G3 Engineering

Configurable Seat Track Latching Mechanism
Final Design Review Documentation

F72 System and Demo	F73 Track and Latch	F74 Seat Articulation
Daniel Turn	Nicholas Holman	Anil Singh
Dturn@calpoly.edu	npholman@calpoly.edu	asingh87@calpoly.edu
Audrey Trejo	Alex Kuznik	Richard Hall
Atrejo02@calpoly.edu	akuznik@calpoly.edu	Rhall09@calpoly.edu
Phoebe Zeiss	Kai Quizon	Emily Sun
Pgzeiss@calpoly.edu	kquizon@calpoly.edu	Eesun@calpoly.edu
Steven Kam	Jacob Winkler	
Shkam@calpoly.edu	jcwinkle@calpoly.edu	

CP.G3Engineering@gmail.com

Team F72, F73, F74

Prepared For:

Dr. Joseph Mello and Ritch Hollingsworth

Mechanical Engineering Department

California Polytechnic State University, San Luis Obispo

2020-2021

Contents

Figures

Tables

1.0 Executive Summary

High occupancy automobile shuttle services require a seating system capable of rapid reconfiguration of the seating layout in their vehicles. This will allow different distributions of cargo and passengers to be easily accommodated by a single automobile. We propose to expand upon an existing system developed by sponsors Dr. Joseph Mello and Ritch Hollingsworth. The project is divided into three teams: system and demo, track and latch, and seat articulation. The system and demo team is responsible for the development of the overall seating system with an emphasis on ergonomic and aesthetic concerns of the seat itself and an end-goal of delivering a manufacturable and marketable product. The track and latch team is dedicated to developing and refining a track and latch system that couples the seats to the automobile body. The seat articulation team is responsible for designing an elegant seat articulation system that allows for the seat to fold into its nested configuration and unfold into a deployed configuration. This document contains the research, technical formulation, concept design, and project management planning approved by Dr. Mello and Mr. Hollingsworth. While many existing products accomplish the basic function of sliding a seat without a configurable seating system, existing products fail to do this in an ergonomic, rapid, repeatable motion. After a considerable amount of ideation and design, a proposed design a conceptual design was developed. Further development has resulted in a final design along with plans to construct verification prototypes. The design is presented in this report both as a complete product and as three independent, but compatible components developed by the three design teams.

2.0 Introduction

High occupancy automobile shuttle services currently employ traditional passenger seats rigidly bolted to the vehicle body. These seats are not configurable and force transit services to either limit the services provided with one vehicle or employ sometimes unsafe practices to transfer passengers and gear by inappropriately loading cargo in egress aisles or passengers in unsafe configurations.

Dr. Joseph Mello, Cal Poly Mechanical Engineering, and Ritch Hollingsworth, LTK Services, have pioneered a rapidly adjustable seating system to allow for multiple seating configurations in one vehicle. This patented system features sliding individual seats that can be rapidly moved between multiple places in the vehicle. The patent also features articulated seats that can be folded into a compact form and nested with each other, allowing for a “stowed” position that maximizes storage space. Dr. Mello and Mr. Hollingsworth are seeking a refinement of the system, latch and rail mechanism, and articulation mechanism in order to prepare to take the product to market.

The purpose of this project is to develop a safe, ergonomic, reliable seating system that allows the seats to slide to multiple configurations easily and efficiently within an automobile. The latch and seat movement will both be operated by the ride operator/driver and thereby require easily understandable user interfaces. Furthermore, it is desired to implement the design as universally as possible for the transit van industry, so the system must adhere to a variety of automobile standards. The design improves on existing products by allowing for rapid changes in seating configurations which allows operators to adapt a single vehicle to various need cases.

Three different teams are involved with the commercialization of this product. The system level team will focus on the development of the design as a whole from a marketability and manufacturability standpoint. The track and latch team will focus on the track and locking mechanism that allows for seats to slide and lock into place. The seat articulation team will focus on how the seat moves from stowed to deployed configurations, and how they nest together.

The system team is composed of three fourth year mechanical engineering students, Daniel Turn, Audrey Trejo, and Phoebe Zeiss, and a fifth year, Steven Kam. The track and latch team consists of two fourth year mechanical engineers, Kai Quizon and Jacob Winkler, and two fifth year mechanical engineers, Alex Kuznik and Nicholas Holman. The seat articulation team has three fourth year mechanical engineering students, Anil Singh, Emily Sun, and Richard Hall. All members of this project hail from California Polytechnic State University in San Luis Obispo.

3.0 Background

There have been multiple projects done in reference to the sponsor's desired project previously that we can draw upon when moving forward. The first team (2018) created a unique seat folding method that could be integrated into a van/shuttle system. This team was granted the 2020 patent that we will be expanding upon in our senior project. The second team (2019) developed a working prototype for our sponsor, while documenting the process. To supplement their work, a master's thesis was written to simulate the loading conditions outlined by the safety standards. These conditions were analyzed via finite element analysis. We will draw on this FEA analysis to support our design, as well as the relevant standards it adheres to.

Although the prior work done on the adjustable seat system will undoubtedly aid in our further development of this product, we will not confine our scope to rely solely on the ideas of the previous products. The design will surely evolve, and the ability to deviate from the prior works will culminate in an effective final design. Additionally, we will focus on refining the adjustable seating system to a final product that is market ready. To do this, ample research was done into potential customers and current, potentially competing products.

3.1 Customer Research

To gain insight on what customers expect from our design, we interviewed our project sponsors and a few companies that use vans and shuttles to transport people and cargo. The people and companies we interviewed include Ride-On SLO, SLO safe ride, Margarita Adventures, DZYNE Technologies, Dr. Mello, Mr. Hollingsworth, and Ted Claghorn. Below is a summarized list of wants and needs based on these interviews:

System and Demo Wants and Needs:	**Track and Latch Wants and Needs:**	**Seat Articulation Wants and Needs:**
• Ergonomic Design	• Be able to switch configurations easily	• Articulation is smooth and free of binding
• Human Centered Design	• Operation requires one person	• Seat collapse is easy and quick
• Seat must be comfortable to sit in for four hours	• Smooth switching between configurations	• Operable under environmental conditions
• Easy accessibility	• The latch system has a maximum mass of 8 lb_f per seat	• No pinch points
• Adequate Leg room	• The system life should be longer than van service life	• Lightweight seating system

System and Demo Wants and Needs:	Track and Latch Wants and Needs:	Seat Articulation Wants and Needs:
• Seat must accommodate 5-percentile female to 95-percentile male	• Material should not overheat when left hot conditions	• The system should not need to be replaced and should outlive the life of the van/shuttle
• Operable by an able-bodied adult	• The latch system should be no larger than 10 in^3 per latch	
• Easy to clean and maintain		

3.2 Product Research

In order to develop new ideas for our design, we conducted research into existing products. Each team focused on products relevant to them. These products were compiled into a list and evaluated based on the benefits and drawbacks of each one. A handful of these products touch on what we aspire our product to achieve, however, none of them fit all of our customer wants and needs.

3.2.1 Current Seating System Comparable Products

To better understand the market for the configurable seat and the needs missing in the current market, several seating systems were identified. These systems can be directly compared to our design.

The first system we found was AbiliTrax Modular Seating as seen in Figure 1. AbiliTrax Modular Seating. This seating system uses removable modular seating that locks into place on rails (similar to e-track) installed in the van. While this accomplishes many of the same goals as our design, there are two key elements that do not meet our design criteria:

1. The seating collapses for ease of removal and to minimize volume, not floorplan area.
2. The seating is designed to be removed from the van when not in use.

Figure 1. AbiliTrax Modular Seating

The second comparable system we found was the Freedman 3pt double fold-away seats as seen in Figure 2. Freedman 3pt Double Fold-Away Seats This seat fills a similar purpose to our design by allowing the seating to be stored in-place in a small area. It differs, however, in that the seating is fixed – it folds in-place and cannot be moved further.

While not modular, this design accomplishes a different part of our design goal – for the seat to be stored in place such that it is readily available to be deployed.

Figure 2. Freedman 3pt Double Fold-Away Seats

Another third product we found was the full ten Passenger Mid-Roof Van Ford Transit 2020 vehicle (Figure 3). This product was included because it exemplifies the luxurious side of the market that still offers removable seating options. However, while this offers quite a comfortable ride, the downside again is that to make extra space a whole seat or row must be removed from the vehicle. Seats are also not configurable as they have set anchor points, which makes it much less versatile of an option.

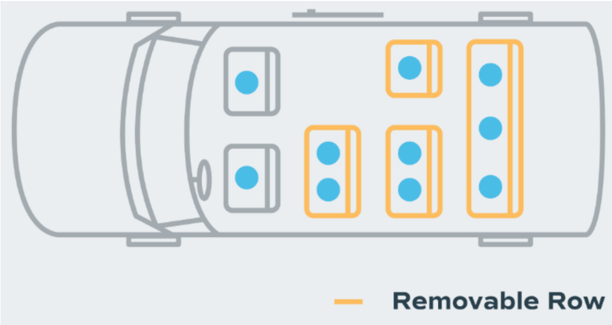


Figure 3. 10 Passenger Mid-Roof Van Ford Transit 2020 Vehicle

3.2.2 Track and Latching Comparable Products

For comparison to the track and latch system, further research was conducted into both existing seat-track systems and into potential existing tracks that may be incorporated into the track design.

Through this research, two main competitors were found. The first major competitor was the QSF Seat Fixture developed by Q'Straint (Figure 4). This system requires two screws on each rail to be tightened by hand to secure a seat, and after loosening the screws the seat can slide along the rails for longitudinal location adjustment or seat removal. While it is a cheap, light weight product which takes up very little space, it requires far more time for seat adjustment than our team is willing to allow.

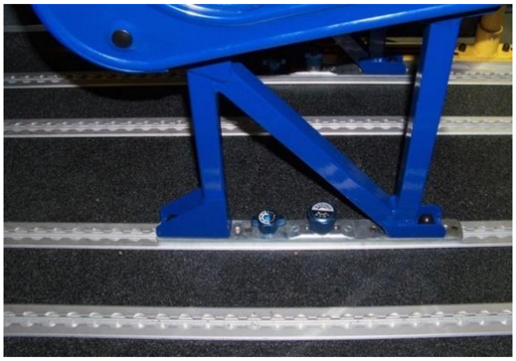


Figure 4. QSF Seat Fixture

The second major competitor found in our research is the V Fitting by NMI Safety (Figure 5). This system is more easily adjustable, requiring the operator to step on a lever and pull on a handle on each side to release the latches in order to slide the seat or remove it. However, the cost and weight are greater than the QSF Seat Fixture.

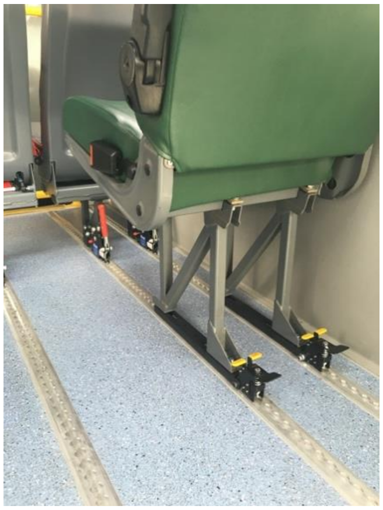


Figure 5. V Fitting

We found a few other products that function in similar ways to our design goal. The first was by All Star Performance. This company sells an aftermarket seat track system like that found in most road cars. Because it is a simple railing system designed for a single non-commercial car seat, it is extremely cheap and fairly light weight. However, it is limited in its adjustability to the length of the product and does not allow for the seat to be removed without extensive work.

Figure 6. Seat Track Assembly

Another product we looked to for inspiration was standard airline seating rails. While there is no one manufacturer who makes railing systems, research has shown us that there are two standard rails used for mass transit seating, one for the aerospace industry and another for ground vehicles. The aerospace grade rails are much lighter and take almost no space, but they are extremely expensive for just one seating component, and do not allow for great adjustability (Figure 7). The standardized ground vehicle rails on the other hand are considerably heavier but allow for much more adjustability (Figure 8). They also take up more space but are still very compact.

Figure 7. Standard Airline Seating Rails

Figure 8. Standard Ground Vehicle Rails

The final product we researched was the SmartFloor^{TM} Flexibility Flooring System by Mobility Works as seen in Figure 9. This product requires that the floor of a van be completely converted to house their smart floor mounting tracks. Compatible seats are also included and can easily be moved into different configurations depending on the needs of the driver. It is quite a versatile design and seems very user friendly. Their only downside is that the seats do not have the ability to nest well, so to keep the interior modular they cannot hold as many seats in the first place, or you must take seats out to make extra room.

Figure 9. Mobility Works SmartFloor

3.2.3 Seat Articulation Relevant Products

For the articulation mechanism, a broad range of research was conducted; to identify the widest possible range of potentially useful mechanisms, research options were considered ranging from folding chairs to cabinet hinges. This produced two notable categories of mechanisms: folding seating systems and relevant mechanisms.

The first folding seating solution we identified was a typical folding chair (Figure 10). As one of the most common modular seating options, these chairs are utilized in many stationary applications. While not designed for transportation use and often uncomfortable, it displays a simple folding mechanism for minimizing floorplan area. This design is simple and elegant. While our design will likely be more complex, examining the simplest solution may provide additional insight.

Figure 10. Typical Folding Seat

Another common design for modular seating, often used for camping or patio applications, is the Anti-Gravity Chair (Figure 11). The primary feature of the Anti-Gravity chair is the variable linkage geometry that allows the seat to recline.

While our design may not have additional functions like the antigravity chair, this is a well-proven design that showcases a variable geometry mechanism.

Figure 11. Anti-Gravity Chair

The railcar seating in the Circa 1800s was another product that had a unique seating mechanism (Figure 12). These seats utilize a compact mechanism to reverse the seating direction. The seat back swings back and forth, causing the conjoined tilting motion of the seat bottom. Unfortunately, very few images of these type of seats are available; the mechanism itself could not be found.

Figure 12. Railcar Seating, circa 1800's

The last seating system we looked at was standard RV seating (Figure 13). Many recreational vehicles designed to haul cargo require the living area to double as cargo space. As such, they often include a couch and a dinette that double as beds, while also having the capability to fold against the walls such that cargo space is maximized.

As with the typical folding seat, this design is simple and ubiquitous, while achieving a similar goal of easily interchanging seating space and cargo space.

Figure 13. RV Seating

The first mechanism we found was the Blum European Style Cabinet Door Hinges (Figure 14). These hinges display the ability of four bar (and for some hinges six bar, such as the wide-angle hinge, picture right) linkages to be utilized for varying the path of two hinged components such that the point of rotation need not be the intersection of the components.

Figure 14. Blum European Style Cabinet Door Hinges

Another relevant actuating mechanism was the Workmate Folding Workbench (Figure 15). This workbench utilizes a variable linkage geometry using a specifically designed slider/slot geometry (slot pictured right). This also displays the integration of latching mechanisms into linear sliding components to reduce stress loads on the latch itself.

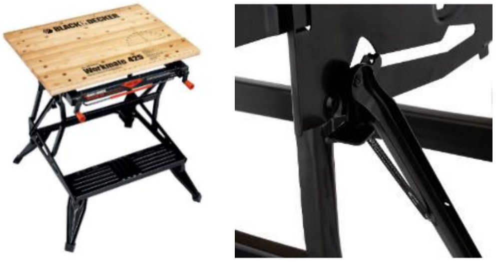


Figure 15. Workmate Folding Workbench

Another hinge mechanism was a laptop watchband hinge on the Lenovo Thinkpad Yoga (Figure 16). This is another mechanism that allows for offset hinging; robust in that each individual segment is a solid piece but flawed in that it requires exposed gears (wear item, pinch points, etc.).

Figure 16. Laptop Watchband Hinge on the Lenovo Thinkpad Yoga

The automobile doorstop was also used as guidance in our design (Figure 17). Commonly utilized in trucks, this mechanism uses a sprung link with indentations along a sector of proper curvature that corresponds to a pin in the hinge. As the door opens, the pin slots into these indentations supplying several stop locations for the door.

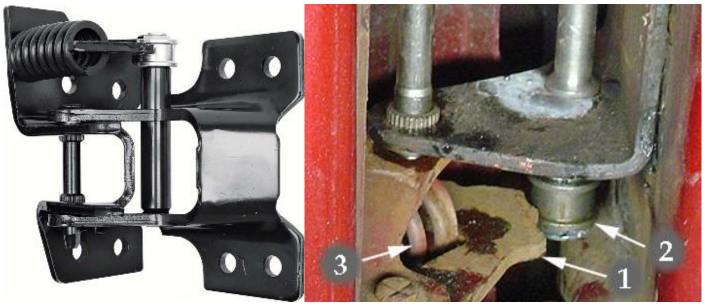


Figure 17. Automobile Door Stop

The final design we looked at were hood hinges for automobiles. These mechanisms are as varied as automobiles themselves; no two are alike. Some provide lift assistance (spring, gas spring, etc.), some are six or eight-bar linkages, and some even utilize sector gears. These linkages have the potential to provide significant inspiration to our design processes. Of the linkages found in our research, three were selected as a sample to be included in this report: six bar linkage (left), four bar linkage with a spring assist (middle), and six bar equivalent linkage (right).

Figure 18. Hood Hinges for Automobiles, Six bar Linkage (left), Four bar Linkage with Spring Assist (middle), and Six bar Equivalent linkage (right)

3.3 Technical Research

To supplement our product research, additional research was conducted into technical documents relevant to the seating system. Such documents include patents, industry or government standards, and technical journal articles and reports.

3.3.1 Patents

The original patent (US10.596.934 B2) submitted for the system by Ritch Hollingsworth outlines a series of configurations of the primary system for implementation in a variety of transit systems. The scope of this original patent is much larger than the intended scope of this project team. The original patent provides insight to the most basic type of latching system: a pin and hole. This system is meant only for preliminary consideration and patent filing.

Further research revealed a number of existing patents for fine positioning latching systems employed in a variety of industries. Some, like a “tractor” system for an automated welding process (US 9.138.822 B2), are designed for maximum precision in movement. These applications traditionally employ a rack and pinion design with encoders for tracking revolutions of the pinion. These systems can be resolute to the millimeter.

While resolution is desired in this application, resolution to the millimeter is not necessary. Other products, such as the DIN Rail Attachment Feature (US 8.066.239 B2), allow for secure fits but currently do not have rapidly adjustable options. The secondary advantage to systems like the Din Rail Attachment is their compatibility with preexisting track systems.

Modifications of both above-described systems will then be integrated with the original patent and similar existing systems. Some, like the Vehicle Seat Moving Device (US 7.229.117 B2) or Seat System for Vehicle (US 5.951.104) accomplish very similar ideals as the original patent. This system allows for the linear reposition of passenger seats using rails laid into the floor of a vehicle bay. We propose to integrate a more streamlined latching and railing design with the original patent by taking inspiration of from these similar systems.

Some other existing patents relate to the scope of our project. Table 1 lists some of these existing patents. Despite the relation to our scope, they do not entirely solve the problem. Comparison of the final product with these other solutions can help determine the effectiveness of our project.

Table 1. Related Patents

Patent Name	Patent Number	Patent Owner	Description
Stowable seat with reduced vibration and improved locking mechanisms[15]	US6846044B2	Freedman Seating Co	This patent allows for the vertical stowing of a vehicle seat bench for the accommodation of a wheelchair.
Floor tile system for mounting vehicle seats and methods for mounting vehicle seats [16]	US10052974B2	Freedman Seating Co	Patent for mounting a vehicle seat to a vehicle floor. Attaches the seat to the floor with the utilization of fastener elements.
Floor for a transport means and profiles for the construction thereof as well as a vehicle provided with such a floor [17]	US6595142B2	SMARTFLOOR BV	Patent for floor rail with unique grooves to attach a removable seat.
Vehicle seat having a folded position [18]	US6655738B2	Johnson Controls Components GmbH and Co KG	A patent for a stationary seat that allows for a seat position and a stowed position.
Vehicle adjustable and stowable rear seat [19]	US5570931A	FCA US LLC	A patent for a longitudinally adjustable seat that allows for an in-use position and a fold-flat stowed position.
Folding Chair with Sliding Leg Structure	US7080877	Maxchief investment Ltd	A patent for a typical folding chair that can articulate between a storage position where the seat, back, and legs of the chair are coplanar, and a sitting position, where the chair can provide seating for an individual.
Fold Flat Seating	US7559594	Schukra of North America	This patent describes a collapsible vehicle seat in which the kinematics and motion are centered around a stationary, fixed base. The seat enters a stowed position by pivoting around a singular hinge.
Height Adjustable Seat	US876220B1		A patent for a height adjustable seat for a bath enclosure.
Apparatus for Back-Folding Standup Seat of Vehicle	US9358907B2		A patent for an automotive seat that folds in on itself to allow for easier passenger loading, or to increase cargo space.

3.3.2 Standards

A multitude of standards limit the possible applications of the system prescribed above. While vehicle standards for seating systems specifically are not prevalent for strictly enforced standards, other regulatory bodies have standards related specifically to the testing of seats. It is most important to note that many of the engineering requirements exceed the minimums required by standards put out by both the American Transportation Authority and SAE.

