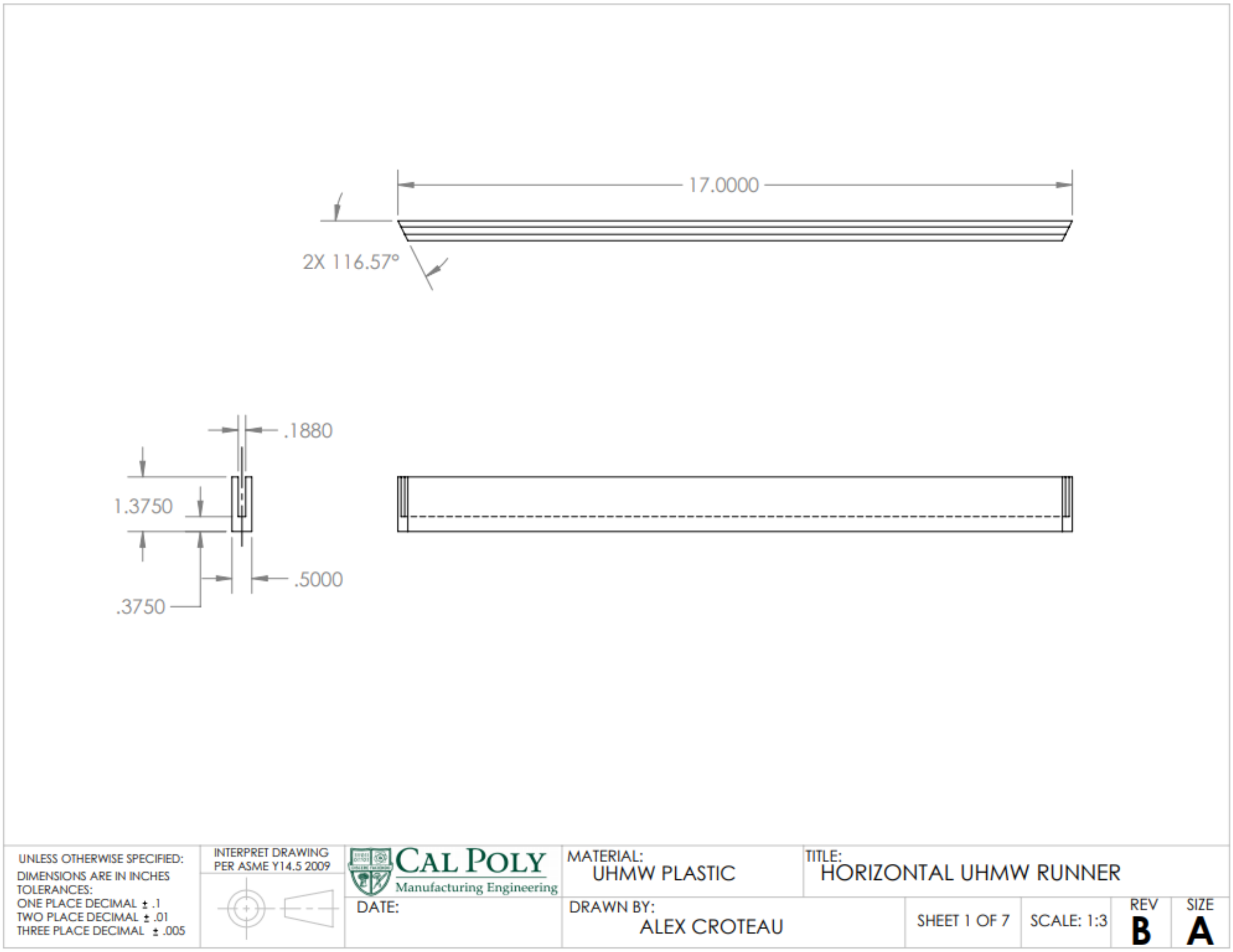
$$(2)(300\,lbf)(5\,g's) \overset{?}{<} \frac{\pi^2 (29{,}000{,}000\,psi)\left(\frac{\pi \left(\frac{0.4419}{2}\right)^4}{4}\right)}{(2\,in)^2}$$

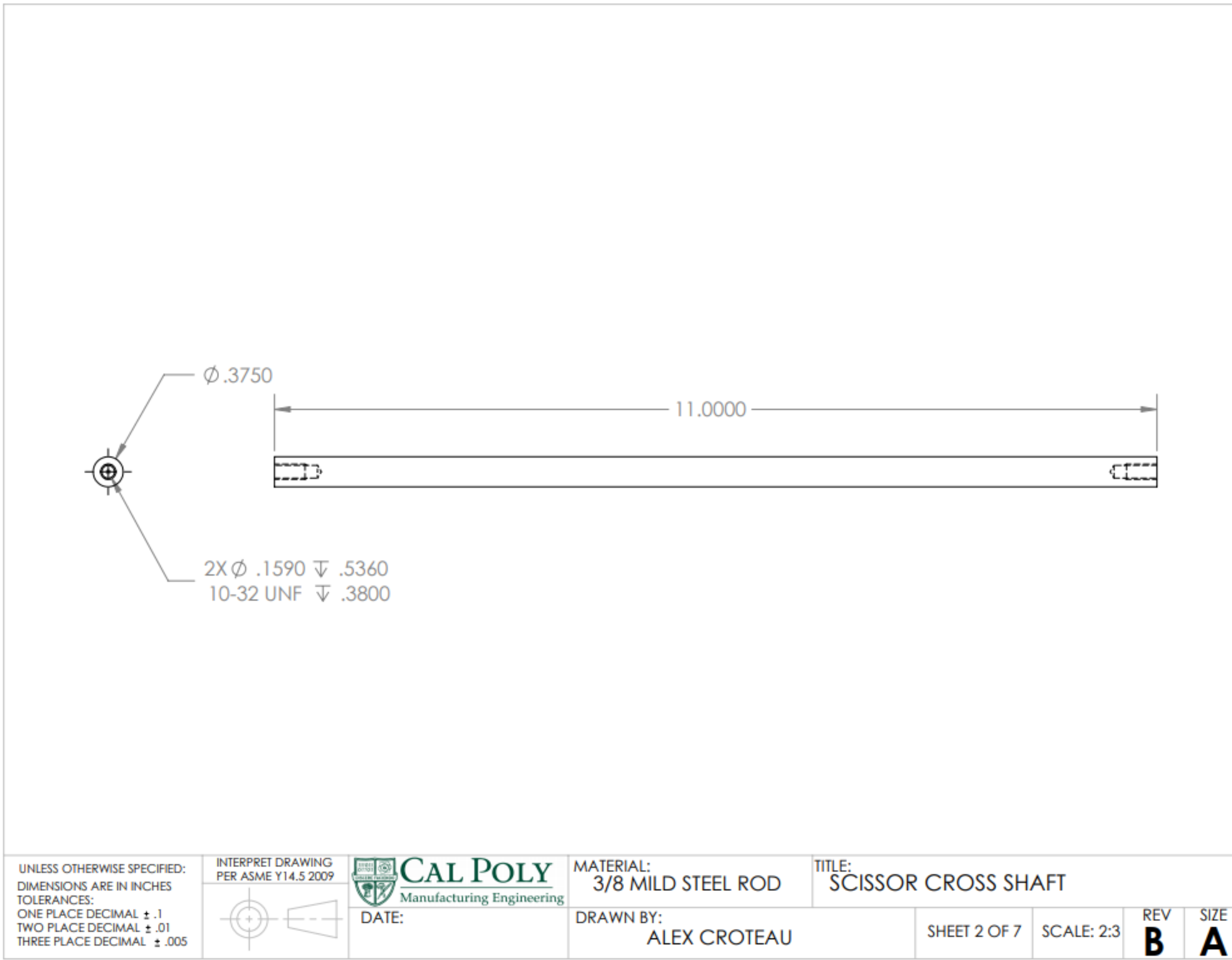
Half way between pin and end

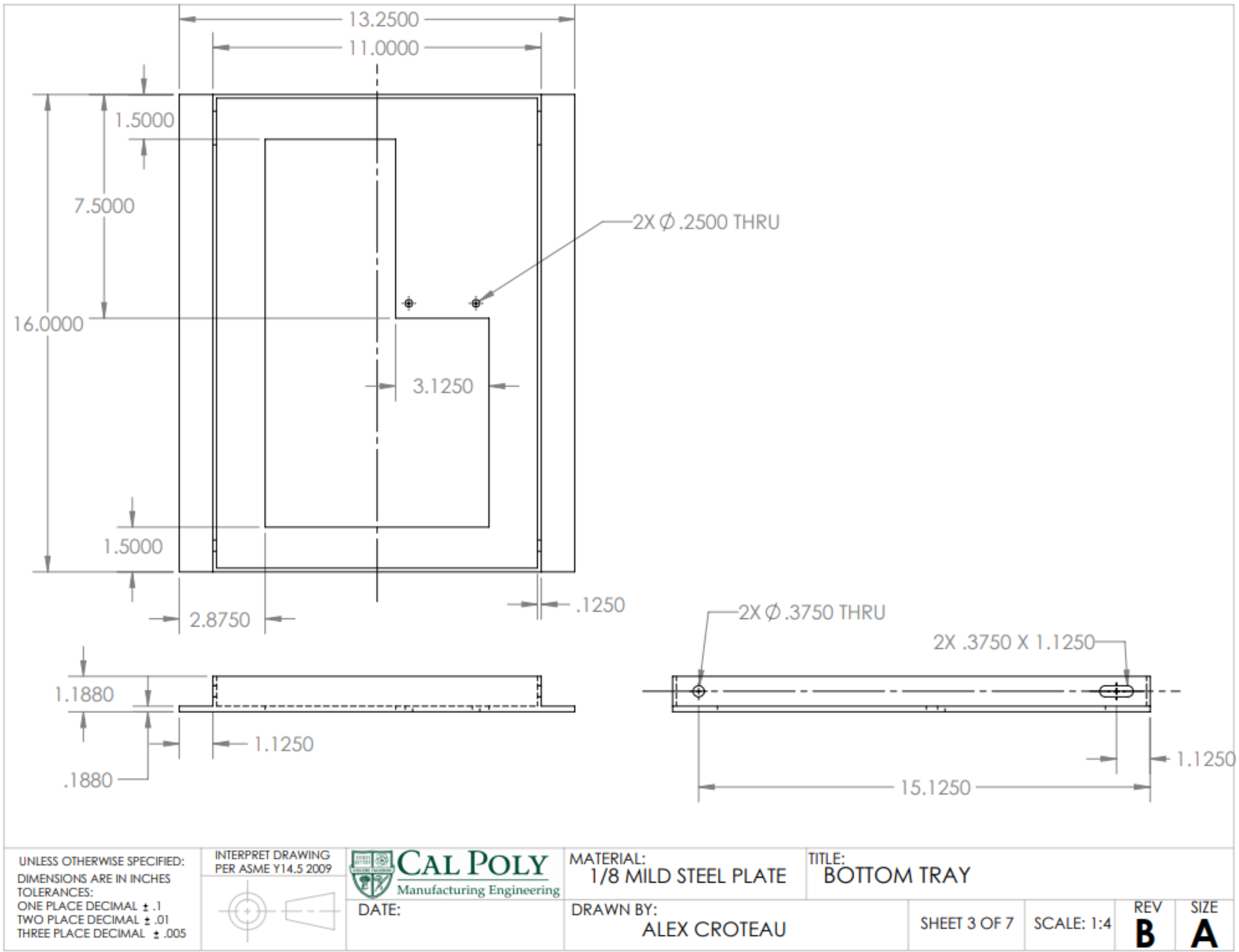
(2) 1500 lbf = 133,937.9 lbf

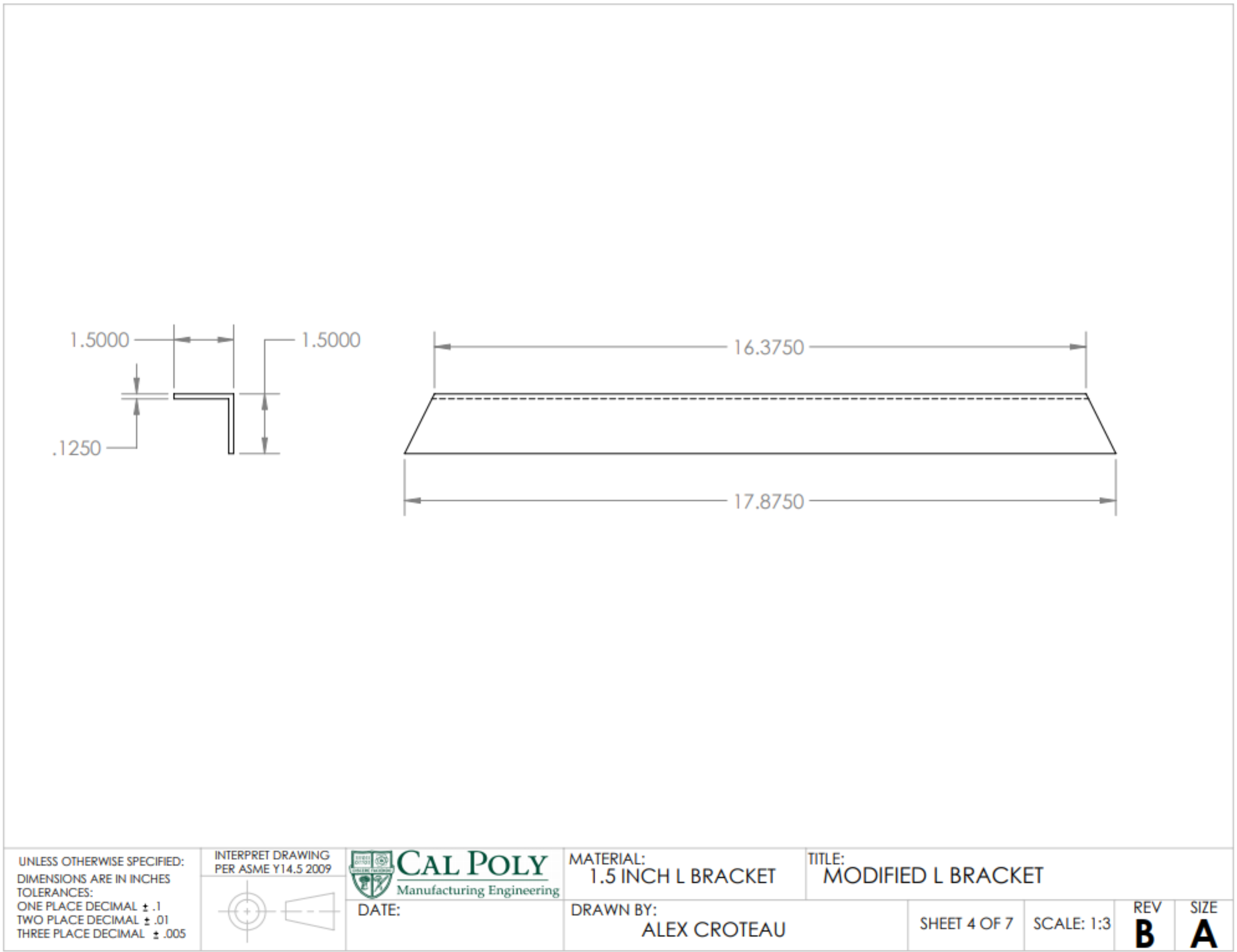
3,000 lbf << 133,937.9 lbf

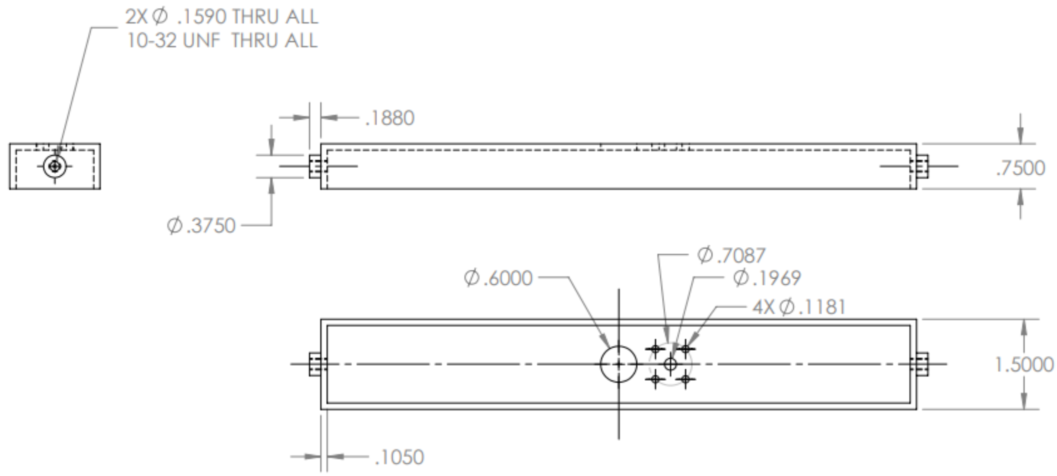
Appendix F: Drawing Package




Ø .3750
11.0000
2X Ø .1590 ↧ .5360
10-32 UNF ↧ .3800
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE PLACE DECIMAL ± .1
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ASME Y14.5 2009
CAL POLY
Manufacturing Engineering
DATE:
MATERIAL:
3/8 MILD STEEL ROD
TITLE:
SCISSOR CROSS SHAFT
DRAWN BY:
ALEX CROTEAU
SHEET 2 OF 7
SCALE: 2:3
REV
B
SIZE
A


13.2500
11.0000
1.5000
7.5000
16.0000
2X ∅ .2500 THRU
3.1250
1.5000
2.8750
.1250
1.1880
1.1250
.1880
2X ∅ .3750 THRU
2X .3750 X 1.1250
1.1250
15.1250
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE PLACE DECIMAL ± .1
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ASME Y14.5 2009
CAL POLY
Manufacturing Engineering
DATE:
MATERIAL:
1/8 MILD STEEL PLATE
TITLE:
BOTTOM TRAY
DRAWN BY:
ALEX CROTEAU
SHEET 3 OF 7
SCALE: 1:4
REV
B
SIZE
A


1.5000
1.5000
.1250
16.3750
17.8750
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE PLACE DECIMAL ± .1
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING PER ASME Y14.5 2009
CAL POLY
Manufacturing Engineering
DATE:
MATERIAL:
1.5 INCH L BRACKET
DRAWN BY:
ALEX CROTEAU
TITLE:
MODIFIED L BRACKET
SHEET 4 OF 7
SCALE: 1:3
REV
B
SIZE
A



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE PLACE DECIMAL ± .1
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