Automotive seating is regulated at both the state and federal level. State regulations vary depending on the state and the operating location of the vehicle. However, federal standards are universally well defined and regulated by the United States Department of Transportation (DOT). The DOT oversees and enforces automotive seating standards mainly through two branches:

- National Highway Traffic Safety Administration (NHTSA)
  - Focuses on regulating the interaction of vehicles and their components with their operators.
- Federal Motor Carrier Safety Administration (FMCSA)
  - Focuses on regulating business and operating procedures to protect cargo, passengers, and drivers.

The NHTSA has more oversight and influence on the industry standards associated with automotive seating requirements, outlined in the Federal Vehicle Safety Standards (FMVSS). According to the FMCSA, these requirements vary with respect to vehicle type, with distinctions made with reference to the vehicle’s Gross Vehicle Weight (GVWR) and passenger capacity. A vehicle’s GVWR is defined as the maximum weight of the vehicle when fully loaded with passengers, cargo, and fuel. To narrow the scope of requirements that need to be met by this seating system, a focus can be placed on multipurpose passenger vehicles that have the greatest applicability towards our consumer base. Multipurpose passenger vehicles must conform to FMVSS codes 207, 208, 209, & 302 (According to 49 CFR, § 571.3 (1970) & 49 CFR, § 571.0 (2014), which are both codes of federal regulations (CFR)). These FMVSS codes are outlined in Table 2 and 3 below.

Table 2. Summary of FMVSS Codes for Multipurpose Passenger Vans

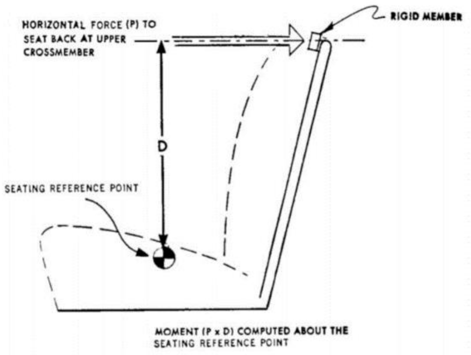
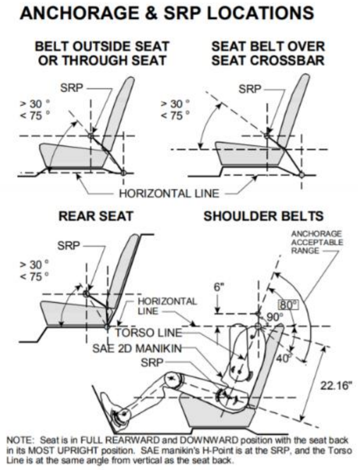
Safety Standard	Overview	Summary
FMVSS 207 [17]	Outlines the force requirements seat system must withstand	• Forward direction, 20x weight of seat system • Rearward direction, 20x weight of seat system • Seat Belt assembly - Rearward and forward forces simultaneously applied  • • 3,300lb-in moment about the seating reference point
FMVSS 208 [17]	Outlines safety standards specific to the type of vehicle	• Each seating position must have a type 1 (pelvic belt) or type 2 (pelvic belt/upper torso) seat belt • Dynamic Testing Requirements: • 3 tests: frontal impact crash, lateral moving barrier crash, rollover crash • Must be completed without action by vehicle occupant • For frontal impact crash test • Belted conditions • Unbelted conditions • Dynamic sled test assembly used for test • For lateral moving barrier crash test & rollover crash test • Entire vehicle must be used in test • Establishes maximum injury criteria for impact dummy
FMVSS 209 [17]	Outlines seat belt requirements	• Must be used by only one passenger • Free from burrs and sharp edges • Adjustable • Must fit biometric data between 5th percentile woman and 95th percentile man • Minimum width of webbing >46mm • Attachment hardware standardized: 7/16-20UNF-2B or ½-UNF-2B or eq. metric • Steel plate used with attachment hardware must be >10mm thick

Table 3. Summary of FMVSS Codes for Multipurpose Passenger Vans Continued

FMVSS 210 [17]	Outlines seat belt anchorage requirements	Must survive 5,000lb forward longitudinal force applied to anchorage point  A line from a point 10mm above and 64mm forward from the seating reference point to the closest anchorage point should extend forward from the anchorage at an angle between 30 and 75 degrees.
FMVSS 302 [17]	Outlines requirements surrounding the burn rate of materials used inside occupant compartments in vehicles	For this project, we will assume all materials are compliant with FMVSS 302, more information on this requirement can be found on the NHTSA website.

3.3.3 Journals and Academic Research Documents

Research reports and articles of various related topics were uncovered in our research. For instance, the research journal article by Hsiu-Ying Hwang, “Minimizing seat track vibration that is caused by the Automatic Start/Stop of an Engine in a Power-Split Hybrid Electric Vehicle” concerns designing vehicle seat tracks to reduce vibration in electric, hybrid cars. We may be able to use this as supplemental analysis to prevent over-the-top vibrations in our design.

Further research into vibration and natural frequency yielded two more journals of interest. One journal, “Natural Frequency Analysis of Automobile Seat”, by Sumit Badwaik and K.R. Jagtap, documents the FEA analysis of a Low Carbon Steel automobile seat. This provides an example after which we would model any supplemental FEA analysis for natural frequency. Additionally, it lists the natural frequencies of some common car seat components. Another journal, “The Dynamic Characteristics of Automobile Seats with Human Occupants”, by John Varterasian and Richard Thompson, records the results of a vibration test of an automobile seat with various human passengers. It provides analysis on optimizing rider comfort, along with a mass-spring-damper model of the rider and seat as a combined system.

The journal entry “Universal Positioning seat track” by F.C. Matthaei Jr, published in *SAE transactions, vol. 62 (1954),* concerns designing vehicle seats/seat tracks for people of varying heights and sizes and considering adjustability. Although this information is quite old, it still holds relevance today in regard to designing seats for adjustability.

A research report titled “Small transit industry vehicle lab study” by Del Peterson, concerns information regarding the current state of the small transit vehicle industry. This paper was published in 2007 by the *Small Urban & Rural Transit Center.* Although the small transit vehicle industry has undoubtedly evolved since this was written, the information is still useful for background knowledge to give us insight into the industry we will be marketing to

Additionally, “Capacity management in automated shuttle bus: Findings from a Lab study” written by Alexander Mirnig et al. documents results from a laboratory study, in which passenger needs in relation to booking and reserving spots (seats, standing spots, and strollers) in an automated shuttle were investigated. It found that automated shuttles "could constitute exclusion criteria for more vulnerable parts of the population, such as older adults, families with small children, or physically impaired individuals." While this information is not directly applicable to us, it gives us insight to the needs of all types of users (with ranging levels of ability/disability) for a shuttle system. Additionally, we can use aspects of the results in this study while marketing our product, showing how our product allows for the flexibility of being able to provide more seats/legroom when necessary, which can improve the satisfaction of users of all ability levels.

Lastly, an article from the *Official Journal of RESNA,* “Everyday use of power adjustable seat height (PASH) systems” (by Sharon Sonenblum et al.), concerns power adjustable seats for wheelchairs. Although automation is outside the scope of this project team it provides groundwork for possible future growth.

4.0 Objectives

To ensure optimal understanding of the project scope and goals, a set of objectives were developed by each team. Over the course of this process, each team developed a problem statement that outlined the design goal, and boundary diagram that defined their scope. Using these definitions, a list of customer wants and needs was develop, which was then utilized in the Quality Function Development process to generate engineering specifications for their design. These objectives were developed separately for sponsor approval and have since been combined into this report.

4.1 System and Demo

This section outlines the scope of our project, the determined stakeholders and their requirements, and the target specifications we will be attempting to achieve with this project. In the end, our deliverables will include CAD renderings and simulations, along with a desktop-sized physical model of the system to accomplish these targets and display our design's capabilities.

4.1.1 Problem Statement

Transit companies need a way to adjust seating to fit different numbers of people and luggage because the needs of shuttle passengers vary dramatically. Although past senior project teams have developed a patent on the mechanics of the design, this senior project is focusing on making this a realistically marketable product that could be pitched and sold to transportation companies for commercial use.

4.1.2 Boundary Diagram

This Boundary Diagram in Figure 19 attempts to exclude the hinging mechanism, seat articulation, and seat track from our influence, but still recognizes that the locations of interaction will still need to be considered. Mainly we will have control over the seat's upholstery and frame, designing these to be manufacturable, ergonomic, and aesthetic.

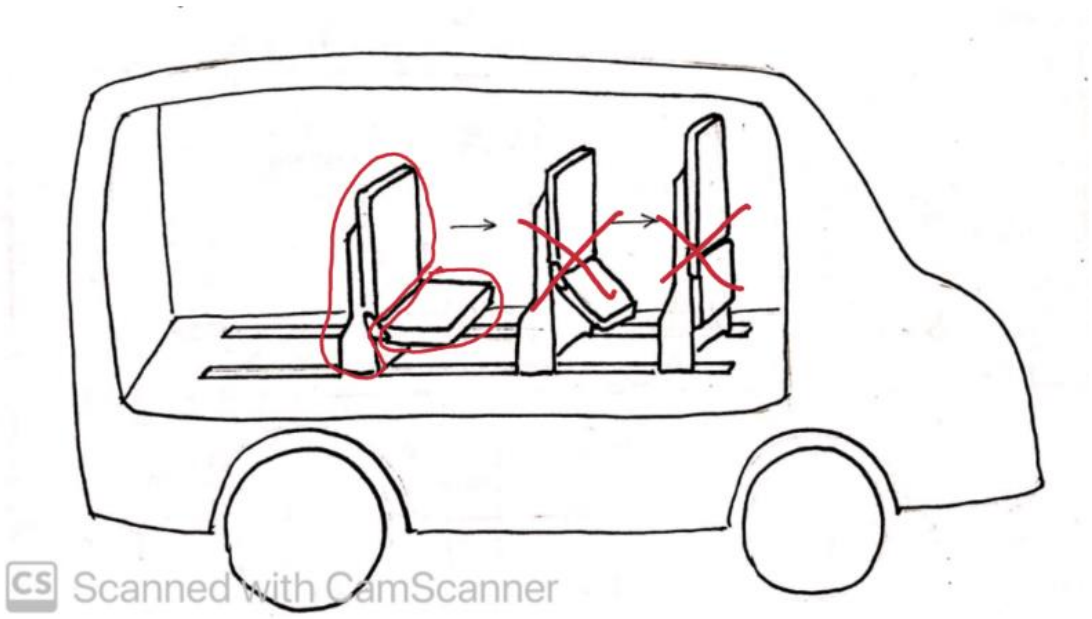


Figure 19. System and Demo Boundary Diagram

4.1.3 Customer Needs and Wants

It was decided that there are four main stakeholders that would have needs and wants when considering this product. The base level stakeholders who will constantly interact with the seat are the passengers who are sitting in the seat and the drivers/transit workers who are adjusting and maintaining the seats. The other, more top-level stakeholders are the manufacturers that are making the seats and the companies that are investing in and purchasing the seats. The company's and the manufacturers' wants and needs were grouped together since they would have very similar economically driven requirements.

The needs/wants list was broken up into these three stakeholder groups as shown in Table 4,

Table 5, and Table 6. There is overlap in many of the needs/wants and the company's list includes most of the needs/wants of the other lists. The wants/needs on this list were determined from research, surveys, and past senior project information.

Table 4. Company's Wants and Needs

Needs	**Wants**
▪ Accommodate wide range human body shapes/sizes 5% F to 95% M o Support excess weight ▪ Nest with adjacent chairs easily and compactly ▪ Needs to meet safety requirements outlined by industry standards – crash standards ▪ Material needs to follow burn rate standard. Safe for human interaction ▪ Easily reproducible and repeatable o Manufacturing o Installation ▪ Last a long time with general wear and tear ▪ Should integrate with defined track/mounting system ▪ Operable by an able-bodied adult ▪ Easy to clean and maintain	▪ Be operable by any person regardless of age or ability ▪ Ergonomic design, elaborate ▪ Design allows for scalable production ▪ Easily replaceable components o Aim towards common parts/fittings ▪ Competitive pricing with current products on the market o Cheap cost of manufacturing ▪ Aesthetically pleasing, Sturdy/Safe looking ▪ Leg Room ▪ Extra accommodations like arm rests and cupholders ▪ Comfortable/ Luxury ▪ Simple, easy, and fast to adjust

Table 5. Passenger's Wants and Needs

Needs	Wants
▪ Accommodate wide range human body shapes/sizes 5% F to 95% M o Support excess weight ▪ Needs to meet safety requirements outlined by industry standards – crash standards	▪ Ergonomic design, elaborate ▪ Aesthetically pleasing, Sturdy/Safe looking ▪ Leg Room ▪ Extra accommodations like arm rests and cupholders ▪ Comfortable/ Luxury

Table 6. Driver's/Transit Worker's Wants and Needs

Needs	Wants
▪ Nest with adjacent chairs easily and compactly ▪ Operable by an able-bodied adult ▪ Easy to clean and maintain ▪ Safe to adjust o Minimize pinch points and sharp corners	▪ Be operable by any person regardless of age or ability ▪ Easily replaceable components o Aim towards common parts/fittings ▪ Simple, easy, and fast to adjust

4.1.4 Quality Function Development

To create our QFD we began by listing the stakeholders: the passengers who use the product, the driver who maintain and operates the product, and the company who buys the product. Then the stakeholder's needs and wants were added and weights were assigned to show their relative importance. Next, the current competition was benchmarked to gage how they met the current needs and wants compared to our product. Then, engineering specifications were created to quantifiably verify if the stakeholder's requirements were met. Finally, engineering targets were set. The completed House of Quality can be found in Appendix A.

4.1.5 Engineering Specifications Table

From our house of quality, the Engineering Specifications Table was created to summarize the specific targets that will be designed towards. Since there will not be a full-sized prototype as our final deliverable many of these specifications will be analyzed through CAD models, customer survey's, industry contacts, and similarity. Each specification will have a target design value, a tolerance on that target, a risk of how difficult it may be to reach that target, and a compliance of how to verify that target is met. All of these are displayed in Table 7 and more in-depth descriptions of each can be found below the table.

Table 7: System and Demo Team’s Engineering Specifications Table

Spec. #	Specific Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Cad Packaging Verification	70% open floor area	Min	M	A, I
2	Customer Satisfaction Survey	80% Satisfaction	Min	M	T, S
3	Bill of Materials	40% Custom Parts	Max	H	I
4	Industry Safety Standards	Pass	Min	H	I, S
5	Fatigue Life Calculations	10 Year Life Cycle	Min	M	A
6	Time to adjust seat	15 seconds	Max	M	T
7	Verify from industry contact	Pass	Min	M	I
8	Industry design standards	Pass	Min	H	I, S
9	Cost to manufacture	$1000/seat	Max	L	A

(H) High, (M) Medium, (L) Low – difficulty to meet the specified requirement
A (analysis) - analysis will be done to see if the requirement is met
T (testing) - testing will be performed to check the if requirement is met
S (similar) - rather than testing or analysis to see if requirement is met for the product, comparing it to an established product to check requirement will be done
I (inspection) - inspecting the product will be sufficient to check the completion of the requirement

The verification process for each of these specifications is described below:

- CAD Packaging Verification
    - Using the CAD model of our design, the floor space will be measured to see the amount of unused space. The aim is to have at least 70% unused floor space when the system is in full use.

    - This metric was created to ensure the nesting design was efficient, since this will be a main selling point.
- Customer Satisfaction Survey
    - A customer satisfaction survey will be given to random customers to test some of the more abstract requirements such as ergonomics or aesthetics of the seats. The target of at least 80% satisfaction will be measured through a rating system and comparison with other existing products.
- Bill of Materials
    - A bill of materials will be made to make a comprehensive list of parts required to make the seat. Our goal is to keep the number of custom parts under 40% of the entire BOM.
    - A "custom" part is one that will need advanced, or more expensive manufacturing techniques such as casting or CNC machining.
    - This is to ensure that the seat will be easily reproducible, repeatable, and repairable.
- Industry Safety Standards
    - All the industry safety standards previously listed were tested and analyzed by the 2019 senior project team and the corresponding master's thesis. To ensure our design is safe and legal, we will be designing with similarity to the previous structure.
    - If our design varies too much from the previous structure, the analysis may need to be redone.
- Fatigue Life Calculations
    - Calculations of the estimated life cycle of the seat will be performed to test the lifetime durability of the seat. A minimum 10-year life cycle is the aim for the durability of the seat.
    - This will only be needed on critical moving components that will undergo fatigue, so this responsibility may be passed on to the seat articulation and/or seat track team.
- Time to adjust seat
    - To test the time to adjust a CAD motion study will be utilized, which will measure the duration of time needed to operate the seating system. The target maximum duration of this test is 15 seconds, to encourage ease of adjustment.
    - This specification may also be passed on to the seat articulation and/or seat track team.
- Verify from industry contact
    - Using the expertise Ritch Hollingsworth and his industry connections, certain specifications which are difficult to gage, such as ease of manufacturing, aesthetics, and ergonomics will be questioned. Our final design should be approved by these industry contacts.
- Industry design standards
    - The seat design will be compared to existing products of similar function for design criteria such as fitting 5% to 95% of users or being compliant with the American Disabilities Act. These criteria will be judged on a pass or fail method.
- Cost to manufacture
    - The total cost to manufacture the seat will be calculated, starting with a small volume production, and will be checked to see if it meets our target cost of $1000 or less per seat to keep our product competitively priced.
    - This currently does not include track manufacturing and installation fees.

4.2 Track and Latch

Using the information gathered from potential customers, technical and product research, and our sponsors, we developed the following problem statement: High occupancy automobile transportation services require a seat securement mechanism for rapidly configurable seats in order to transport variable amounts of cargo and passengers. The below boundary diagram was created to define the aspects of the adjustable seating system our senior project team will focus on.

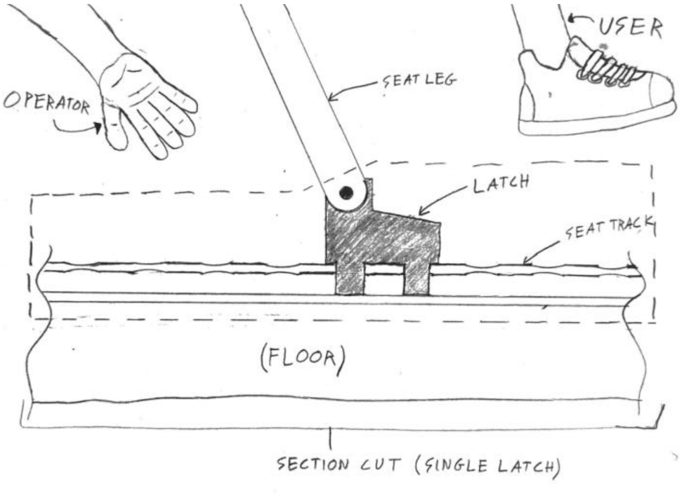


Figure 20. Seat Track and Latch Boundary Diagram

Figure 20 above illustrates a section cut of a single latch in the seat track. As depicted in the diagram, we consider the seat track, the latch, and the hinge that attaches the latch to the seat leg as the parts of our system that we will directly control and change. The van floor and the seat leg are aspects of the design that we may be able to suggest alterations to and thus have an indirect effect on the design. Lastly, the user and operator are aspects of the system we cannot change but must consider in our design.

4.2.1 Design Considerations

After meeting with our sponsor, the design considerations were separated into wants and needs. The needs were deemed necessary for the product to function safely and effectively, while the wants were specifications that would improve the overall product.

Table 8. Track and Latch System Needs and Wants Table

Needs	Wants
Reliability	Light weight
Low manufacturing cost	Visually appealing
Easy to use	Smooth operation
Safe to operate	No training required to operate
Durable	Compact

Table 8 outlines the needs and wants for this project. We complied this information based on interviews with our sponsors and possible customers. The operation of the track and latch system will be operated by one person, most likely the driver of the van/shuttle. For this reason, our design must be easy and simple to use. Van and shuttle services do not want to force their passengers to move and change the seat configuration. As a result, liability and risk of injury are also design considerations. In order to reduce risk of injury, we must design our system to have minimal pinch points.

4.2.2 Quality Function Deployment

In order to help develop our product we created a quality function deployment. This helped define the problem based on a House of Quality diagram as shown in Appendix C. The House of Quality was divided into sections for who, what, how, now, how much, and interactive sections between each section. The "who" section included all the possible customers: shuttle company owners, shuttle/van drivers, passengers, patent holders, and manufacturers. Our "what" sections described the needs of the customer as explained by them. Between the "who" and "what" a relative weight system was created. Each requirement was given a weight to signify the importance of that requirement for each customer. Through this, we discovered which customer requirements held the most importance. This helped us decide which requirements we needed to focus on the most when it came to designing our product. The "how" section laid out basic tests to see how well our product met the customer requirements. The interactive section between the "what" and "how" showed how well each test tested each requirement. This section helped us validate our requirements by putting real life tests and applications to check on how well we can satisfy these requirements. The "now" section holds some of the competitors to our design: bench seats, aircraft rails, NMI safety, and Qstraint. By comparing our product to these, we found some things that were already done well, and certain areas our design could beat the competition in. The "how much" section gives engineering specification to each test as targets our system should meet. When combined, these sections help us optimize our design and compare and test it against products it would compete against.

4.2.3 Engineering Specifications and Risk Assessment

As seen in Appendix C, the QFD House of Quality lists the engineering specifications we devised for this project. The relevant specifications along with their initial target values are shown in Table 9 below.

Table 9. Seat Track Engineering Specifications Table

Spec. #	**Specification**	**Description**	**Requirement or Target**	**Tolerance**	**Risk**	**Compliance**
1	Weight	Total weight of all the latches for each seat	8 lb_f	min	M	A, I
2	Force Required for Actuation (Disengagement)	Force required to latch/unlatch mechanism	2 lb_f	min	H	A, T
3	Mechanical Stress Analyses	Desired minimum safety factor for all loading cases	2.67	target	M	A
4	Vibration Resistance	Minimum Natural Frequency	200 Hz	max	L	A
5	Customer Surveys	Max Customer Satisfaction	(-)	max	H	I
6	Force Required for Movement	Force required to slide seat back and forth	10 lbf	min	L	A, I
7	Thermal Properties (Material Selection)	Minimum specific heat (of latch material)	0.09 BTU/(lbm*^{o} F)	max	M	A
8	Size	maximum volume per latch	10 in^3	min	L	A, I
9	Only Standard Manufacturing Processes	Only use standard CNC processes in manufacturing	CNC Production	target	M	A
10	Cost Analyses	Minimize cost while satisfying other requirements	Below competitors' prices	min	M	I
11	Minimum Yielding Instantaneous Loading	Latch must withstand 5G force without yielding	5G	max	H	A, T

(H) High, (M) Medium, (L) Low – difficulty to meet the specified requirement
A (analysis) - analysis will be done to see if the requirement is met
T (testing) - testing will be performed to check the if requirement is met
I (inspection) - inspecting the product will be sufficient to check the completion of the requirement

The verification process for each of these specifications is described below:

- Weight
  - We will weigh our latches once built on a scale
- Force required for actuation
  - We will use a force gauge to measure how much force it takes to lock and unlock the latches from the track
- Mechanical stress analysis
  - FEA analysis will analyze the safety factor in our various load cases
  - The load cases were taken from Zach’s thesis
- Customer surveys
  - After users test the product we will conduct a customer survey to see what they like and do not like
- Force required for movement
  - A forge gauge will measure the force required to slide the entire system

- Thermal properties
    - The metal chosen will not burn users in hot temperatures
- Size
    - The size of the latch will not interfere with the system teams specifications for space saving
    - The size will be measured once manufacturing is complete
- Only standard manufacturing processes
    - To save on cost of full-scale manufacturing, the components will be limited to industry standard processes
- Cost analyses
    - The product to manufacture will remain below our budget of $1000
    - The product overall will be comparable in price to manufacture and install to competitors
- Minimum yielding instantaneous loading
    - FEA analysis will confirm our load cases for yielding and stress

4.3 Seat Articulation

In this section, the objectives of the project are developed. To accurately define the scope of our project, a problem statement was developed. The scope is further represented visually using a boundary diagram. With the boundaries of our team's scope in mind, a simplified list of customer wants/needs was developed which was then utilized to define a list of engineering specifications through the Quality Function Deployment process.

4.3.1 Problem Statement

Transit van operators and passengers need a way to easily stow a seat in a more compact area, allowing for increased cargo capacity. Because of the way conventional vans are arranged, there is little room for configurations that adjust to cargo and passenger requirements. The seat must articulate in a way that optimizes usable space reliably and easily.

4.3.2 Boundary Diagram

The boundary diagram pictured in Figure 21 provides a visual representation of the scope of our project. Contained within the boundary are the mechanisms governing the kinematics of the seating – how it articulates from the deployed position to the stowed position, as shown in the diagram.

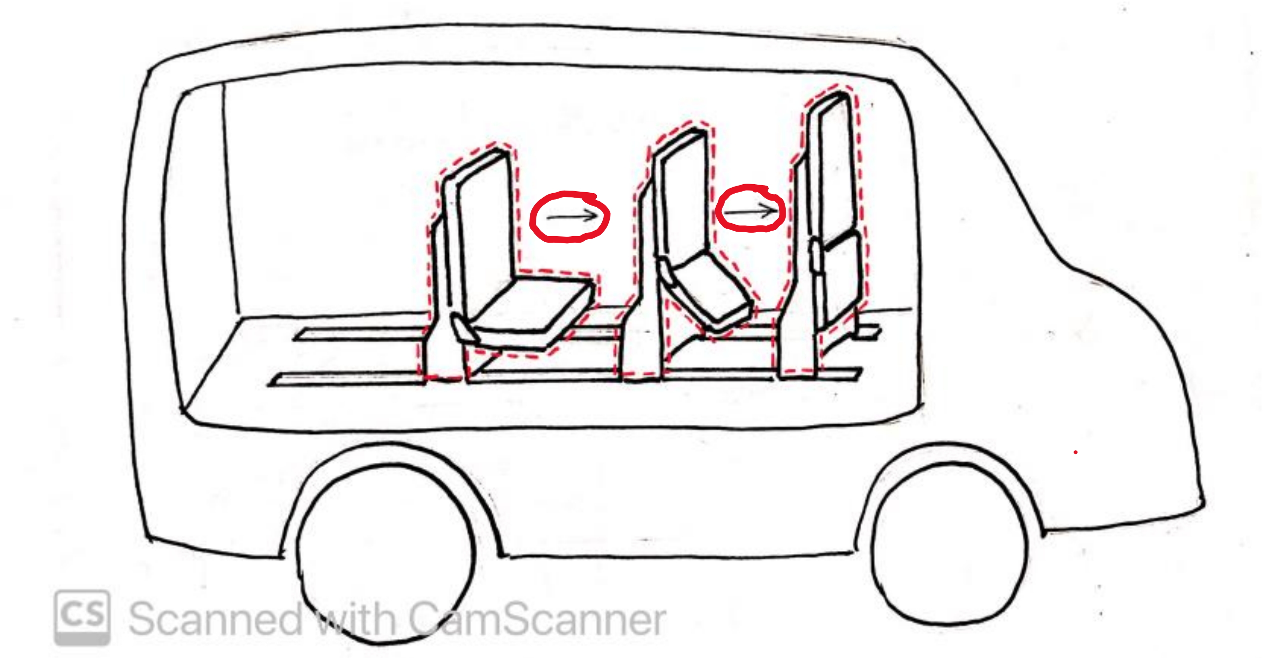


Figure 21. Boundary Diagram Highlighting the Design Focus of the Articulation Team

4.3.3 Customer Want and Needs

Based on our customer interviews and research, the following customer wants/needs were identified:

Table 10. Seat Articulation System Needs and Wants Table

Needs	**Wants**
Robust (effective operation in a variety of situations i.e. dirty, wet, dusty	Easy to use (operates very smoothly)
Lightweight (not super heavy so that it would impede on operation)	Intuitive (useable with little to no training)
Safe (limited pinch points, meets highway standards)	Simple (preferably only mechanical)
Manufacturable	Cost Value (good quality at reasonable cost)
Compactable (effectively collapses into a smaller space)	Aesthetic (something a user would want to buy)
Elegant/Refined (commercialized and marketable)	

4.3.4 QFD Process

In order to develop appropriate engineering specifications, the Quality Function Deployment (QFD) process was used. In this process, the customer needs are converted into engineering terminology. Then, a comparison relative to existing products assists in defining numerical engineering specifications. These specifications will be utilized to determine the effectiveness of our design and how well it meets the sponsor’s expectations. From this process we learned how well other existing market products preform under our specified qualities and needs. We were also able to transform ambiguous customer needs such as “intuitive” and “easy to use” into effective, measurable engineering specifications. Additionally, by compiling information relating customer requirements to engineering specifications along with analysis of how competitors satisfy their customers, we can establish clear, tangible goals for our design that will effectively work towards solving the “right” problems. Refer to Appendix E for detailed QFD.

4.3.5 Engineering Specifications Table

Extracting from our developed QFD, our specifications were further refined and detailed in an Engineering specifications table. Our engineering specifications table seen below (Table 11), is divided into several sections. The parameter is what we are measuring or testing and comes from the “how” section of our QFD. The target value/requirement for each specification is the numeric we are aiming to achieve and comes from the “how much” section of our QFD. The tolerance delineates the acceptable variation from the target value as a maximum, minimum or +/- tolerance. Risk is how challenging our team thinks it will be to meet each specification. And lastly, compliance is how our team plans to determine if our target goals were achieved (by Test, Analysis, Inspection, or Similarity).

Table 11. Engineering Specifications Table

Spec. #	Specification	Description	Requirement or Target	Tolerance	Risk	Compliance
1	Single Seat Storage Space	Maximize useful space made available by collapsing seat. Due to the geometry of a van interior, this relates to Floorplan Area more than pure Volume.	8" x 24"	Max	H	A,I
2	Strength	Ability to withstand anticipated forces within industry standards.	Transverse Load of: 20·(Seat Mass) *	Min	L	A,T
3	Stiffness	Deflection of the mechanism when the seat is in the deployed position, exposed to maximum loading conditions.	0.25 in	Max	L	A,T
4	Operation Effort	Force input required for a user to move a single seat between the stowed and deployed positions.	5 lb **	Max	M	A,T,S
5	Lifetime	Total number of cycles the system can endure before signs of failure.	10^5 Cycles	Min	M	A
6	Operation Time	Time required for a user to move a single seat from the deployed position to the stored position.	5 sec	Max	L	T,I
7	Weight	The total mass of an individual seat. This criteria is heavily impacted by the design of group F72 and will require collaboration.	50 lb	Max	H	A,I
8	Exposed Machinery	The number of exposed pinch points that will affect the user's safety.	No Exposed Pinch Points		L	I

Notes:
* Industry standards for load requirements are dependent on the final mass of the seat, among other variables. As such, additional research will be required to develop a precise tolerance. Refer to FMVSS 207

** The operation effort specification is a placeholder pending testing of current automotive seating. See Section 2.5.

(H) High, (M) Medium, (L) Low – difficulty to meet the specified requirement
A (analysis) - analysis will be done to see if the requirement is met
T (testing) - testing will be performed to check the if requirement is met
S (similar) - rather than testing or analysis to see if requirement is met for the product, comparing it to an established product to check requirement will be done
I (inspection) - inspecting the product will be sufficient to check the completion of the requirement

The verification process for each of these specifications is described below:

- Single Seat Storage Space
    - Measure the footprint area of the contracted seat when in its stowed position
- Strength
    - FEA analysis to verify the strength of the seat articulation system
- Stiffness
    - FEA analysis to estimate seat deflections. Additionally, a test plan involving known loading and measured deflections can be used.
- Operation Effort
    - Test plan using force gauges to estimate the load required to deploy system. (push and pull operations)
- Lifetime
    - Cannot be tested; spec will be met in design analysis.
- Operation Time
    - Time how long it takes for users to articulate and inarticulate the seat
- Weight
    - Weigh final prototype with scale
- Exposed Machinery
    - Inspecting final prototype and counting the number of pinch points and exposed machinery

Of these specifications, most will be relatively simple to work around. The high-risk specifications (weight and floorplan area) are specified as such due to the high reliance on inter-team communication. Of these two, the floorplan area specification is of higher concern.

5.0 Concept Design

The concept ideation process consisted of performing functional decomposition, ideation, creating function prototypes, and evaluating different functions in Pugh and weighted decision matrices in order to develop the final concept design of the rapidly reconfigurable seat system. We divided ideation into three sections based on teams: seat actuation, track and latch, and system design. The process from ideation to deciding upon the preliminary design involved many individual team efforts culminating with collaboration between all three teams. Figure 22 outlines the team interactions during the concept design process.

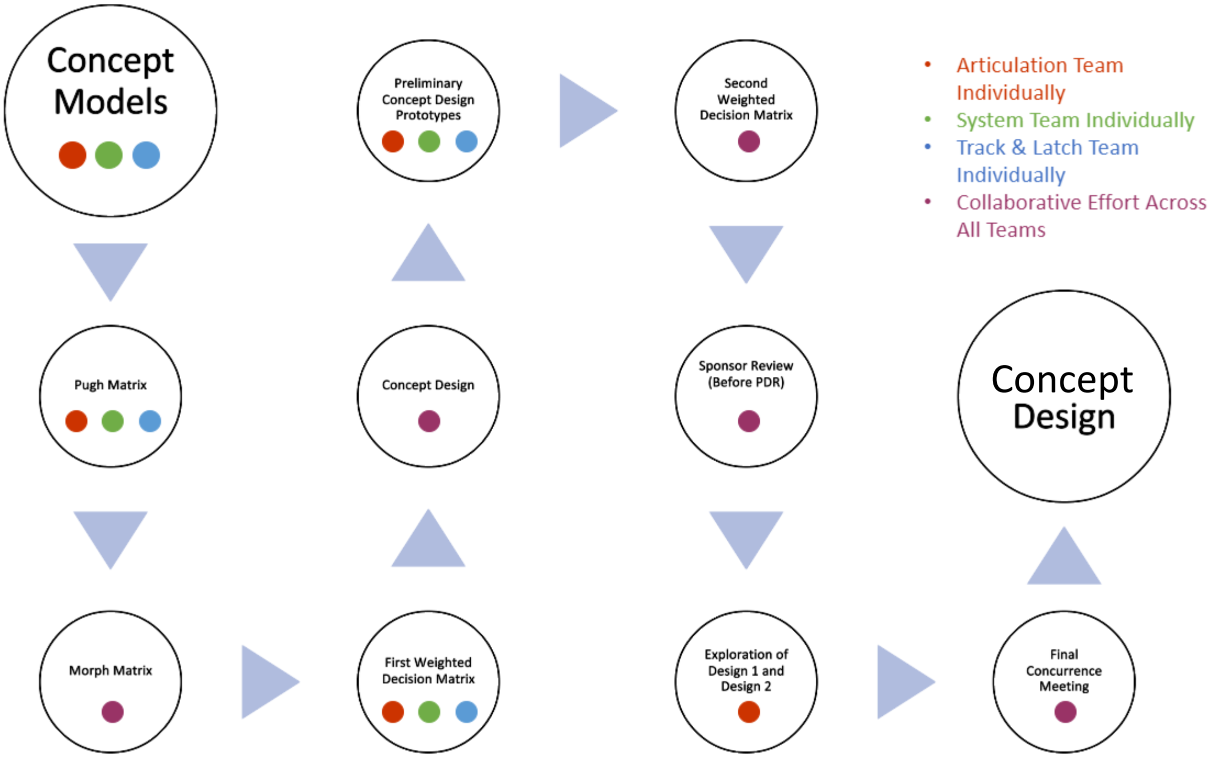


Figure 22. Concept Design Convergence and Divergence Plot

5.1 Concept Development/Ideation and Function Concept Prototypes

To help guide ideation we performed a functional decomposition to divide our system into discrete functions. We then ideated on each subfunction to find possible solutions and ways to fulfill these functions. The top of the tree held the most basic function: to reconfigure seats. The functions were further divided as seen in Figure 23-Figure 25. Descending the tree shows “how” to accomplish each function, while ascending the tree answers the question “why” each function is necessary. We divided the function tree into three sections: overall system, track and latch, and seat articulation. Figure 23 shows the general function tree while Figure 24 and Figure 25 show the function trees for the track and latch team and seat articulation teams, respectively.

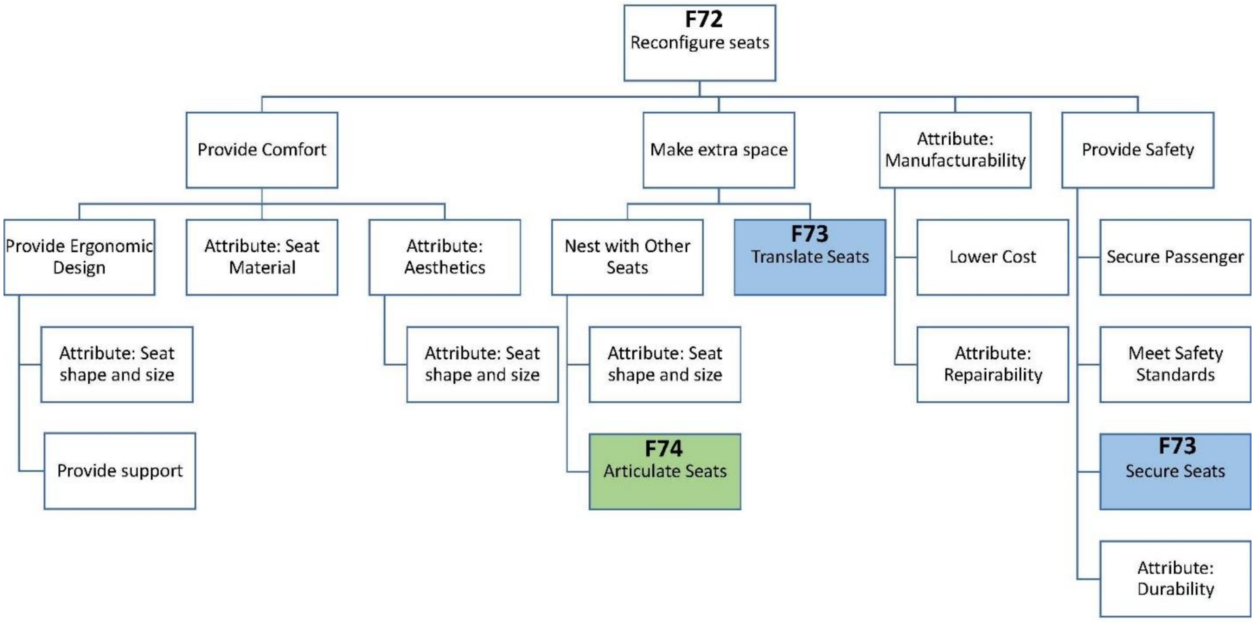


Figure 23. System Level Function Tree

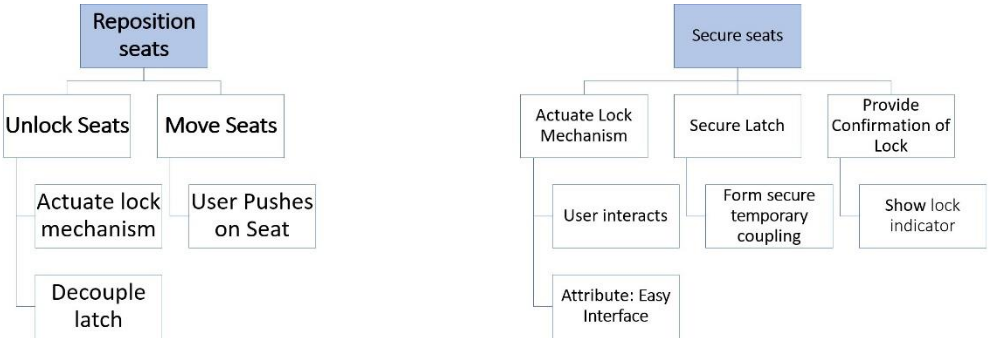


Figure 24. Track and Latch Function Tree

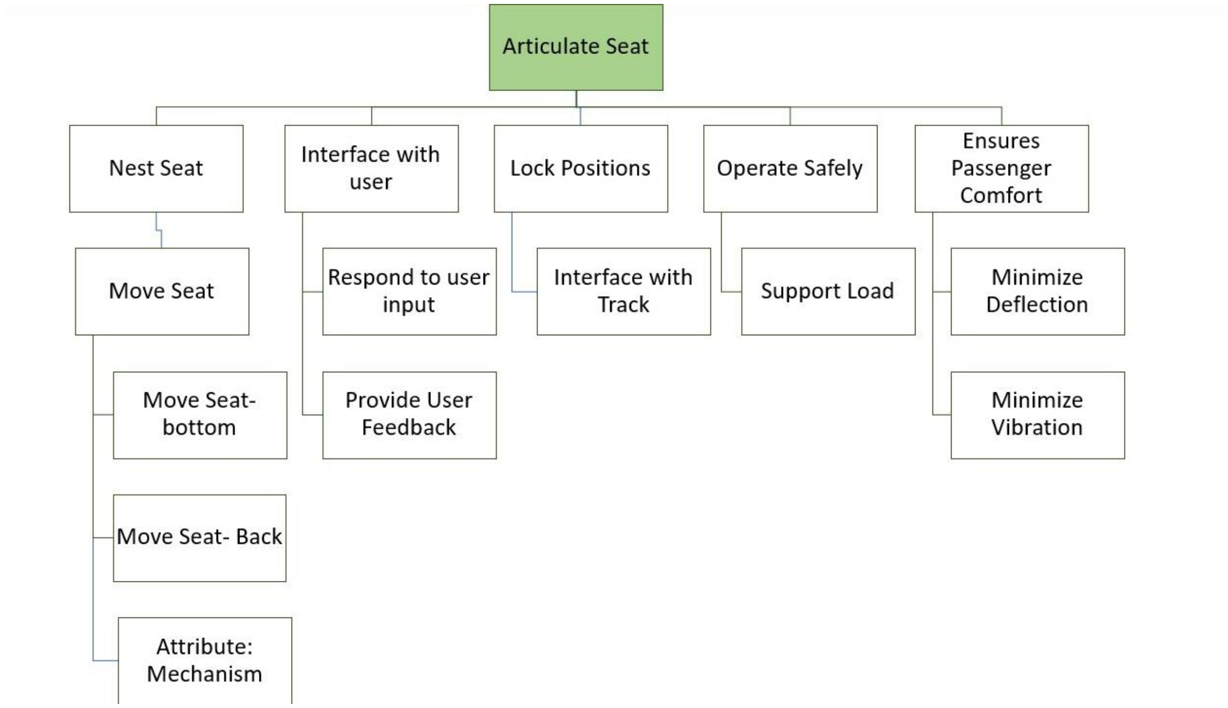


Figure 25. Seat Articulation Function Tree

Once we created the function trees, the three teams diverged and began ideation.