INTERPRET DRAWING PER ASME Y14.5 2009

CAL POLY Manufacturing Engineering

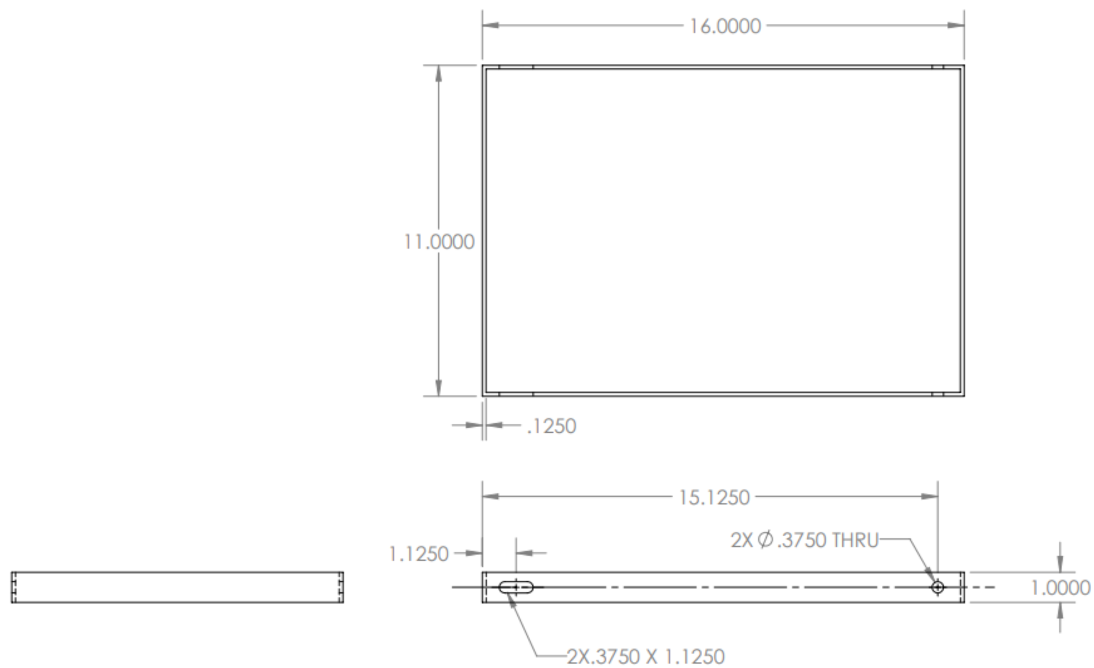
MATERIAL: 1/8 MILD STEEL PLATE

TITLE: PIVOTING GEARBOX CROSSMEMBER

DATE:

DRAWN BY: ALEX CROTEAU

SHEET 5 OF 7 | SCALE: 1:2 | REV B | SIZE A



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE PLACE DECIMAL ± .1
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

INTERPRET DRAWING PER ASME Y14.5 2009

CAL POLY
Manufacturing Engineering

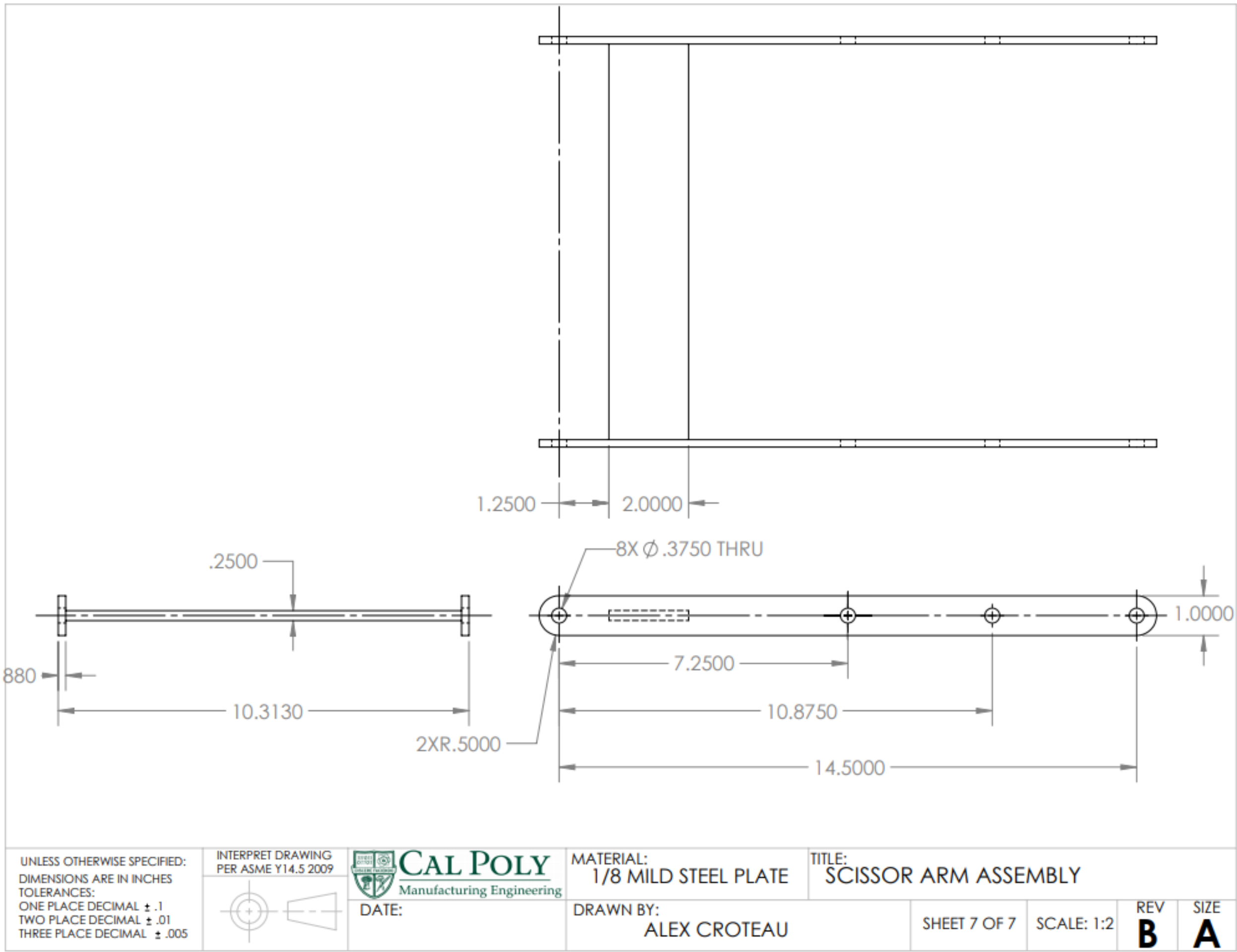
DATE:

MATERIAL: 1/8 MILD STEEL PLATE

TITLE: TOP TRAY

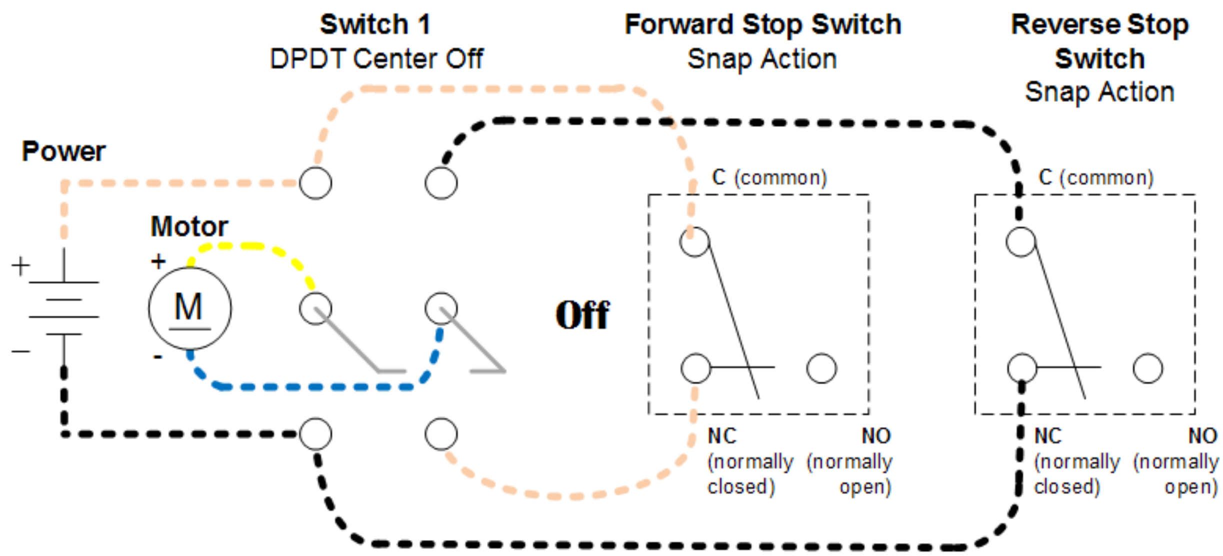
DRAWN BY: ALEX CROTEAU

SHEET 6 OF 7 | SCALE: 1:2 | REV B | SIZE A



1.2500
2.0000
.2500
8X ⌀ .3750 THRU
1.0000
880
7.2500
10.3130
10.8750
2XR.5000
14.5000
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ONE PLACE DECIMAL ± .1
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005
INTERPRET DRAWING
PER ASME Y14.5 2009
CAL POLY
Manufacturing Engineering
MATERIAL:
1/8 MILD STEEL PLATE
TITLE:
SCISSOR ARM ASSEMBLY
DATE:
DRAWN BY:
ALEX CROTEAU
SHEET 7 OF 7
SCALE: 1:2
REV
B
SIZE
A

Appendix G: Electrical Schematic



Appendix H: BOM

Indented Bill of Material (BOM)

Assembly Level	Part Number	Description	Vendor	Qty	Cost	Ttl Cost
		Lvl0 / Lvl1 / Lvl2 / Lvl3 / Lvl4				
0	10000	Final Assy	------	------	------	------
1	10100	Top Assembly	------	------	------	------
2	10110	Scissor	------	------	------	------
3	10111	125 inch Scissor arms	Metal Shop	4	20	80
3	10112	Scissor arms	Metal Shop	2		0
3	10113	Extended cross brace	Metal Shop	2		0
3	10114	.75" Rotating Shaft	McMaster	2	10.28	20.56
3	10115	.25" Shaft Pin	McMaster	2	10.28	20.56
2	10120	Top Scissor bracket		------	------	------
3	10121	Outside slider face	Metal Shop	2		0
3	10122	Front slider face	Metal Shop	2		0
2	10130	Bottom Scissor bracket		------	------	------
3	10131	Outside slider face	Metal Shop	2		0
3	10132	Front slider face	Metal Shop	2		0
2	10140	Horizontal Gear Box		------	------	------
3	10141	Housing	Metal Shop	1	20	20
3	10142	12V Motor	Andy Mark	1	35	35
3	10143	ACME Round Nut	McMaster	1	2.68	2.68
3	10144	Load Gear	McMaster	1		0
3	10145	Lead Screw	McMaster	1	5.93	5.93
2	10150	Verticle Gear Box		------	------	------
3	10151	Housing	Metal Shop	1		0
3	10152	12V Motor	Andy Mark	1	35	35
3	10153	ACME Round Nut	McMaster	1	2.68	2.68
3	10154	Load Gear	McMaster	1		0
3	10155	Lead Screw	McMaster	1	5.93	5.93
1	10200	Bottom Assembly		------	------	------
2	10210	Sliding Base		------	------	------
3	10211	Bottom Face	Metal Shop	1		0
3	10212	Floor Mount	Metal Shop	1		0
3	10213	L-brackets	Metal Shop	2		0
1	10300	Electrical		------	------	------
		Switches	Amazon	2	3.98	7.96
		Limit Switches	Amazon	4	2.01	8.04
	Total Parts			40		244.34

Appendix I: Owner's Manual

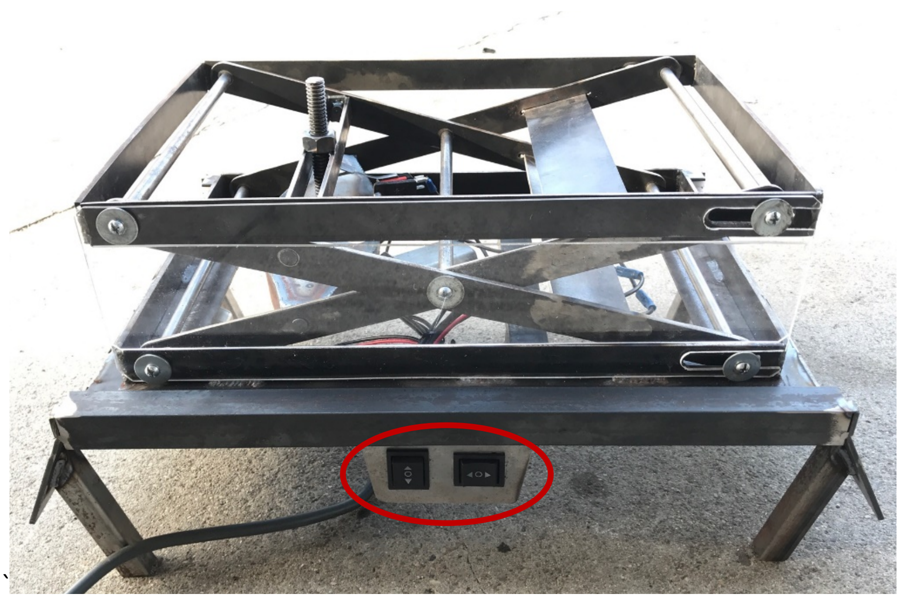
Please ensure safe practices are being followed during installation and operation of the electric seat base. The product has been designed to be as safe as possible to use, but hazards still exist. By reading through this owner's manual, we hope to mitigate any risks associated with installing and using this product.