5.1.1 System and Demo Team Ideation

After deciding the system's functions, we decided that only certain functions could be ideated on further to create concept models while other functions would be considered later in the design process, such as manufacturability and safety. However, these were kept in mind while ideating. The four functions we conducted ideation sessions on were ergonomics, aesthetics, nesting, and seat undercarriage.

The first ideation method used was coming up with the worst ideas for a seat regarding aesthetics and ergonomics individually, and then coming together to determine what makes them bad and how they can be improved on. We each came up with at least 10 ideas and then shared what made them bad chairs. Using this insight, we then created a Google Jamboard to decide on the characteristics of a chair that contribute to aesthetics and ergonomics.

The second ideation session used the brainwriting method to ideate about the nesting function. This was done by first individually sketching ideas for 10 minutes, then uploading them to a Google Jamboard where we rotated through each other's ideas in 5-minute increments to build off the ideas and comment on improvements that could be made to them. We then synthesized what we learned from this process.

An additional brainwriting session was done to ideate for the seat undercarriage using the same process as above. Each of the Jamboards used in these three ideation sessions can be found in Appendix G.

With our findings about each function in mind, concept models of each function were created to prove feasibility of the function and to move forward in determining which ideas would be possible for the system design.

5.1.2 Track and Latch Team Ideation

We implemented a different ideation technique on each of our general functions from our function tree. Beginning with the latch, we hosted a virtual brain write session to write down as many ideas as we could on a shared document. Once we all wrote down as many ideas as we could in five minutes, we compiled our list and grouped similar solutions together. We discussed each idea a little to help visualize each idea.

Next, we hosted an ideation session for actuation. We asked the question; what are ways we can actuate the movement of the seat on the rail? For this session, we used a drawing technique. One person drew an aspect of the mechanism, and then each teammate took a turn adding to the drawing to add another aspect or flush it out further. We each added two components to the drawing then discussed how the system would function and the pros and cons of each feature. In total, we drew five separate systems. These drawings can be seen in Appendix H.

We then hosted a worst possible idea ideation session for the latching and unlatching mechanism. This involved the brainstorming of awful latch ideas that would never work. Some of these ideas included training large dogs to function as the seat and using a million bolts to hold the seat down. Once we compiled a hefty list, we gave each idea the attribute that defined them as a horrible idea. We then found the opposite of attribute so that we could define our system by these positive attributes. This list helped compose a list of good design goals for this function. This technique was the most fun, and it really help stimulate a lot of ideas and positivity.

The last ideation session ideated upon ways to achieve the locking force. It began with writing down different ways we could achieve this force. We came up with five ideas for forces: magnetic force, rack and pinion, friction force, tensile force, and attaching the seats to the wall. We then ideated ways we could achieve each of these forces using the brainstorm technique.

5.1.3 Seat Articulation Team Ideation

To begin our ideation, our team conducted the “worst possible idea” exercise discussed earlier by the track & latch team and the system team. Although the process was humorous in nature due to the absurdness of some of the ideas, this exercise allowed our team to gain insight into the negative, undesirable attributes associated with vehicle seat design, seat articulation, and linkage design. Among many other qualities, some particularly useful ones included a lack of storage space for the seat, potential hazards to the operator, and undesirable power usage.

Before moving on to the more collaborative ideation techniques, our team conducted a “braindump” – a process of recording all ideas that were developed individually. This helped to reduce some of the individual preconceived notions about optimal solutions. We followed this up with “brainwriting,” a process through which individual ideas are allowed to develop during set periods of time, then passed to other group members to be built upon. This largely overlapped with the braindump but allowed the ideas to develop further through collaborative effort.

The last ideation session we conducted was brainstorming. It was a collaborative session where our team facilitated discussions framed by “how might we” questions. These types of questions were created to address specific angles of our design problem. For example, one question posed was “How might we lock the starting and end positions?” To create ideas, our team wrote one “how might we” question on a board. Then we brainstormed as group as to how we would answer that question. This method was helpful in that individual team members could easily bounce and build ideas off each other. These ideation sessions can be found in Appendix I.

5.2 Pugh Matrix Results

In order to weigh each function’s various ideas, our teams utilized Pugh matrices to narrow down our number of feasible designs. A Pugh matrix compares all the different ideas relating to one function using a set of criteria. One idea is used as the datum to serve as a baseline for comparison. The other ideas were then scored +. - or S corresponding to if it met the criteria better, worse, or the same (respectively) as the datum. The scores were then totaled to compare the ideas to one another. This resulted in quantitative results that determine which ideas best met the customer requirements. Each sub team created their own set of Pugh matrices for their respective functions, shown in the Appendices J-L. The concept designs compared in each of the Pugh matrices described below.

5.2.1 System and Demo Team Pugh Matrices

Starting with aesthetics, the datum for this function was based on a simple, flat seat often found in buses which can be seen in Figure 26 below as Design #1. The detailed Pugh Matrix can be found in Appendix J.

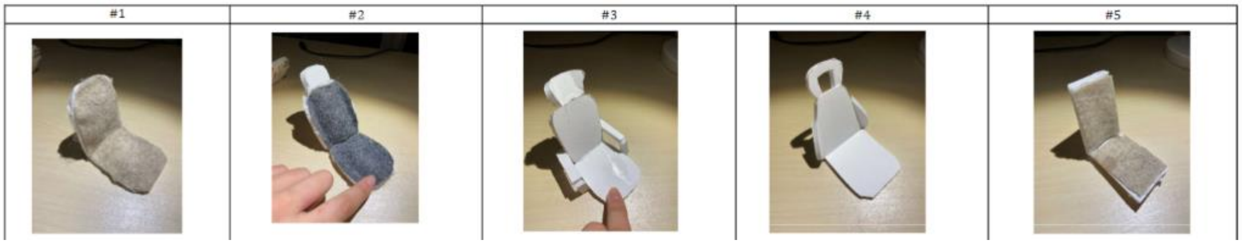


Figure 26. System and Demo Team Aesthetics Pugh Matrix Designs

Based on this Pugh matrix, the design that scored the best was a concept model that has a relatively simple seat and back but with a fitted headrest and armrests (Design #3 above). This model excelled due to the simplicity of the actual seat while still having elements that add to the aesthetics and ergonomics of the design. Takeaways from this comparison are that while a large focus is on designing for simplicity so that the seat will be competitively priced, focusing on smaller details will contribute the most to the aesthetics of the seat.

Now focusing on the undercarriage, which will act as the legs and support structure for the seat, the datum of the existing senior project design was selected. This datum consisted of four separate legs on four separate tracks with the rear staggered in between the front legs and is shown as design #1 in Figure 26. The other main designs experimented with different numbers of tracks, locking and nesting mechanisms, and support shapes as shown also in Figure 27. Once the initial six designs (#1-6) were scored, the additional 4 designs (#7-10) were created by mixing and combining the features of the previous designs that made them successful as shown in the Pugh matrix in Appendix J.

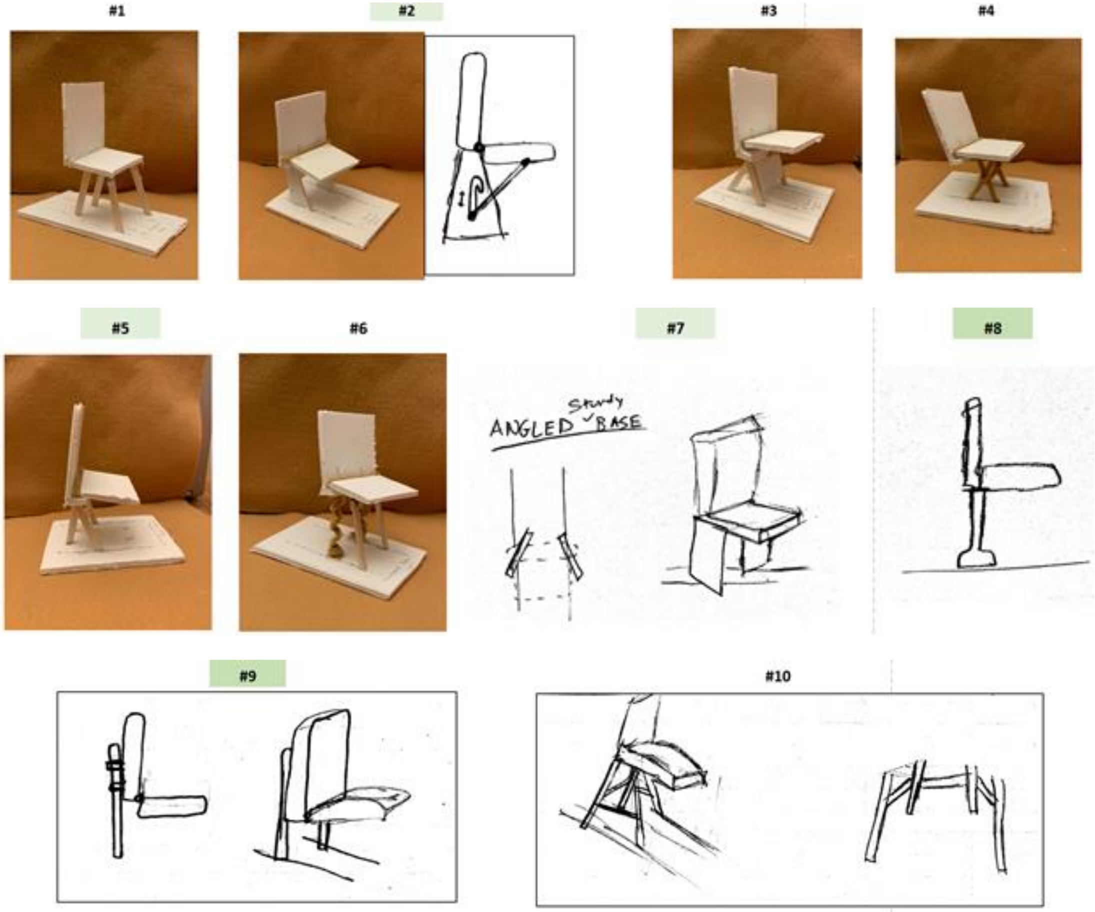


Figure 27. System and Demo Team Undercarriage Pugh Matrix Designs

It is important to note that when rating the designs, many of the requirements were based off the complexity of the chair and number of moving parts, since it is impossible to objectively know things like whether the seat is “Operable” or “Easily Producible” without having a final design to test on. Because of this many of the simpler designs with the least number of components rose to the top. These designs often had only two tracks and a simple support structure with the “Slim Sturdy Base, Two Track” (#8) scoring the highest due to its simplicity, sturdiness, and slim profile for nesting. While this did score the highest, it may not necessarily be the final design we will settle on since our undercarriage may also need to have additional features to meet the needs of the articulation, but the concepts highlighted in green will represent our most promising options. In the future, the compatibility with the patent design must also be a consideration, but at this point in the design process it is not a driving factor.

The Pugh matrix designs concerning seat nesting are shown below in Figure 28 with the matrix shown in in Appendix J. There are a total of 9 initial ideas that were created to maximize the horizontal space saved from the seated position to the collapsed position. As with the other functions, we analyzed various needs and requirements of the user and customer alike and compared them with each idea, with the original patent nesting as the datum.

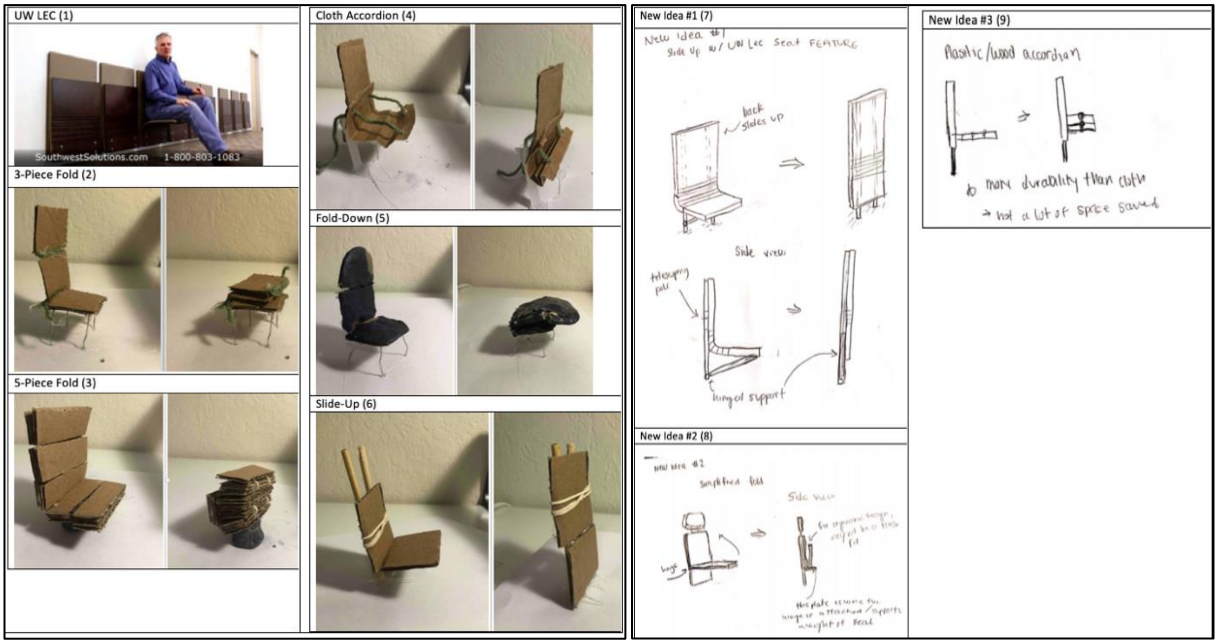


Figure 28. System and Demo Seat Nesting Pugh Matrix Designs

“UW Lec”, “5-Piece Fold”, “Fold-Down”, and “New-Idea #3” all scored the same as the datum when analyzing them based on the criteria. While “UW Lec” nests well, is aesthetically pleasing, and easy to operate, it must be manufactured in a specific way which increases price and makes it not easily repairable. In addition, the ergonomics of the seat would be a concern as it would be made of a flat plank of wood, cut in a specific way. The “5-Piece Fold” would be challenging to adjust and the folds would cause issues for ergonomic concerns. The “Fold-Down” scores poorly in horizontal space saved as does “New-Idea #3”.

The “Cloth Accordion” while versatile and takes up the least space, is neither ergonomic nor sturdy. The “Slide-Up” idea also scored high as it saves a lot of horizontal space. “New Idea #2” is simple to operate and saves a fair amount of space, though not the most. The highest scoring idea is “New idea #1” which is a combination of “UW Lec” and “Slide-Up”. This design incorporates a notched seat that can lay completely flat in the vertical position and as a seat. This design does not score high with ergonomics as it is made of wood and must be a particular shape for the motion to work.

After considering all relevant factors and looking at the top-scoring ideas, the “Slide-Up” articulation with a focus on creating an ergonomic seat was chosen for further designs. This is similar to the highest-scoring design but taking comfort into account instead of sacrificing it to save more space as the “UW Lec” component would.

For ergonomics, six concept models were drafted with comfort and fit for the passengers in mind shown in Figure 29. The first design, also the datum for the Pugh matrix, was a standard car seat. The second design attempted to be a more human centered fit. Design 3 took inspiration from first class airplane seats but ended up very inconvenient for automobiles. Design 4 was based off seats that may be seen in busses meant for overnight travel, hence the much simpler design and goal to allow passengers to sleep. The fifth design was a novel bungee cord chair, a simple chair frame with bungee cords to support the passenger. The sixth design attempts to make a folding chair that fits snuggly together to save the most amount of space. The chairs were scored on several criteria which could be summed up as passenger comfort, space efficiency, and manufacturability. After the scoring shown in Appendix J, design 2 and 6 were ranked number one, meaning these were the chair designs most likely to be used in the final design.

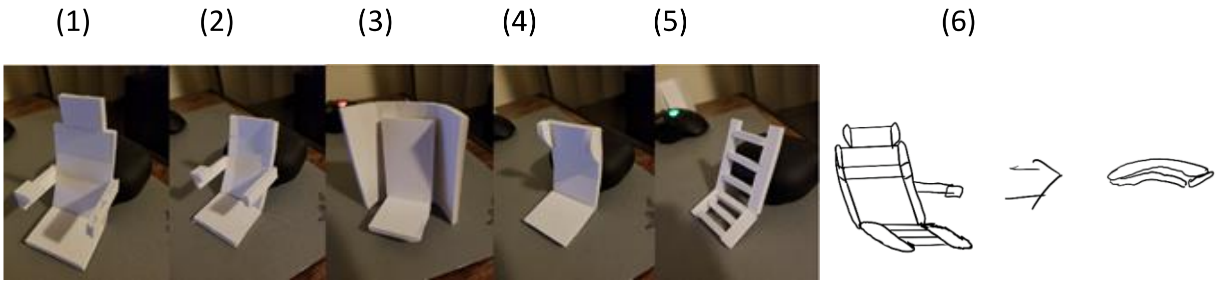


Figure 29. System and Demo Ergonomics Pugh Matrix Designs

The Pugh Matrices above showed not only the specific concepts that fit the criteria the best, but also showed the reason that some designs ranked higher than others. After this step, designs of each function were combined and iterated before converging with the other teams to combine all the functions.

5.2.2 Track and Latch Pugh Matrices

Our team divided our Pugh matrices into four separate matrices for our separate functions: lock confirmation, actuation of locking mechanism, locking mechanism itself, and the seat movement. All 4 of these Pugh matrices can be found in Appendix K.

For the lock confirmation, we used an audible click as the datum. Depictions of each design are included below in Figure 30.

"click"
Audio Confirmation Pulley System Manual Lever Automated Sensor Pressure Plate

Figure 30. Track and Latch Lock Confirmation Pugh Matrix Designs

The audio confirmation seems to be the best option to fulfill the locking confirmation function. However, another option to consider is the pulley system. In fact, these two can work in tandem for extra safety. The other options are much less ideal and fall short on multiple specifications. However, the automated sensor could still work under certain conditions. The manual lever and pressure plate are not the best for our application due to failure to a driving desire for simplicity. Another option we considered was a simple indicator that when locked is hidden from view. When in the unlocked position this red indicator is visible and indicates the system is in the unlocked position.

The next Pugh matrix involved actuating the locking mechanism function. We created five concept models to solve the need for a locking mechanism actuation. For this function, we used the pin pull lever as the datum. Figure 31 shows the initial concept models.

(1) (2) (3) (4) (5)

Figure 31. Track and Latch Actuating Locking Mechanism Pugh Matrix Designs

The pin pully system (2) consists of pins holding the latch on the rail. These pins are then released by a string/chord that comes out at the bottom of the seat between the rails. The pin pully design is light, cheap, and allows for easy disengagement. However, this design is not the most ergonomic. This idea seems to be the best method of actuation because of its simplicity. Its lack of moving parts means that it must be incredibly reliable, and it does not take up very much space and is light weight. Despite its simple design, it is still easy to actuate, making it a very good method for actuation.

The other locking mechanisms had too many cons to be considered any further. A major concern for our potential users was weight, which eliminated all screw and magnet ideas due to the nature of their designs.

The next Pugh matrix focused on the locking mechanism itself. Here, we used the din latch as the datum. Din latches are commonly used in securing heavy weight shelving as well as electrical components; they are commercially available. The din latch was the datum due to its simplistic nature, and its resemblance to pre-existing products. Figure 32 shows the concept models for this function.

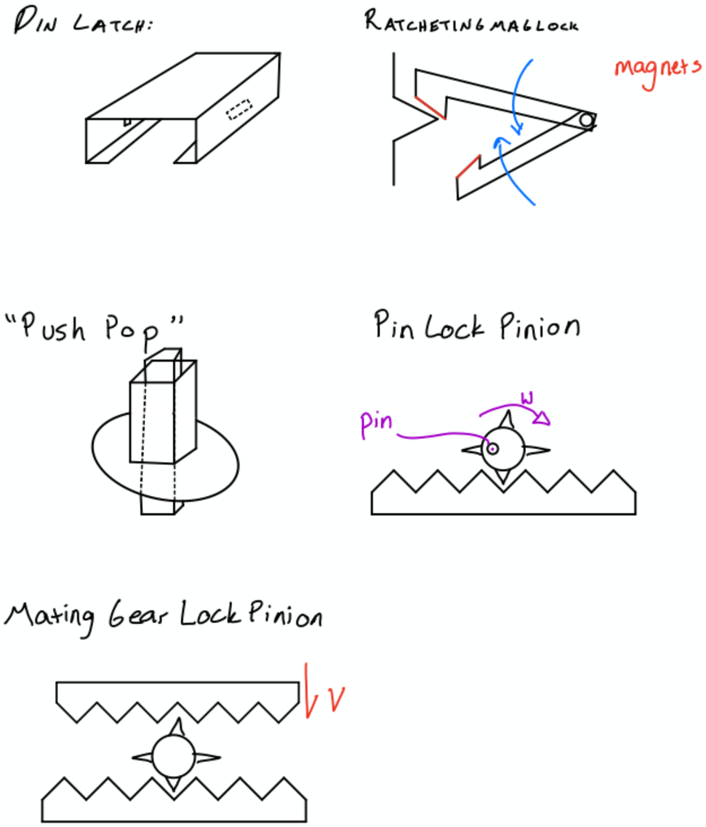


Figure 32. Track and Latch Locking Mechanism Pugh Matrix Designs

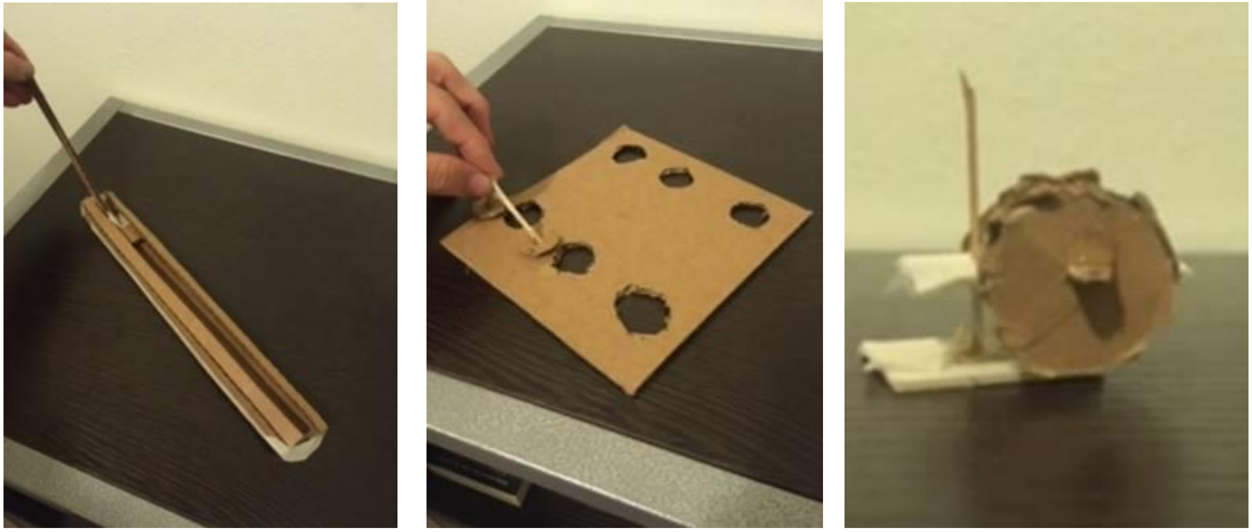
The ratcheting maglock is a simple ratchet type system with magnet-based locking. The primary advantage of this mechanism is that it is never fully disengaged. One of the locking magnets is always engaged as the system is moved. This does, however, result in a higher required moving force and much higher complexity. This type of ratcheting movement is also not as quick and efficient as the other designs. It also would require a system much larger than the din latch.

The push pop design relies on a rack and pinion drive and was deemed one of the better designs based on the Pugh matrix. The system disengages the casters that allow movement of seat, hence the name "push pop." This system is very secure with high reliability and safety, due to its high locking forces. It can also be design compactly allowing for efficient use of space. This system's major drawback is the necessity to design two systems to take the full weight of the system (one during locked mode and one during movement mode).

The pin-lock pinion system relies on a rack and pinion drive. The pinion allows the chair to be moved along the track. A pin inserted radially through the pinion locks the mechanism in place. While this system has a strong locking force and is reliable, it becomes more complicated the more position-ability that is required. Further, the rack will need to be covered to prevent guest inconvenience.

The mating gear lock pinion design is nearly identical to the pin lock pinion with the exception that the locking mechanism is a meshing rack that lowers onto the pinion and prevents movement. It is easier to position than the pin lock and is much more easily engaged and disengaged.

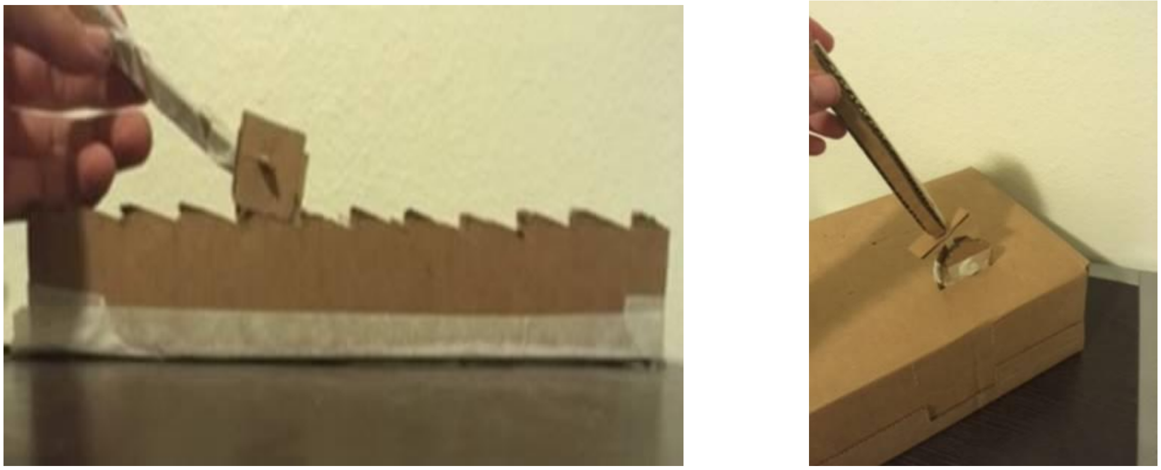
The final Pugh matrix covered the seat movement function. Concept models for seat movement are shown in Figure 33 below. The Here we used the sliding seat track as the datum due to its simplistic nature. The sliding track consists of a simple slot in the rail where the seat can easily slide back and forth. This track would run the length of the vehicle, and every seat would be on the same track.



Sliding Seat Track

Seat track with wheels and groves

Wheel with push-up pin mounts



Rack and Pinion

Swivel Wheel

Figure 33. Track and Latch Seat Movement Pugh Matrix Designs

The seat track with wheels and groves has circular feet with circular floor slots. This design is simplistic and is relatively simple to secure. However, this design involves completely detaching the seats from the track and moving them to the next hole. This could cause difficulty moving the seats and could be unsafe to maneuver.

The Wheel with push-up pin mounts involves mounted wheels on a track. These wheels would freely move along the track until pushed up, causing movement to stop. This system allows for easy translation due to the wheels, with a minimal movement force required.

The rack and pinion system is exactly what it sounds like. The “wheel” would be the pinion, and the track the rack. With a small enough rack, this system could allow for configurations in any position. However, this system could be hard and complicated to secure.

The swivel wheel with floor slots is similar to a standard rolling chair with slots in the ground for the wheels to “click” in place. This system would allow for easy translation, as it rolls along the floor, and allows for a unique customization of the layout of the seats. However, this sort of movement would make seat securement extremely difficult, and since the seats completely detach from the floor, maneuverability could be unsafe and difficult.

5.2.3 Seat Articulation Pugh Matrices

The functions our team created Pugh matrices for included: user input/feedback, seat articulation, and locking mechanisms. The section below describes the designs compared in the Pugh Matrices. The Pugh matrices themselves are each depicted in Appendix L.

It should be noted that the user interface, user feedback, and locking mechanisms discussed in this section exist only within the context of articulating the seat. That is, the locking mechanism pertains to locking the seat between stowed and unstowed positions, and the user interface and feedback pertain to a user interacting with the seat to articulate it. These functions should not be confused with the functions of the other two teams. Figure 34 shows the designs in the Pugh matrix for our user input function. We set the Arduino push button as our datum due to its simplicity and ease of use.

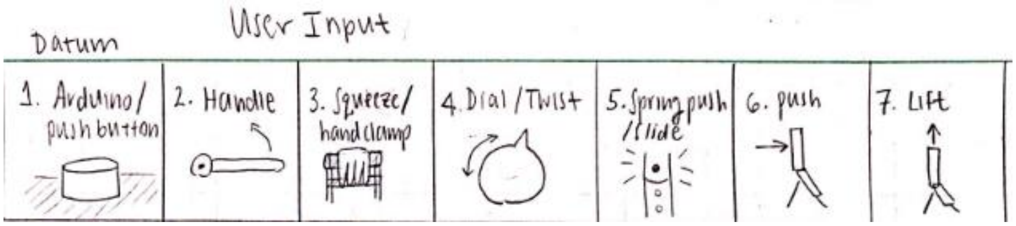


Figure 34. Seat Articulation User Input Pugh Matrix Designs

Based on our initial assessment, the handle and twist dial are the best options. They both allow for reliability, ease of manufacture, and are inexpensive. Also, these forms of user input are used in all sorts of products and work fantastically.

Figure 35 shows the Pugh matrix designs for user feedback. We set general observation as the datum for this Pugh matrix. Since the movement of the seats is on a larger scale, general observation could work since it is fast and efficient.

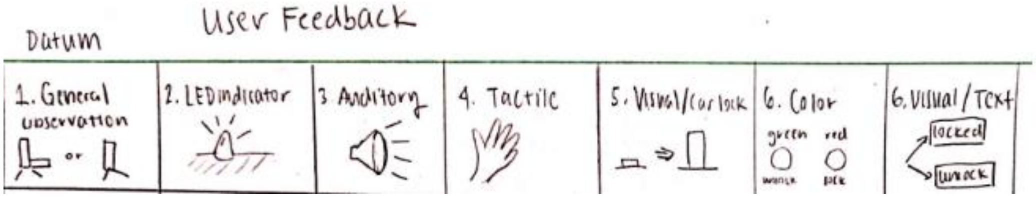


Figure 35. Seat Articulation User Feedback Pugh Matrix Designs

Based on this Pugh matrix, the tactile method for user feedback most efficiently meets the criteria. Since the user feedback mechanism is easily changed, multiple can be used if necessary. Other components such as auditory and LED indicators are also good systems for user feedback.

Figure 36 illustrates the concept designs for the Locking Mechanism Pugh matrix. This matrix focused on the locking mechanisms associated with latching the seat in its deployed and folded state at each end of the articulation path. A simple latch & pin was determined as the datum due to the simplicity of the design, and its universal use in latching applications.

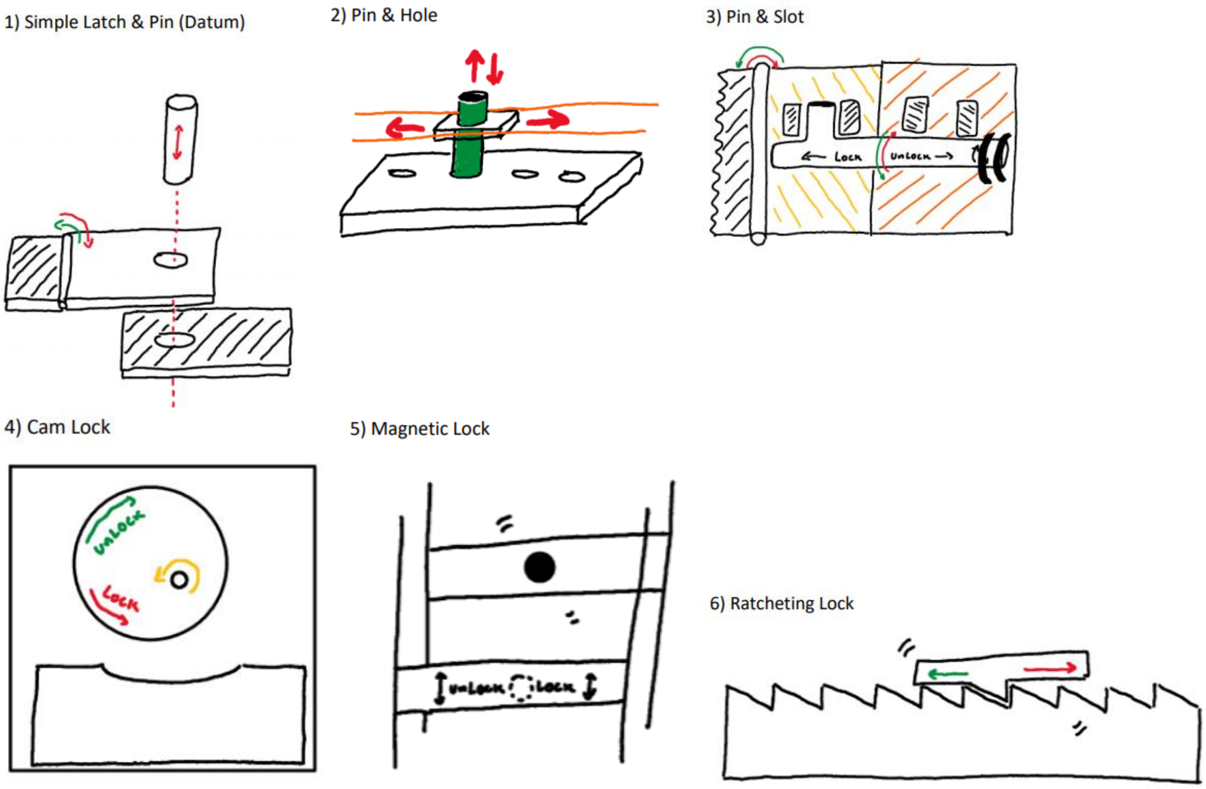


Figure 36. Locking Mechanism Pugh Matrix Designs

The simple latch and pin involved two concentric holes mated by a pin sliding between each hole, locking the geometries attached to the holes in place with one another. The pin and hole design was similar to this, however, it added another degree of freedom to the system, constraining the pin to the first hole, and restraining the movement to a guide rail. The pin and slot design was a latch mechanism that utilized a bar with an ‘L’ shaped geometry, positioned to slide axially along a fixed support. The ‘L’ shaped component could also rotate in and out of different locking positions, enabling multiple locking positions to be achieved. The cam lock utilized a circle mounted off its axis and friction to create a lock that could be engaged and disengaged. This concept however could work with any geometry to fit a specifically designed latch. The magnetic lock used magnets to snap into place when the correct proximity was achieved. Finally, the ratcheting lock consisted of grooves that allowed for unidirectional axial movement without separation of the components from one another. An initial review of the matrix yielded this ratcheting mechanism as the most beneficial locking mechanism.

At this point in the process, we recognized that the primary function of concern for PDR was the seat articulation. Because the locking mechanism and user interface functions could be easily adapted to best accommodate our seat articulation, they were considered secondary. Thus, moving forward we prioritized the seat articulation as the pivotal function in our concept ideation. Some of the concept models made for this function can be seen in Figure 37.

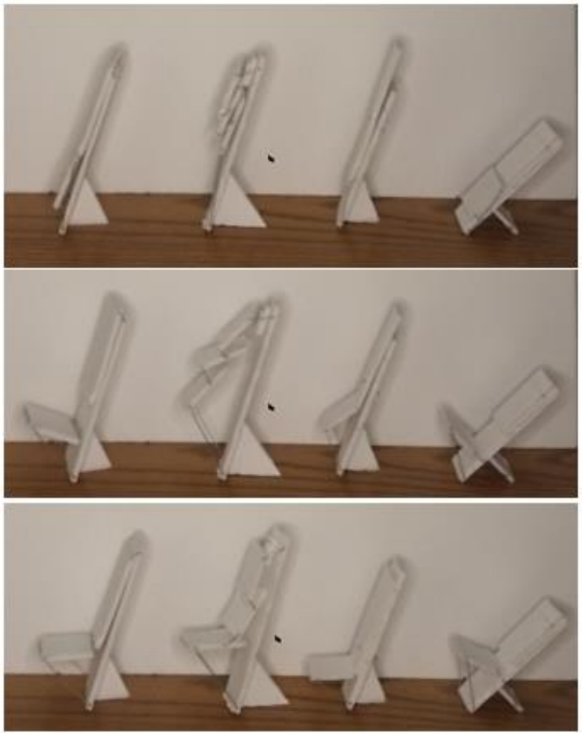


Figure 37. Articulation Concept Models

The Pugh matrices for the seat articulation were broken up into three subset matrices: seat movement which defined the seat bottom movement, back movement which defined the seat back movement, and seat nesting which depicts how the seat parts interface with each. Different combinations of these three movements defined our overall seat articulation. For each of these Pugh matrices, the datum utilized was the seat articulation utilized in the second of the two prior Senior Projects.

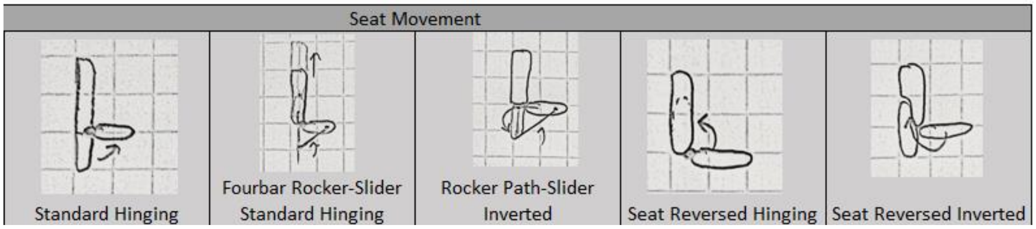


Figure 38. Seat Articulation Seat Bottom Pugh Matrix Designs

The design alternatives considered for the movement of the seat bottom are summarized in Figure 38. The Standard Hinging option folds down (Standard) with no back movement. This was the design the first iteration Senior Project utilized, with a removable pin to actuate. The Four bar Rocker-Slider moved by lifting the seat back up, causing the seat to fold down. This uses a four-bar linkage where the seat is connected to a rocker (going to the ground) and the seat back as a slider. This was the design the second iteration Senior Project utilized, with a linear actuator to provide powered motion. In the Inverted Rocker Path-Slider the seat dives down (inverted) with no vertical back movement. This is also a four-bar linkage transformation, with the back of the seat bottom running along a slot that determines its path. The Seat Reversed Hinging simply folds the seat up (Reversed) into a hollow section of the seat back. Finally, the Seat Reversed Inverted tucks the seat under the seat back. The rocker-slider seat movement, despite being the datum, was found to be the optimal design in this matrix as it is fairly simple and does not contain any specific design flaws.

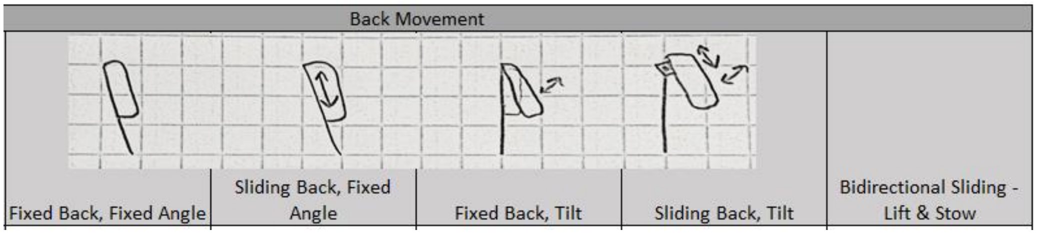


Figure 39. Seat Articulation Seat Back Pugh Matrix Designs

The design alternatives considered for the movement of the seat back are summarized in Figure 39. For the back motion, the first four motions considered are rather self-explanatory. The fifth motion considered was the ‘Bidirectional Sliding’ option. For this option, motion occurs in both directions over the course of articulating the seat. This gives a wide variety of design options, most notably allowing for the motion at each end of the articulation to be downward and eliminating the need for any sort of retaining latch. As a result, the Pugh matrix indicated this to be the optimal motion, followed closely by the fixed/sliding option.