Installation:

1. Remove existing seat in vehicle from seat mount
    a. CAUTION: Car seats can be heavy and require reaching into the vehicle to lift. Ensure hands are clear of possible pinch points after removing all hardware
2. Remove existing seat base from floorboard
3. Clean area and prepare new seat base for install
4. Install seat base adapter to your specific vehicle. This will allow for the product to be installed in a variety of applications.
5. Install seat base onto adapter
    a. Place seat base onto adapter
        i. CAUTION: Seat base weighs 25 lbs and needs to be reached into the vehicle in order to install. Use care when lifting and wear proper footwear.
    b. Install 4 mounting bolts and washers to secure seat base onto seat base adapter
        i. CAUTION: The seat base would be loose during this process. The bolt locations are designed to be away from pinch hazards, but care should still be used while the base is loose
6. Install seat onto seat base
    a. CAUTION: Car seats can be heavy and require reaching into the vehicle to install. Ensure hands are clear of possible pinch points before installing all hardware
7. Wire seat base into 12v system of vehicle. The seat base can be wired to 12v directly or to 12v accessory power, but we do not recommend wiring to ignition power.
    a. The electric seat base has a fuse built into the seat base itself, so use the included wiring to connect to a reliable 12v source and ground.
        i. CAUTION: Electrical hazards exist when doing vehicle wiring. Ensure negative battery cable is disconnected so the vehicle has no power in case of short. If a short does occur, the fuse will blow in the seat base and will need to be replaced to use the product.

Use:

1. The electric seat base comes set up from the manufacturer to travel 6” fore/aft and 3” up/down. To trigger this motion, use the switches on outside of the seat base to provide current to the motors.
    a. CAUTION: The switches are located near moving components of the seat base. Shielding has been added for the user’s protection. Do not modify or remove this shielding.
2. When the seat reaches the end of its travel, the motion will stop. At this point, no current will be sent to the motor unless the switch is pressed in the reverse direction.
    a. CAUTION: In case of limit switch failure, the motor will push the seat base to the mechanical stop. This will cause overcurrent to occur and the fuse to blow. The fuse and limit switch will need to be replaced to move the seat base. Call the manufacturer for help in this situation.



Thank you for purchasing your new electric seat base! We hope you enjoy the use of our product for years to come.

Appendix J: Links To Purchased Parts

Motors:

https://www.andymark.com/products/snow-blower-motor-with-hex-shaft?via=Z2lkOi8vYW5keW1hcmsvV29ya2FyZWE6OkNhdGFsb2c6OkNhdGVnb3J5LzViYjYxOGI0YmM2ZjZkNmRlMWU2OWZkZg

Lead SScrew:

https://www.mcmaster.com/98935a911

Lead Screw Nut:

https://www.mcmaster.com/94815a045

Cross Bar Dowel

https://www.mcmaster.com/8920k115

Steel Plate

https://www.mcmaster.com/1388k471

Appendix K: Risk Assessment

designsafe Report

Application:	Off Road Seat Base	Analyst Name(s):	Spencer Kubik, Alex Croteau, Brennan Slater
Description:	Senior Project - Spencer Kubik, Alex Croteau, Brennan Slater	Company:	
Product Identifier:		Facility Location:	
Assessment Type:	Detailed		
Limits:			
Sources:			
Risk Scoring System:	ANSI B11.0 (TR3) Two Factor		

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-1	Operator (Customer) normal operation	mechanical : crushing sticking finger in lift	Moderate Unlikely	Low	fixed enclosures / barriers /Not Applicable	Moderate Unlikely	Low	
1-1-2	Operator (Customer) normal operation	mechanical : pinch point sticking finger in lift	Moderate Unlikely	Low	fixed enclosures / barriers /Not Applicable	Moderate Unlikely	Low	
1-1-3	Operator (Customer) normal operation	electrical / electronic : energized equipment / live parts Actuating against mechanical block	Minor Likely	Low	sound wiring, electrical safety	Minor Unlikely	Negligible	
1-2-1	Operator (Customer) basic trouble shooting / problem solving	mechanical : crushing sticking finger in lift	Moderate Unlikely	Low	fixed enclosures / barriers	Moderate Unlikely	Low	
1-2-2	Operator (Customer) basic trouble shooting / problem solving	mechanical : pinch point sticking finger in lift	Moderate Unlikely	Low	fixed enclosures / barriers	Moderate Unlikely	Low	
1-2-3	Operator (Customer) basic trouble shooting / problem solving	electrical / electronic : energized equipment / live parts Actuating against mechanical block	Minor Likely	Low	sound wiring, electrical safety	Minor Unlikely	Negligible	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-2-4	Operator (Customer) basic trouble shooting / problem solving	electrical / electronic : improper wiring Does not stop with limit switch	Serious Unlikely	Medium	ensure proper product testing eliminates faulty limit circuit	Serious Remote	Low	
1-2-5	Operator (Customer) basic trouble shooting / problem solving	electrical / electronic : overvoltage /overcurrent Motor draws more current than specified	Minor Unlikely	Negligible	run all elecrical with proper grounds, breakers, and sufficient wire size	Minor Remote	Negligible	
1-2-6	Operator (Customer) basic trouble shooting / problem solving	ergonomics / human factors : lifting / bending / twisting Overloading	Serious Likely	High	add safe lifting points to design to allow customer to move product around	Serious Unlikely	Medium	
1-3-1	Operator (Customer) misuse	mechanical : crushing sticking finger in lift	Moderate Unlikely	Low	fixed enclosures / barriers	Moderate Unlikely	Low	
1-3-2	Operator (Customer) misuse	mechanical : cutting / severing sticking finger in lift	Moderate Unlikely	Low	fixed enclosures / barriers	Moderate Unlikely	Low	
1-3-3	Operator (Customer) misuse	mechanical : pinch point sticking finger in lift	Moderate Unlikely	Low	fixed enclosures / barriers	Moderate Unlikely	Low	
1-3-4	Operator (Customer) misuse	electrical / electronic : energized equipment / live parts Actuating against mechanical block	Moderate Likely	Medium	sound wiring, electrical safety	Moderate Unlikely	Low	
1-3-5	Operator (Customer) misuse	electrical / electronic : improper wiring poor connections	Moderate Unlikely	Low	sound wiring, electrical safety	Moderate Unlikely	Low	
1-3-6	Operator (Customer) misuse	electrical / electronic : water / wet locations water in floorboards	Serious Unlikely	Medium	sound wiring, electrical safety	Serious Unlikely	Medium	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-3-7	Operator (Customer) misuse	electrical / electronic : overvoltage /overcurrent alternator voltage spike	Moderate Remote	Negligible	run all elecrical with proper grounds, breakers, and sufficient wire size	Moderate Remote	Negligible	
1-3-8	Operator (Customer) misuse	electrical / electronic : power supply interruption Dead battery	Minor Likely	Low	none	Minor Remote	Negligible	
1-3-9	Operator (Customer) misuse	ergonomics / human factors : lifting / bending / twisting Overloading	Serious Unlikely	Medium	add safe lifting points to design to allow customer to move product around	Serious Unlikely	Medium	
2-1-1	Fabricator (Company) Assembly	mechanical : cutting / severing Sharp sheet metal parts	Moderate Likely	Medium	add regulations for workers before product is finished	Moderate Unlikely	Low	
2-1-2	Fabricator (Company) Assembly	mechanical : pinch point sticking finger in lift	Moderate Unlikely	Low	fixed enclosures / barriers	Moderate Unlikely	Low	
2-1-3	Fabricator (Company) Assembly	electrical / electronic : energized equipment / live parts Testing movement	Minor Unlikely	Negligible	sound wiring, electrical safety	Minor Unlikely	Negligible	
2-1-4	Fabricator (Company) Assembly	ergonomics / human factors : lifting / bending / twisting Lifting heavy parts	Moderate Unlikely	Low	add safe lifting points to design to allow user to move product around	Moderate Unlikely	Low	
2-1-5	Fabricator (Company) Assembly	material handling : stacking / storing Parts falling	Serious Unlikely	Medium	dont stack heavy parts high, will be less of a risk depending on lean production	Serious Unlikely	Medium	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-2-1	Fabricator (Company) trouble-shooting / problem solving	electrical / electronic : energized equipment / live parts Parts moving during testing	Serious Likely	High	add testing regulations for safe testing	Serious Unlikely	Medium	
2-2-2	Fabricator (Company) trouble-shooting / problem solving	electrical / electronic : improper wiring Test wiring incorrect	Moderate Remote	Negligible	run all elecrical with proper grounds, breakers, and sufficient wire size	Moderate Remote	Negligible	
2-2-3	Fabricator (Company) trouble-shooting / problem solving	electrical / electronic : unexpected start up / motion Test switch faulty	Moderate Unlikely	Low	run all elecrical with proper grounds, breakers, and sufficient wire size	Moderate Remote	Negligible	
2-2-4	Fabricator (Company) trouble-shooting / problem solving	electrical / electronic : overvoltage /overcurrent Test source voltage surge	Moderate Unlikely	Low	run all elecrical with proper grounds, breakers, and sufficient wire size	Moderate Remote	Negligible	
2-2-5	Fabricator (Company) trouble-shooting / problem solving	ergonomics / human factors : lifting / bending / twisting Lifting heavy parts	Moderate Unlikely	Low	add safe lifting points to design to allow user to move product around	Moderate Unlikely	Low	
2-3-1	Fabricator (Company) start machine	mechanical : crushing sticking finger in lift	Moderate Unlikely	Low	add regulations for workers before product is finished	Moderate Unlikely	Low	
2-3-2	Fabricator (Company) start machine	mechanical : pinch point sticking finger in lift	Moderate Unlikely	Low	fixed enclosures / barriers	Moderate Unlikely	Low	
2-3-3	Fabricator (Company) start machine	electrical / electronic : energized equipment / live parts Faulty test switch	Serious Unlikely	Medium	run all elecrical with proper grounds, breakers, and sufficient wire size	Serious Unlikely	Medium	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-3-4	Fabricator (Company) start machine	electrical / electronic : improper wiring Test wiring incorrect	Moderate Remote	Negligible	run all elecrical with proper grounds, breakers, and sufficient wire size	Moderate Unlikely	Low	
2-3-5	Fabricator (Company) start machine	electrical / electronic : unexpected start up / motion Test wiring/switch faulty	Serious Unlikely	Medium	run all elecrical with proper grounds, breakers, and sufficient wire size	Serious Unlikely	Medium	
2-3-6	Fabricator (Company) start machine	electrical / electronic : overvoltage /overcurrent Test supply voltage surge	Moderate Unlikely	Low	run all elecrical with proper grounds, breakers, and sufficient wire size	Moderate Unlikely	Low	
2-4-1	Fabricator (Company) Fabrication	mechanical : cutting / severing sticking finger in lift	Moderate Unlikely	Low	fixed enclosures / barriers	Moderate Unlikely	Low	
2-4-2	Fabricator (Company) Fabrication	mechanical : pinch point Assembling scissor components	Moderate Likely	Medium	fixed enclosures / barriers	Moderate Unlikely	Low	
2-4-3	Fabricator (Company) Fabrication	ergonomics / human factors : posture Bad assembly height	Moderate Unlikely	Low	ensure manufacturing conditions are ergonomically safe	Moderate Unlikely	Low	
2-4-4	Fabricator (Company) Fabrication	ergonomics / human factors : repetition Assembly line style manufacturing	Minor Likely	Low	ensure manufacturing conditions are ergonomically safe	Minor Unlikely	Negligible	
2-4-5	Fabricator (Company) Fabrication	ergonomics / human factors : lifting / bending / twisting lifting heavy parts	Moderate Unlikely	Low	add safe lifting points to design to allow user to move product around	Moderate Unlikely	Low	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-4-6	Fabricator (Company) Fabrication	wastes (Lean) : correction / defective parts poor laser quality control	Minor Unlikely	Negligible	pull samples often to measuere and ensure accuracy	Minor Unlikely	Negligible	
2-4-7	Fabricator (Company) Fabrication	wastes (Lean) : overproduction poor marketing	Moderate Unlikely	Low	market better	Moderate Likely	Medium	
2-4-8	Fabricator (Company) Fabrication	wastes (Lean) : moving material / transport moving steel to production	Moderate Likely	Medium	ensure proper forklift and lifting safety is in place	Moderate Unlikely	Low	
2-4-9	Fabricator (Company) Fabrication	wastes (Lean) : inventory too much/ little in stock parts	Moderate Likely	Medium	track stock until stability is achieved with orders	Moderate Likely	Medium	
3-1-1	Installer (Customer or Reseller) Install	mechanical : crushing sticking finger in lift	Moderate Unlikely	Low	fixed enclosures / barriers	Moderate Unlikely	Low	
3-1-2	Installer (Customer or Reseller) Install	mechanical : pinch point sticking finger in lift	Moderate Unlikely	Low	fixed enclosures / barriers	Moderate Unlikely	Low	
3-1-3	Installer (Customer or Reseller) Install	electrical / electronic : energized equipment / live parts Parts moving during testing	Serious Likely	High	run all elecrical with proper grounds, breakers, and sufficient wire size	Serious Unlikely	Medium	
3-1-4	Installer (Customer or Reseller) Install	electrical / electronic : lack of grounding (earthing or neutral) Test wiring incorrect	Moderate Remote	Negligible	run all elecrical with proper grounds, breakers, and sufficient wire size	Moderate Unlikely	Low	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
3-1-5	Installer (Customer or Reseller) Install	electrical / electronic : shorts / arcing / sparking Test switch faulty	Moderate Unlikely	Low	run all elecrical with proper grounds, breakers, and sufficient wire size	Moderate Unlikely	Low	
3-1-6	Installer (Customer or Reseller) Install	electrical / electronic : improper wiring Test source voltage surge	Moderate Unlikely	Low	run all elecrical with proper grounds, breakers, and sufficient wire size	Moderate Unlikely	Low	
3-1-7	Installer (Customer or Reseller) Install	electrical / electronic : water / wet locations water where electrical resides	Serious Unlikely	Medium	run all elecrical with proper grounds, breakers, and sufficient wire size	Serious Unlikely	Medium	
3-1-8	Installer (Customer or Reseller) Install	electrical / electronic : overvoltage /overcurrent lack of surge protection	Moderate Unlikely	Low	run all elecrical with proper grounds, breakers, and sufficient wire size	Moderate Unlikely	Low	
3-1-9	Installer (Customer or Reseller) Install	slips / trips / falls : falling material / object dropping product during install	Moderate Unlikely	Low	add safe lifting points to design to allow customer to move product around	Moderate Unlikely	Low	
3-1-10	Installer (Customer or Reseller) Install	ergonomics / human factors : lifting / bending / twisting lifting heavy product	Moderate Likely	Medium	add safe lifting points to design to allow customer to move product around	Moderate Unlikely	Low	
3-1-11	Installer (Customer or Reseller) Install	material handling : instability installing instable product	Moderate Likely	Medium	add safe lifting points to design to allow customer to move product around	Moderate Unlikely	Low	