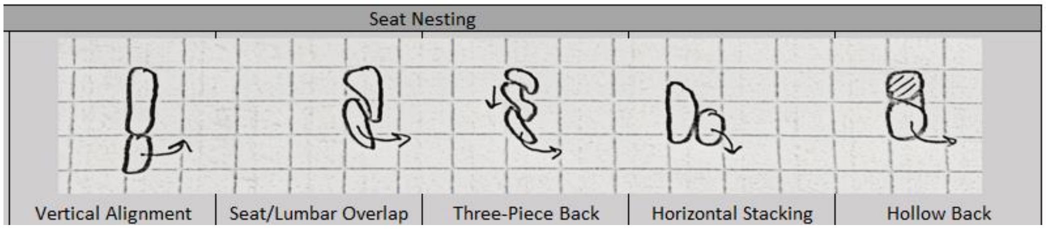


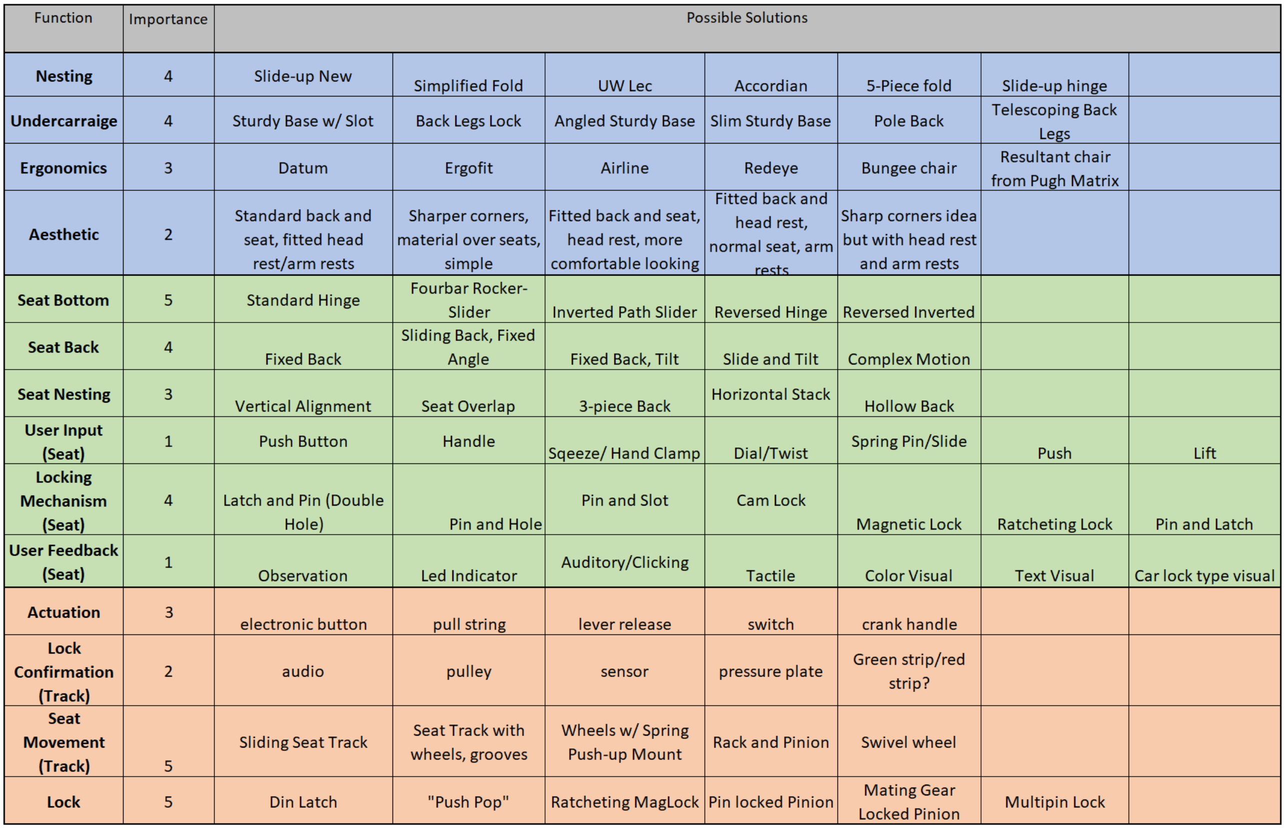
Figure 40. Seat Articulation Seat Nesting Pugh Matrix Designs

The design alternatives considered for the nesting method of the seat are summarized in Figure 40. Of the nesting alternatives, the simplest options were the vertical alignment and horizontal stacking, each of which could be accomplished with relatively simple mechanisms. The hollow back option was in essence a reduction of the horizontal stacking into a combined vertical space, reducing final volume. The lumbar overlap and three-piece back further attempted to reduce volume by collapsing additional components into a smaller space. Based on the matrix results, it was apparent that the increased complexity of such space-saving measures and the significant cost increases of custom-made seat components lead to a preference for simpler options. As such, the vertical alignment was found to be the preferred design.

5.3 Morphological Matrix

After completion of initial ideation, the three teams converged to complete a morphological matrix. This was done in order to see which designs would work best with each other and acted as the first time that the system overall was considered. The morphological matrix, shown in Table 12, was broken up into three sections, one for each team's functions. The blue section signals the system and demo team, green for seat articulation, and red for track and latch. Combined, these sections make the entire morphological matrix and show all the design options for each function of the system.

Table 12. Rapidly Configurable Seat Morphological Matrix



Function	Importance	Possible Solutions						
Nesting	4	Slide-up New	Simplified Fold	UW Lec	Accordian	5-Piece fold	Slide-up hinge	
Undercarraige	4	Sturdy Base w/ Slot	Back Legs Lock	Angled Sturdy Base	Slim Sturdy Base	Pole Back	Telescoping Back Legs	
Ergonomics	3	Datum	Ergofit	Airline	Redeye	Bungee chair	Resultant chair from Pugh Matrix	
Aesthetic	2	Standard back and seat, fitted head rest/arm rests	Sharper corners, material over seats, simple	Fitted back and seat, head rest, more comfortable looking	Fitted back and head rest, normal seat, arm rests	Sharp corners idea but with head rest and arm rests		
Seat Bottom	5	Standard Hinge	Fourbar Rocker-Slider	Inverted Path Slider	Reversed Hinge	Reversed Inverted		
Seat Back	4	Fixed Back	Sliding Back, Fixed Angle	Fixed Back, Tilt	Slide and Tilt	Complex Motion		
Seat Nesting	3	Vertical Alignment	Seat Overlap	3-piece Back	Horizontal Stack	Hollow Back		
User Input (Seat)	1	Push Button	Handle	Sqeeze/ Hand Clamp	Dial/Twist	Spring Pin/Slide	Push	Lift
Locking Mechanism (Seat)	4	Latch and Pin (Double Hole)	Pin and Hole	Pin and Slot	Cam Lock	Magnetic Lock	Ratcheting Lock	Pin and Latch
User Feedback (Seat)	1	Observation	Led Indicator	Auditory/Clicking	Tactile	Color Visual	Text Visual	Car lock type visual
Actuation	3	electronic button	pull string	lever release	switch	crank handle		
Lock Confirmation (Track)	2	audio	pulley	sensor	pressure plate	Green strip/red strip?		
Seat Movement (Track)	5	Sliding Seat Track	Seat Track with wheels, grooves	Wheels w/ Spring Push-up Mount	Rack and Pinion	Swivel wheel		
Lock	5	Din Latch	"Push Pop"	Ratcheting MagLock	Pin locked Pinion	Mating Gear Locked Pinion	Multipin Lock	

This process included collaboration in small groups with members of all three teams so that all teams' interests were represented while ideating on system designs from the morphological matrices. From the overall morphological matrix, each subgroup selected a combination of the possible ideas from each function to create an overall product concept design. The concept designs from the morph matrix for each subgroup are shown in Appendix N.

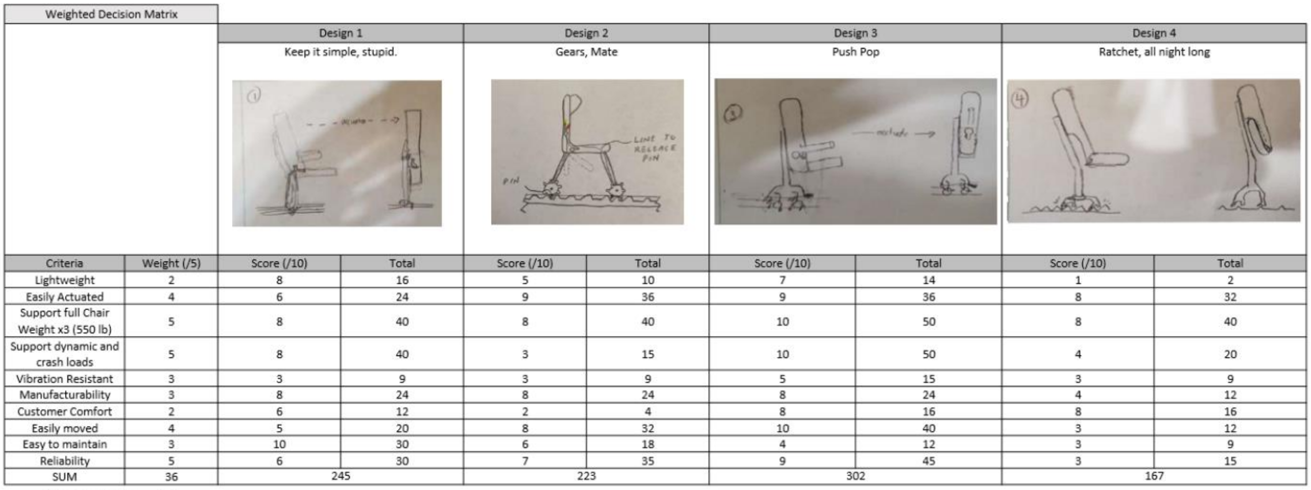
5.4 Weighted Decision Matrix

After collaborating to create these concept designs, each team created their own weighted decision matrix to help narrow the concepts down to the top ideas that best fit their individual criteria. During this process it became apparent that the system and articulation designs were heavily dependent on each other, while the track and latch design was more independent since it could most likely be adapted to almost any seat base. Because of this, the system and articulation teams collaborated on a single decision matrix to select the overall articulation that the rest of the seat would be designed around, while keeping in mind the system requirements, too. The track and latch team diverged from the group and made their own decision matrix, focusing solely on the goals of their subsystem.

5.4.1 Track and Latch Team Weighted Decision Matrix

The track team created four designs that we placed into the Weighted Decision Matrix: keep it super simple (aka KISS), gears/mate, push pop, and ratchet all night long. Each design has a sketch at the top of the decision matrix in Table 13.

Table 13. Track and Latch Weighted Decision Matrix



Weighted Decision Matrix		Design 1		Design 2		Design 3		Design 4	
		Keep it simple, stupid.		Gears, Mate		Push Pop		Ratchet, all night long	
Criteria	Weight (/5)	Score (/10)	Total	Score (/10)	Total	Score (/10)	Total	Score (/10)	Total
Lightweight	2	8	16	5	10	7	14	1	2
Easily Actuated	4	6	24	9	36	9	36	8	32
Support full Chair Weight x3 (550 lb)	5	8	40	8	40	10	50	8	40
Support dynamic and crash loads	5	8	40	3	15	10	50	4	20
Vibration Resistant	3	3	9	3	9	5	15	3	9
Manufacturability	3	8	24	8	24	8	24	4	12
Customer Comfort	2	6	12	2	4	8	16	8	16
Easily moved	4	5	20	8	32	10	40	3	12
Easy to maintain	3	10	30	6	18	4	12	3	9
Reliability	5	6	30	7	35	9	45	3	15
SUM	36	245		223		302		167	

***Max Possible Score: 360**

We ranked how each design met our various criteria. The list of criteria each had a relative weight out of five. If the criterion was more important, it had a higher number. We then deemed how well each design fulfilled each criterion by giving it a number out of ten. The larger the number, the better it met the criteria. By the end, the push pop design ranked the highest followed by the Keep it super simple (KISS) design.

5.4.2 Demo System + Seat Articulation Decision Matrix

For the System and Articulation decision matrices, four main designs were considered, all based of off unique articulations that the rest of the seat was designed around. The first concept, shown in Figure 41, was the most complicated design out of the four concepts explored. It featured a seat that would stow away using a ratchet system so that it would be flat with the seatback. To compensate for the new space needed for the seat bottom to stow away, the seat back would-be adjustable height wise sliding up and down supporting poles. The downfall of this design is due to the complicated nature of how the chair would interact with the track rails, with only the poles connecting to the tracks leaving not much support for any applied moments.

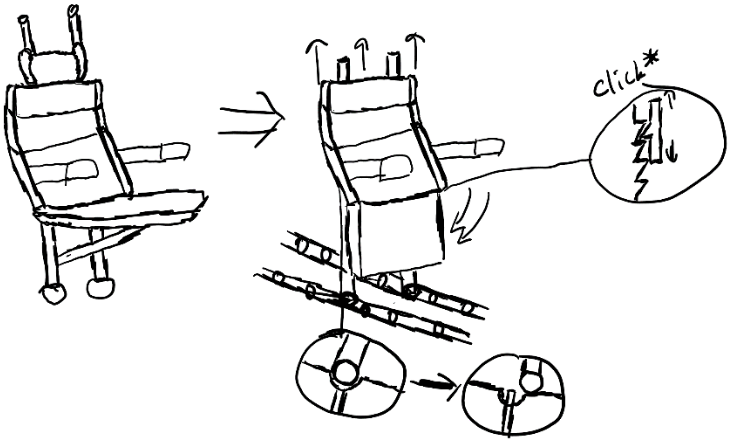


Figure 41. First Concept Design

The second concept, shown in Figure 42 focused on simplicity and minimalism for ease of manufacturing and usage. The seat would fold up like a stadium seat and the sturdy base would incorporate a slot to guide the supporting struts so they would simply lock in place due to their position in the slot. This results in a very simple and intuitive motion, with a basic, thinner seat.

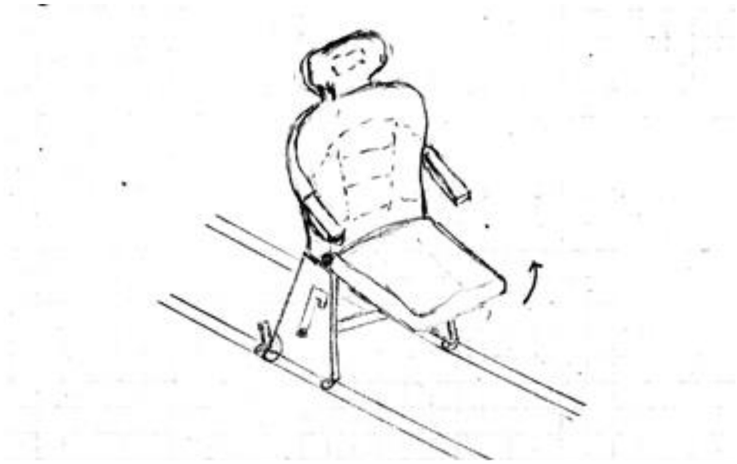


Figure 42. Second Concept Design

The third concept used a standard chair back and seat with an added headrest and armrests for comfort. The articulation method used was a hinged seat that forced the seat and back to be in one line which would make nesting with other chairs easy. This design can be found below in Figure 43.

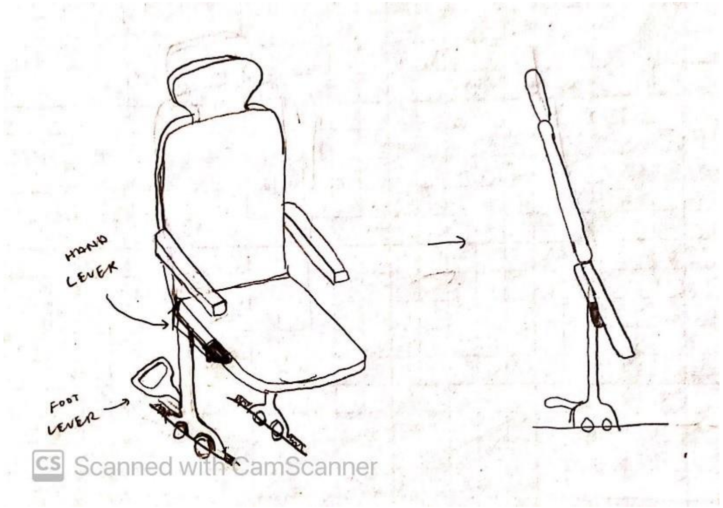


Figure 43. Third Concept Design

The fourth concept consists of a standard seat and a back that is cut out to fit perfectly with the seat, as illustrated in the side view, collapsed in Figure 44. The seat and back are connected to a bar that rotates at both connection points. The motion of the bar allows for the sitting and collapsed positions to be easily achieved. The legs are stationary and connect to the back and the track.

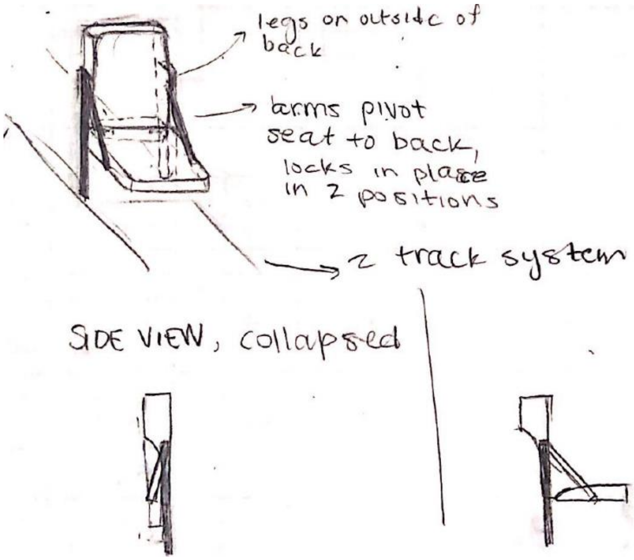


Figure 44. Fourth Concept Design

After the Demo System team and Seat Articulation team completed their individual weighted decision matrices (Appendix N), it was found that different final designs were chosen by each team. This discrepancy in outcome was due to differences in judging criteria between each team. Subsequently, both teams performed a second decision matrix together using a combined set of criteria to weigh the top three designs from the individually conducted decision matrices. These top three designs each had a unique articulation, which the overall system design would need to design around.

Design 1 consisted of an articulation system that utilized a four-bar linkage to allow for back tilting adjustments and a smaller stowed position than the other designs. This articulation tilted the seat down to store vertically flush with the seat back. Design 2 focused on a more simplified hinging articulation that folded the seat up. It achieved this via a slotted path in the seat base. Finally, Design 3 used an inverted articulation that moved the seat bottom behind the seat back for storage.

To further develop and understand these top designs, both teams created concept models to demonstrate the feasibility and functionality of these designs as shown in Table 14. The demo system team focused on creating models that delineated the ergonomics and aesthetics of each design. While the articulation team focused on creating models that demonstrated the motion of the seat through 2D foam core representations.

Table 14. Concept Models for the Top Three Articulation Designs

Design 1	Design 2	Design 3
		
		

By building these prototypes, we gained insight into how each articulation would affect the seat itself. For Design 1 which used a linkage system, the articulation would allow for the most freedom of what the seat could look like and was the only option that would allow for the seat to be at an angle which makes it the most ergonomic of the three. Design 2 was the simplest which would help with cost and manufacturability, but it would also leave little room to add features to make the seat ergonomic and aesthetic. For Design 3 the seat bottom would nest into the back of the seat which would allow for the seat to nest efficiently, but the design is not intuitive and would also not allow for the seat to have many ergonomic features.

Now with more insight into each design after creating the concept models, the second decision matrix was created, as seen in Table 15. The Articulation criteria is highlighted in green, and the Demo criteria is highlighted in blue, with both sets contributing to the outcome of the decision matrix.

Table 15. Seat Articulation and Demo System Weighted Decision Matrix

Weighted Decision Matrix		Design 1 Four bar		Design 2 Fold		Design 3 Nest in Back	
Criteria	Weight	Score	Total	Score	Total	Score	Total
Seat Storage Space	0.14	4	0.57	2	0.29	3	0.43
Strength/Stiffness	0.11	4	0.44	5	0.55	1	0.11
Operation Effort/Time	0.12	2	0.24	3	0.36	3	0.36
Weight	0.01	3	0.03	4	0.04	3	0.03
Manufacturability	0.05	3	0.16	4	0.22	3	0.16
Operating environment	0.02	3	0.07	3	0.07	3	0.07
Intuitive Design	0.10	4	0.40	4	0.40	3	0.30
Design Compatibility	0.04	5	0.22	2	0.09	1	0.04
Nest next to adjacent chairs	0.13	5	0.66	2	0.26	4	0.53
Durability of seat	0.09	3	0.26	4	0.35	4	0.35
Ergonomic Design	0.08	4	0.31	1	0.08	3	0.23
Competitive Pricing	0.03	2	0.07	4	0.13	3	0.10
Aesthetically Pleasing	0.07	4	0.26	4	0.26	3	0.20
SUM	1		3.69		3.10		2.91

From this matrix, the design for PDR was reduced to two designs, designs 1 and 2, due to their strength and spatial efficiency among other characteristics. However, design 1 had the potential to be much more ergonomic than design 2 due to the nature of its packaging and would also offer a much more elegant articulation and nesting solution if done properly.