Appendix L: FMEA

System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	Priority	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Severity	Occurence	Criticality
Vertical Adjustment / Motion	motion stops due to component failure, not smooth travel	no motion occurs, excessive deflection occurs, user is dissatisfied	10	Mechanical blocks, motor is underpowered, lurching, poor tolerances/finish	effective manufacturing , tight tolenerancing, double check design calculations	1	Real world testing, 3D modeling simulations	1	10						
Vertical Adjustment / Mechanical Stop	motor not stopped mechanically	potential for untested safety hazards	9	limit switch is broken, no mechanical stop, weak materials, over powering motor	size parts correctly, use robust mechanical stops	3	actuate to ends of travel	3	81	strong mechanical stop, limit switch supports no load	Designers, by CDR	mechanical stop added, limit switches set	5	4	2
Vertical Adjustment / Travel Range	doesn't meet travel spec	user is unsatisfied	6	space constrains, poor design, failure on dimensioning	double check dimensioning	2	actuate to ends of travel and measure	2	24						
Horizontal Adjustment / Actuator	not triggered by switch inputs	no motion occurs	8	Electrical Failure, power transmission failure, wiring failure	use robust connector, size motors correctly	3	activate switch	1	24						
Horizontal Adjustment / Motion	motion stops due to component failure, not smooth travel	no motion occus, excessive deflection occurs, user is dissatisfied	10	Mechanical blocks, motor is underpowered, lurching, poor tolerances/finish	effective manufacturing , tight tolenerancing, double check design calculations	1	Real world testing, 3D modeling simulations	1	10						
Horizontal Adjustment / Mechanical Stop	motor not stopped mechanically	potential for untested safety hazards	9	limit switch is broken, no mechanical stop, weak materials, over powering motor	size parts correctly, use robust mechanical stops	3	actuate to ends of travel	3	81	high quality switches, oversize wiring, high quality breakers, strong mechanical stop, limit switch supports no load	Designers, by CDR	mechanical stop added, limit switches set	5	4	2
Horizontal Adjustment Travel Range	doesn't meet travel spec	user is unsatisfied	6	space constrains, poor design, failure on dimensioning	double check dimensioning	2	actuate to ends of travel and measure	2	24						
Safety / Pinch points	exposed, points exist	user is injured	7	lack of shielding, poor design	add a sheild	5	look for shield	2	70	extensive shielding, design for pinch points to be contained within base frame	Designers, by CDR	shielding added, only able to add to sides however	6	5	5
Safety / sharp edges	exist, exposed to rider	user is injured	6	lack of shielding, poor manufacturing	add a sheild, make sure to de-burr all edges	4	look for shield, finger gauge	3	72	add protective material to edges, insure sufficient de burring during manufacturing	Technitions, during manufacturing	all parts deburred at all steps of manufacturing	2	1	1
Safety / electrical safety	electrical short, breakers don't trip, motors overheat	user is injured, product failure	7	incorrectly sized fuses/wires, switch malfunction	size fuses and breakers correctly	2	Electrical testing, protoype testing	4	56	high quality switches, oversize wiring, high quality breakers, limit switch supports no load	Designers, by CDR	fused power supply used, plan for inline fuses created for future prototypes	4	3	3
Safety / deflection	doesn't meet deflection spec	seat feels unstable, user may get injured	6	poor tolerances on lift components, greater force inputs then expected	add factor of safety, careful machining	6	prototype testing	3	##	Add factor of safety, tight tolerances on sliders and rails, quality gear boxes, enough gear reduction to prevent back drive	Designers, by CDR	care taken during manufacturing	5	4	4
Space Efficiency / Modularity	doesn't fit / bulky	user is unsatisfied	8	bolt hole location discrepency, poor design, over emphasis on safety	double check math, test prototypes throughout manufacturing process	2	mount and visually inspect	1	16						
Space Efficiency / Mount adaptiblility	incompatible with floor boards/bucket seat tabs	user is unsatisfied	7	poor design	double check math, test prototypes throughout manufacturing process	3	test a plethora of vehicles	1	21						

Appendix M: DVP&R

Senior Project DVP&R

Date: 11/20/19	Team: 2 Axis Electric Off Road Seat Bas	Sponsor: Professor Thomas Mackin	Description of System: 2 axis motion front/back, up/down	DVP&R Engineer: Spencer Kubik

TEST PLAN									TEST REPORT			
Item No	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES TESTED		TIMING		TEST RESULTS			NOTES
					Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	Horizontal Speed	less than 7 seconds end to end	Alex Croteau	FP	1	sys	11/20/2019	11/20/2019	42.4 sec	0	1	Same motor used for horizontal
2	Horizontal Distance	at least 6 inches	Spencer Kubik	FP	1	sys	11/20/2019	11/20/2019	6.25 in	1	0	
3	Vertical Speed	less than 7 seconds end to end	Alex Croteau	FP	1	sys	11/20/2019	11/20/2019	7.5 sec	0	1	
4	Vertical Distance	at least 3 inches	Spencer Kubik	FP	1	sys	11/20/2019	11/20/2019	2.3 in	0	1	limit switches set for safety
5	300 lbf static deflection	less than 2 inches	Spencer Kubik	FP	1	sys	11/20/2019	11/20/2019	4.75 in	0	1	