5.5 Selected Concept Design

From the results of the weighted decision matrix, design 1 was selected to move forward with. However, our sponsors did have concerns about the feasibility of this design's articulation due to its complex motion path. Going forward the articulation team aimed to prove that this design 1 could be made intuitive for the user, with the system team designing a seat system that would accommodate this articulation. Due to the relative independence of the track and latch team, they did not need to design for specific compatibility with design 1, since their system would work with practically any seat base that was selected. With confidence from the articulation team on the feasibility of their design, all teams moved forward with a full design for design 1, with the system and articulation teams working closely together to make sure that both of their designs were compatible.

5.5.1 Selected System and Demo Concept Design

With the design selected from the weighted decision matrix, the specific features of the overall "system design" were defined with a preliminary CAD model. This CAD model encompasses the seat cushion, base, and preliminary interactions with the articulation linkages as shown in Figure 45. The overall features from the decision matrix include an ergonomically fit seat with armrests, standard aesthetics, and a slim study base. The track-latch system is not shown in the CAD since that interaction has not yet been designed.

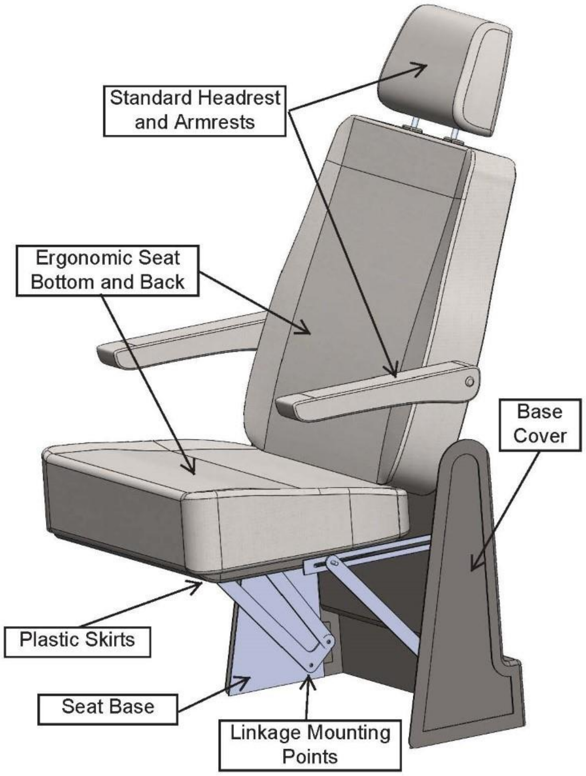


Figure 45. Isometrix View of Concept CAD

The seat cushion and general seat shape were designed to satisfy the decision matrix goals of being ergonomically fit with armrests, a headrest, and a contoured seatback, along with the standard aesthetics of a general sprinter van seat. To determine the basic dimensions and shape that would provide the greatest comfort for the occupant of the seat, we referenced existing collapsible van seat models and normal automotive seats (see Appendix O) as well as a study concerning automobile seat ergonomics. The Freedman 3PT seats are fold-away seats designed to fit Sprinter and Promaster vans. We used its dimensions as well as dimensions found in *Survey of Auto Seat Design Recommendations for Improved Comfort* to complete the shape and size of our seat, which is summarized in Figure 46.

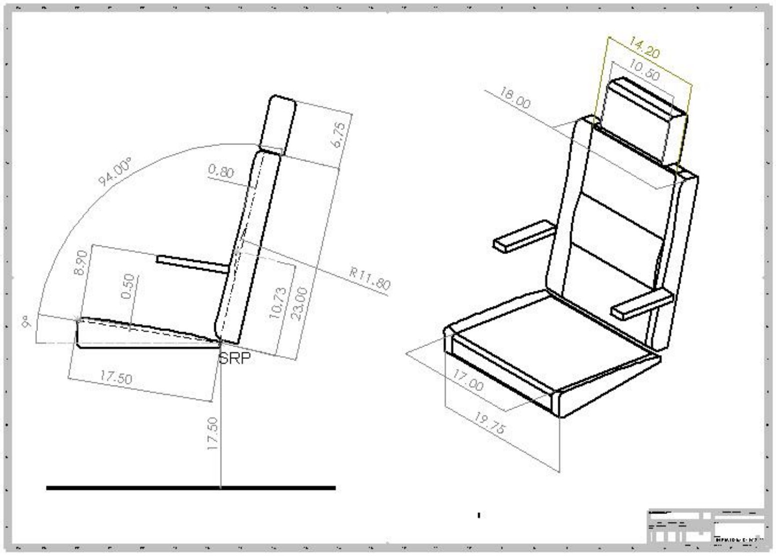


Figure 46. The Basic Dimensions the Seat Must Maintain to Satisfy Ergonomic Concerns

With the general location and dimensions of the cushion, armrests, and headrests defined, the shapes and outlines of the components were arbitrarily defined to create an aesthetic feel to the seat. The aesthetics were inspired by general van seats found on the internet like those shown in Figure 47. This resulted in the outer contours shown in the isometric view. These can be adjusted for personal taste as the base ergonomic dimensions are defined and constant, but the outer contours are arbitrary. As for the material and color of the seat, these have not been fully selected yet and will be focused on in the future design.

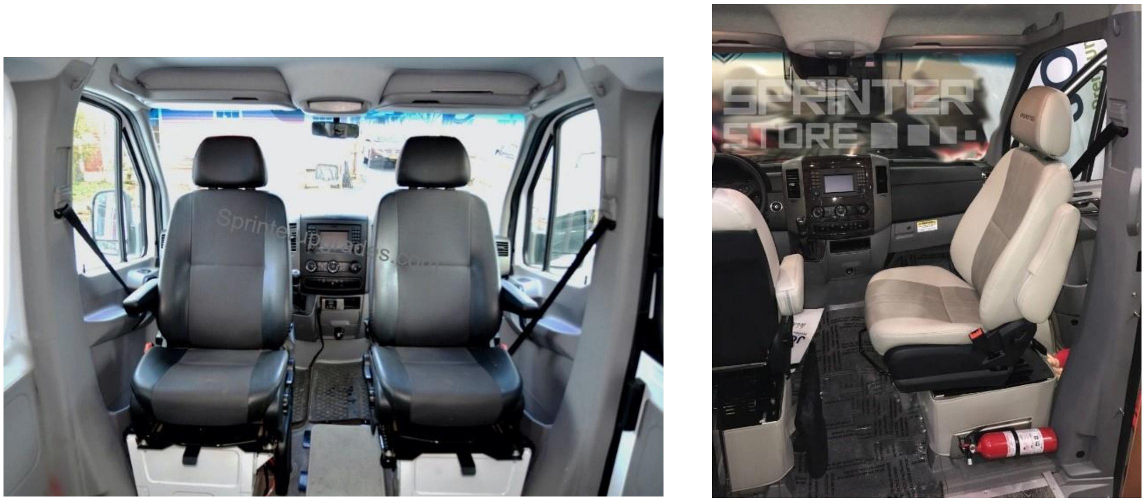


Figure 47. General Seating Styles and Aesthetics of Sprinter Vans

To define the shape of the seat base, the main considerations were to match the “slim, sturdy base” style defined in the decision matrix and to offer mounting points defined by the proposed articulation. The structural component of the base is proposed to be a steel plate with two holes in the appropriate locations for articulation mounting and a triangular shape for structural reasons. The size of the base is influenced by the size of the seat cushion, so that it is just big enough to cover the cushion to not take up any additional space for optimal nesting. This design along with the nesting method contributes to about 71% of floor spaced saved in the nested configuration, as shown in Figure 48. The official structural requirements defined by the FMVSS vehicle codes 207-210 have not yet been accounted for in the design, so the thickness of the seat base is currently arbitrary. With future analysis, the seat thickness and shape will be optimized to meet these requirements. If this analysis shows that this shape style will not be sufficient, then other options from the initial morphological matrix will be investigated.

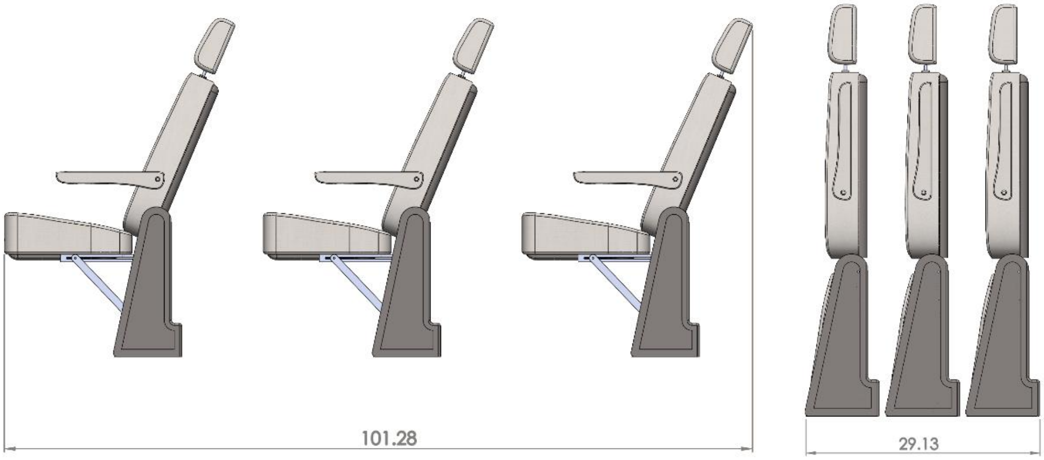


Figure 48. Nesting of Concept Designs

To create a more aesthetic base, protect many of the moving components, and shield pinch points, a base cover was designed. This cover would most likely be a molded plastic and cover the sides and back of the seat base. The shape is defined by the components and their motion to not take up any additional space. The rear portion of the cover is not completely necessary, but it does simplify the component. If needed, the base cover could be split up to cover the moving components on each of the sides of the base instead, leaving the middle open. This will be investigated more when the mounting locations of all the linkages are defined.

The interaction points for the articulation are currently only defined in the seat base mounting holes. The current CAD model shows where the linkages would mount and how they would move but does not show the details on how they will be attached or where they will lie along the width of the seat. This will be one of the main focuses of our design in the future as mounting methods must be selected to ensure the safety of the passenger through its structural rigidity and the minimization of exposed moving parts and pinch points. The linkages also should be concealed and streamlined into the seat design for aesthetic purposes, so plastic skirts were added in the CAD to create a compartment the linkages would be able to mount in. They would also cover up the internal framework of the seat, which the linkages would mount to. These mounting points will also be contingent on this internal structure of the seat, which is not yet defined. This will also be a main point of focus as to ensure the seat itself will be able to meet FMVSS requirements. Lastly, the track system mounting has not yet been designed and will also be a focus in the future.

In addition to the CAD model, a full-scale concept prototype was created to check if the dimensions were reasonable. This prototype was simplified since the main purpose was a sanity check and to make sure that the size was realistic before moving forward. As seen below in Figure 49, this prototype was compared to an adult male and a normal car seat in order to check sizing.

Figure 49. Comparison of Concept Prototype at Full Scale Dimensions

This prototype showed that the dimensions are viable as we moved into more detailed design. Since we were using dimensions that we found were standard for vehicles, building the seat at full scale allowed us to check that these dimensions would be comparable to existing car seats. It also allowed us to make sure that the seat would allow for an adult male to comfortably sit in the seat with our chosen dimensions.

5.5.2 Selected Track and Latch Concept Design

Based on our above decision matrix, we decided to further develop the “Push Pop” system into our final design. Our group concluded that designing our latch around a standard, stock track would result in the most effective approach. We selected the Koller Low Profile Rail (product code: KFP0021) and used its dimensions shown in Figure 50 to design our latch. The resulting “Push Pop” design is illustrated in Figure 51-Figure 53 below. Note that our designed latch is shown in red and the stock track is shown in gray.

Figure 50. Koller Low Profile Rail

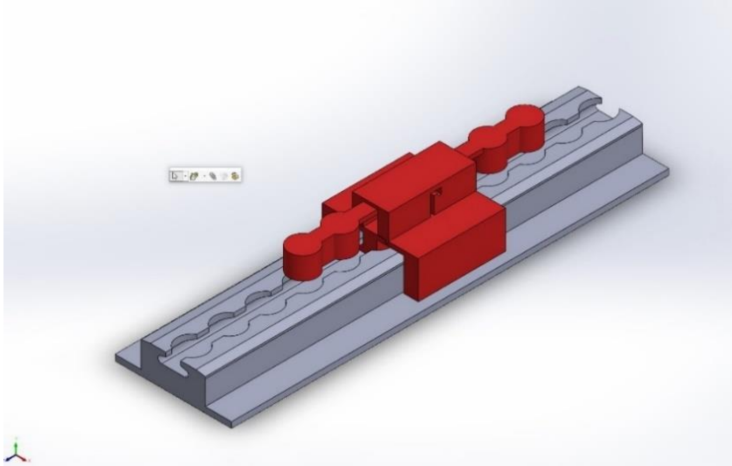


Figure 51. Unlocked Latch Isometric View

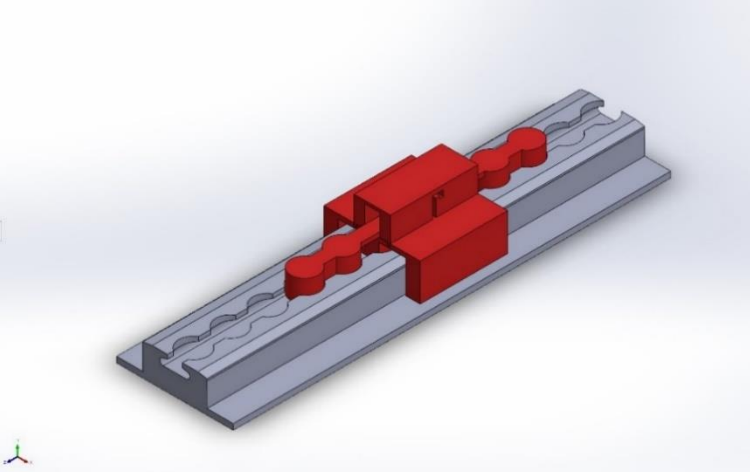


Figure 52. Locked Latch Isometric View

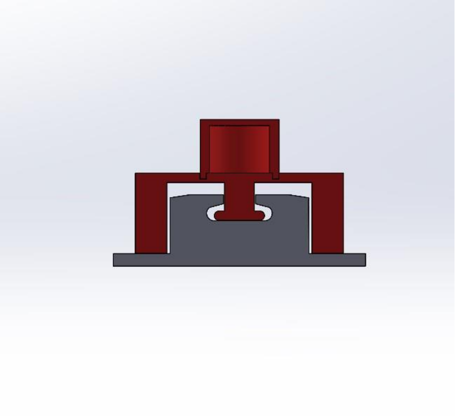


Figure 53. Latch Front View

As can be seen in Figure 51-Figure 53 above, the latch is comprised of two main components: the Housing, and the Interlocking pin. The Housing will slide into the track as shown in Figure 53, and its main purpose is to hold the pin in line with the track and secure it in the locked and unlocked positions. In further iterations of the design, wheels or sliders may be added to the sides of the housing to decrease friction between the track and latch and allow for easier movement in the overall system. The interlocking pin was designed with a “double pin” profile on both the front and the rear side to reduce moments in all directions when the pin is in the locked position. Further dimensioning and detail on actuation of the latch between the two positions will be developed during detail design.

5.5.3 Selected Seat Articulation Concept Design

The framework of Design 1 was chosen as the final candidate from our combined decision matrix and thus refined for our final design for PDR. Specifically, there were two main concerns addressed in this refinement –the strength of the tilting seat back (ensuring that it is properly supported) and the interconnection of the tilting and seat-folding motions (ensuring mechanical viability and reducing the system to one degree of freedom/single input motion).

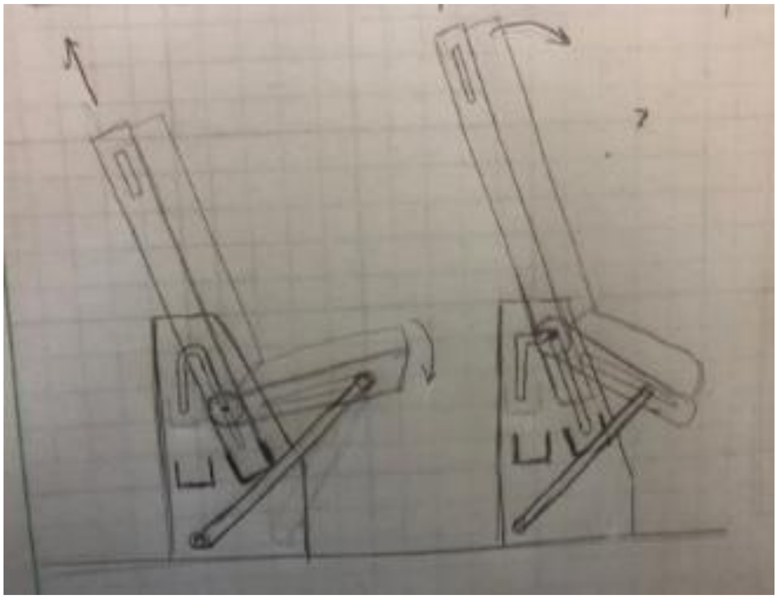


Figure 54. Seat Articulation Sketch 1

To ensure suitable support for the seat back, we took advantage of this design's greatest strength: the downward direction at each end of the motion. By applying an extension to the seat back link, the link could slide into an indexed slot that would provide mechanical support for any loads on the seat back and restrict the seat from moving unexpectedly (Figure 54). Additionally, this design lent itself well to a slot-path to guide the motion between the two locations, thereby restricting the design to a single required input motion (Figure 55).

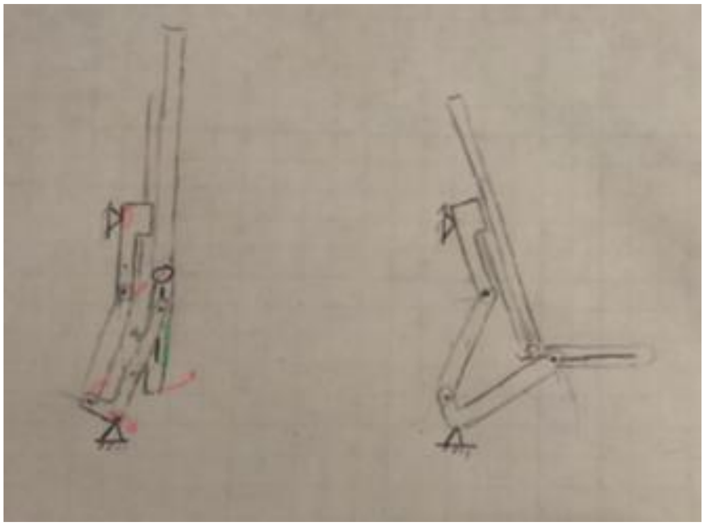


Figure 55. Seat Articulation Sketch 2

In our original concept design, the seat back and seat bottom were interconnected by a mechanism on the seat bottom that would act as either a pin (fixed at a single point) or a slider (linear motion, no rotation) depending on the angle of the seat bottom. This was not an ideal solution for various reasons, most notably the lack of availability of a stock component for this type of motion. As such, several other options were explored. The optimal solution identified was a simple four bar linkage conjoining the two motions. The design evolved from a simple rocker-slider linkage with difficult mechanical additions to two conjoined linkages (a slot-path-slider linkage and a simple four bar linkage) which define the location of the seat bottom. Between this solution and the slot-path/index-slot solution, Design 1 was refined into a PDR-ready solution.

In order to develop sufficiently accurate dimensions to prove the concept, a graphical method of geometric equivalency was utilized. In a SolidWorks sketch, the two end constraints of the seat position were defined, then the design's four-bar linkage was applied with arbitrary fixed points. By altering the dimensions applied to the sketch, the design was iteratively developed to an appropriate geometry (Figure 56). While these dimensions allowed for the development of concept models and prototyping, they will be further refined to optimize the design using analytical methods.

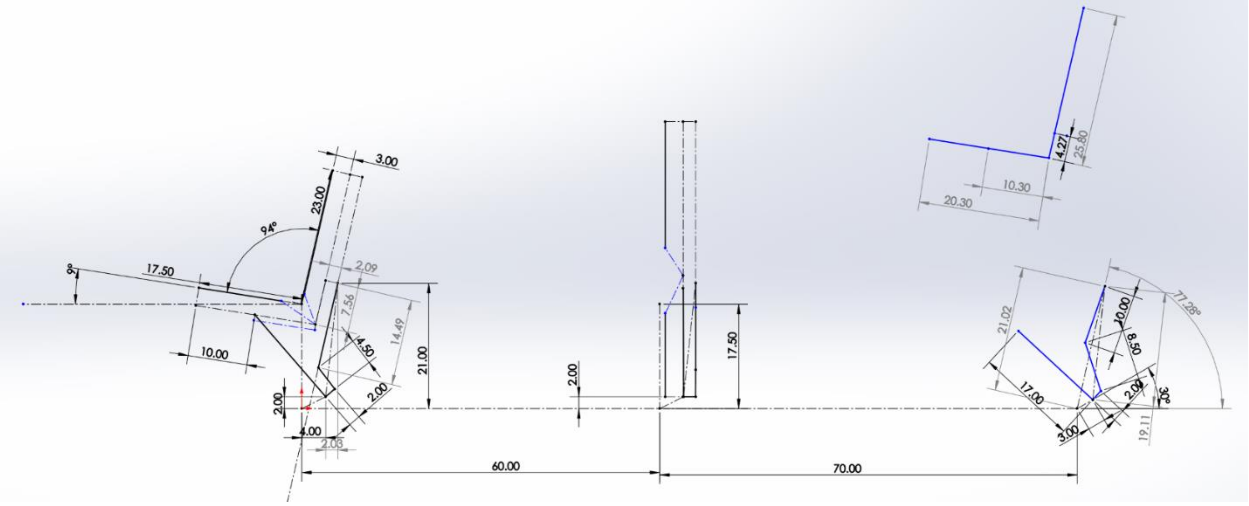


Figure 56. SolidWorks Geometric Equivalency Linkage Solution

From these dimensions, a CAD model was developed to prove the mechanical viability of the design. The concept CAD was then utilized to guide the construction of the concept prototype. The CAD model is displayed extensively in Figure 57.

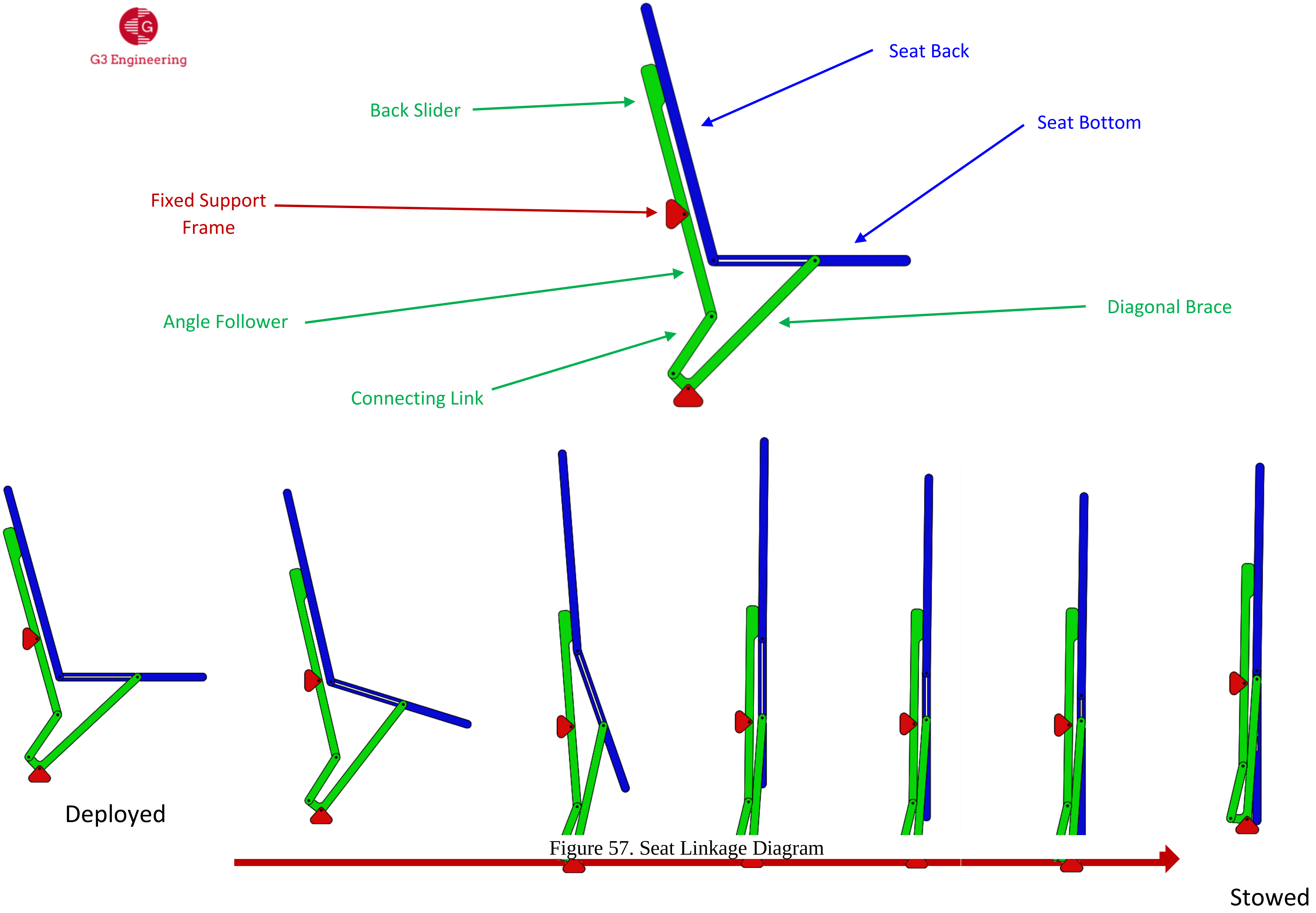


Figure 57. Seat Linkage Diagram

For rigidity and structural demonstration, the prototype was constructed out of surplus ½ inch prefinished plywood, with ¼ inch bolts acting as pins (Figure 58). To demonstrate the motion, a time-lapse image was taken (Figure 58), as well as photos of the front and back views at a critical position in the movement (Figure 59). The design functioned as intended and illuminated several minor refinements that need be made – for example, the guide slot will not necessarily be able to be perfectly linear on either end causing difficulties for the planned structural supports near the guide pin. None of these flaws were critical; they will be minimized as possible in further detailed design but do not affect the viability of our chosen design direction.

Figure 58. Still Frame Representation of Seat Articulation Path

Figure 59. Single Position Display of Prototype

To show all components, two images are included; the linkage is displayed on the left and the guide slot is displayed on the right.

5.6 Preliminary Design Risks

With our preliminary designs finished each team performed a FMEA analysis to prepare and plan for possible design risks. This FMEA helped discover the aspects where failure is most likely to occur. Using this knowledge, each team thought up preventative measures limit and stop these failures. These techniques range from increase the factor of safety during design to performing stress tests on our function prototypes.

5.6.1 System and Demo Design Risks

When moving forward with this design, there are some risks and challenges that we foresee having to work through as we create a more detailed design. A main challenge that still needs to be worked through is better integration of the linkage system and the chair. Although the design does have preliminary connection points established, these will likely be changed to be more aesthetic and provide more support to the chair.

Another risk going forward will be determining possible pinch points from the seat and linkage system and minimizing or concealing them. Currently the plastic base cover is designed for this, but this was not a primary concern when designing the system, so optimizing this will be a focus moving forward. Like mentioned before, the internal structure of the seat and the attachment to the track-latch system is not yet defined either, so these will need to be addressed in the future. Lastly, the overall weight of the system must be considered, which will be minimized as much as possible when selecting and sizing components.

5.6.2 Track and Latch Design Risks

Moving forward, the major risks in our “Push-pop” design are the life expectancy and lock confirmation. Since we do not know how often the seats will be unlatched, moved, and latched, it is difficult to give an estimated life for the latch in years. We may need to design a manual counter to tally the total number of times the latch has been engaged/disengaged and will include the estimated life for the latch in “uses” rather than units of time. Additionally, it may be difficult/impossible to visibly confirm that the latch has engaged, and it will be difficult/impossible to hear the audible click that indicates latch engagement in the high-noise environments that will be common for the operators. Therefore, designing means to confirm that the latch is engaged and secure may be a design challenge as we further develop the latch actuation device.

5.6.3 Seat Articulation Design Risks

Moving forward in the process, the major risks present in our design include lifetime wear, linkage strength, presence of pinch points, and binding. In relation to the lifetime estimation, our team is concerned about the number of sliding components and friction in the bearings. To counter this, we plan to utilize lubricant and Teflon washers where appropriate. Another concern is putting too much load on the linkages, however by transferring the brace load to the frame we can prevent this. Additionally, our team is concerned about the presence of pinch points which can be resolved by appropriately shielding parts. Finally, the mirrored frame basis for our design raises the concern of binding due to the two sides progressing at different rates. We plan to remedy this by ensuring the 3D movements do not interfere.

6.0 Final Designs

The main feedback from our sponsors was that our initial designs did not show how each system would integrate and work as a cohesive product, so this became our focus moving forward. In addition to complete integration, each team performed feasibility calculations and testing to make sure our product would be reasonable to manufacture and use as a customer. The culmination of these efforts is described in each team's final designs in the following sections.

6.1 System and Demo Final Selected Design

Since the PDR, the design of the seat has gone from a larger, cushioned seat to a smaller, plastic one that is fit for shuttle buses. We have changed the direction of our project from designing for vans to shuttle busses to cater more towards higher volume vehicles. More specifically, we will be designing for Startrans Bus's Candidate II to get concrete evidence that our seating system will be viable. However, for the final product, we hope to have a universal system for shuttle busses as to reach the entire market.

As mentioned, one of the biggest design changes was shifting from a cushioned seat style normally found in cars to a plastic shell seat like those in the transit industry. This swapped out cushions for a hard plastic to define the ergonomic seat shape and reduced the size and complexity of the manufacturing. The main focuses of our additional design changes were to ensure reasonable user comfort, smooth integration with the articulation and latch system, and ensure user and operator safety. This section will describe in detail our integrated final design, how it functions, how it will meet our specifications, floorplan layout, safety and repair considerations, and concerns for our next steps.

6.1.1 Description of Final Design

The final design will be an injection-molded seat made of polyethylene with handles, head support, armrests, and a thin layer of cushioning as seen in Figure 60. This design is sturdy enough to support to the passenger and light enough to allow for easy articulation. It is a lighter and more simple design than previous iterations for ease of articulation and integration into the appropriate vehicle. Currently these components are designed considering injection molding practices, like draft angles and ribbing, but before they are manufactured, they should be reviewed by a professional as these designs are mainly to convey the concepts.

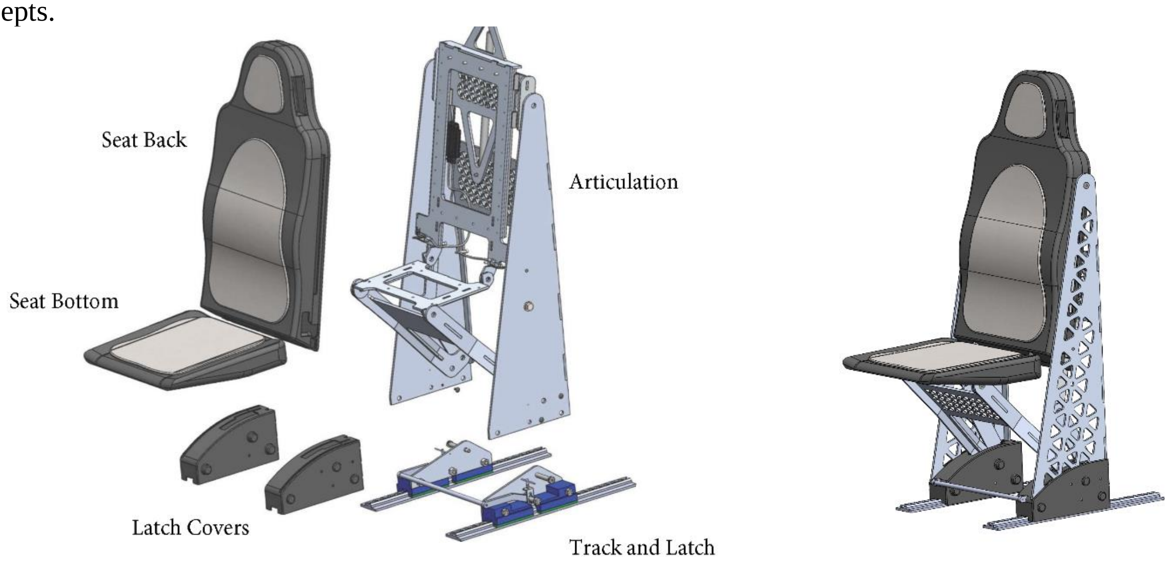


Figure 60. Full System Design

The seat has two main parts – the back and the base, the base is often referred to as the "seat". These two pieces will connect to the articulation plate frames so that they can move independently of each other and are more rigid laterally. The back and seat are shaped and angled to provide ergonomic support and include thin cushions for comfort. The overall color and aesthetics can be determined at the recommendation of our sponsors since all components can be selected or coated to be any color.

The seat base is a very simple hollow plastic part with a wall thickness of 1/4". Its main functions are to provide a comfortable seat for the user and to accommodate the articulation. The seat is notched and angled at the bottom so as to not interfere with the articulation linkages and diagonal plate when nested in the vertical position. The bottom of the seat base is indented 1.25" to fit the articulation plate within its profile. It also has ¼" holes molded into the bottom for threaded inserts to be placed, as seen in Figure 61, so the seat base can be mounted to the articulation plate.

Figure 61. Seat Base with Mounting Indents and Holes

The seat back is a more complex part and was designed to not only provide ergonomic comfort, but also to house a majority of the articulation components and provide an easy interface for the operator. It is comprised of two ¼" shells, the front and back, with the front providing the shape of the seat and the back acting as a housing for the articulation components. The seat back has a slot going up its side to allow for the back frame to slide vertically when articulating and has notches in the bottom to allow for the gas spring to pass through while in its nested position as shown in Figure 62. The seat back shells are split just in front of this slot. Lastly, there are handles molded into the sides of the head rest for the operator to grab while articulating. The seat is thin enough for the operator to grab the entire seat back, but the handles offer a convenient place to lift the seat by. Overall, this shape is just big enough to house the main articulation components while also providing some ergonomic shape for the user.

The interior of the two shells have mounting holes and reinforcing ribs molded into their shape as shown on the left in Figure 63. The front is mounted to the articulation frame via ¼" screws and threaded inserts in the molded holes. The back is mounted to the front via long ¼" Allen head screws that can be accessed from the outer face of the back and go all the way through to the threaded inserts in the front panel as seen on the right in Figure 63. These holes are counterbored into the back of the seat back so they sit set back from the surface

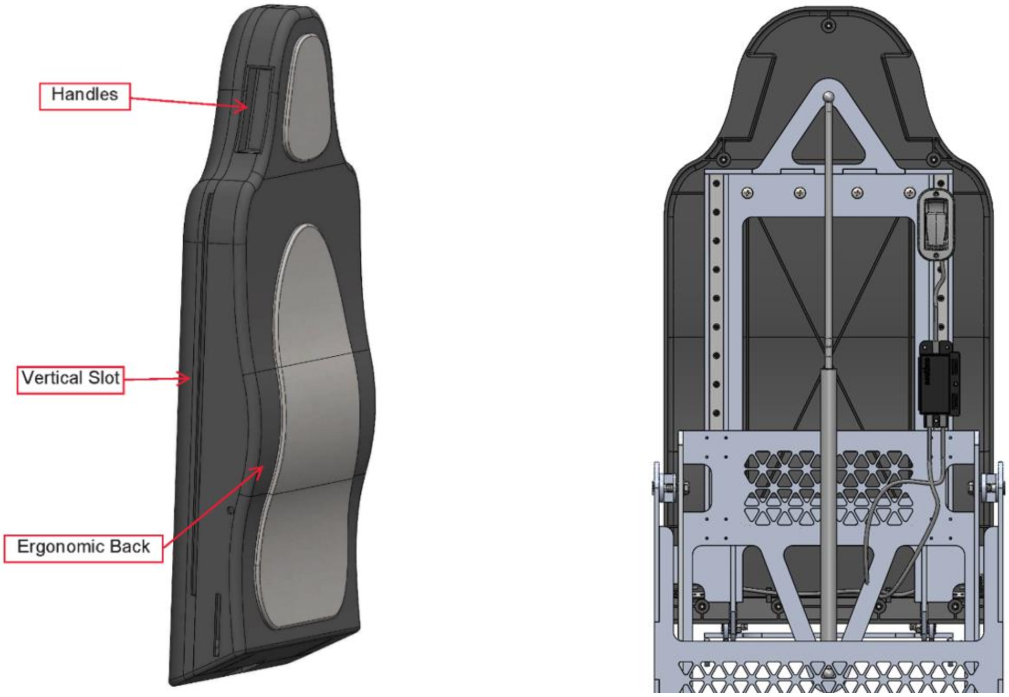


Figure 62. Seat Back Features and Articulation Nesting

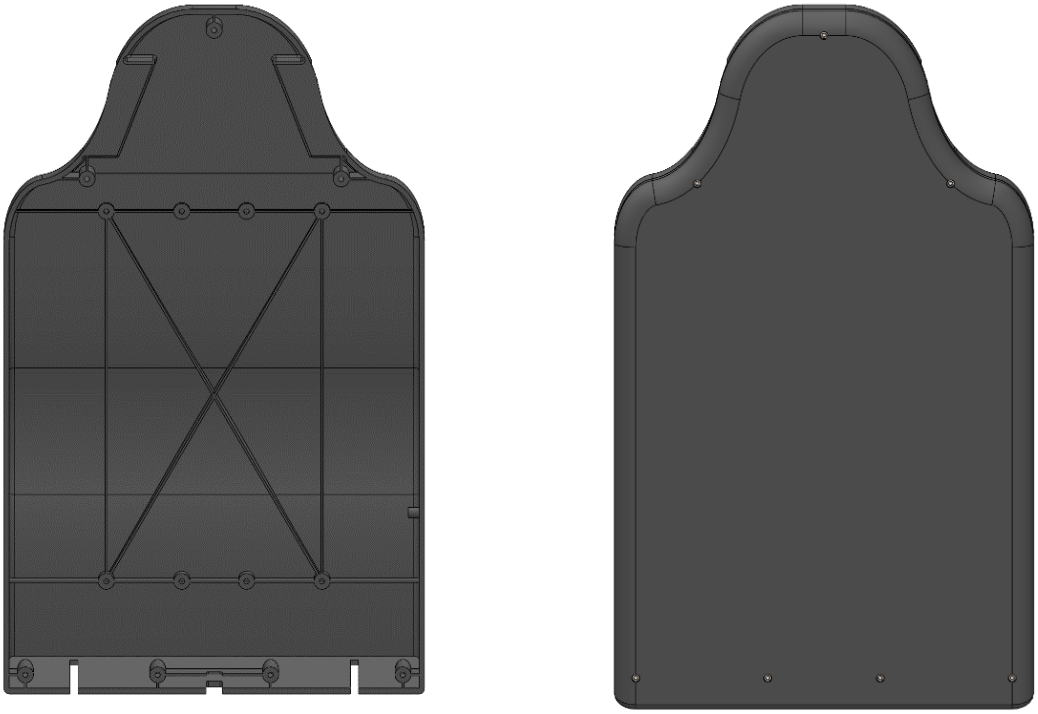


Figure 63. Seat Back Mounting and Ribbing Designs

Although armrests have since been redacted from this design, the seating system remains compatible with armrests if desired by the consumer. The armrests are additional components provided for user comfort and are shown for conceptual purposes. The armrest profile is only 1" wide as to not increase the width of the seat footprint by much. Its method of attachment to the seat is common to armrests, with a knob coming out of the side with a stud coming out of it. This knob will rotate in the opening on the side of the seat back and the stud will define its range of motion by hitting the mechanical stops molded into the seat as seen in Figure 64.

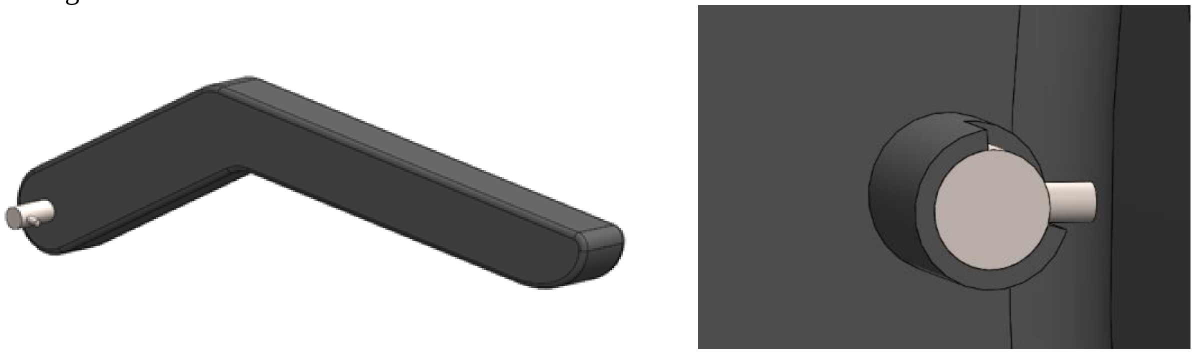


Figure 64. Armrest Design and Rotational Locking Mechanism

The armrests have an angled section to reach the proper height above the pivot point so that when the operators are nesting the chairs they do not have to worry about manually folding the armrests. This angle creates a slight moment arm above the hinge point so that when the chair in front of it hits the armrests they will automatically fold up as displayed in Figure 65.

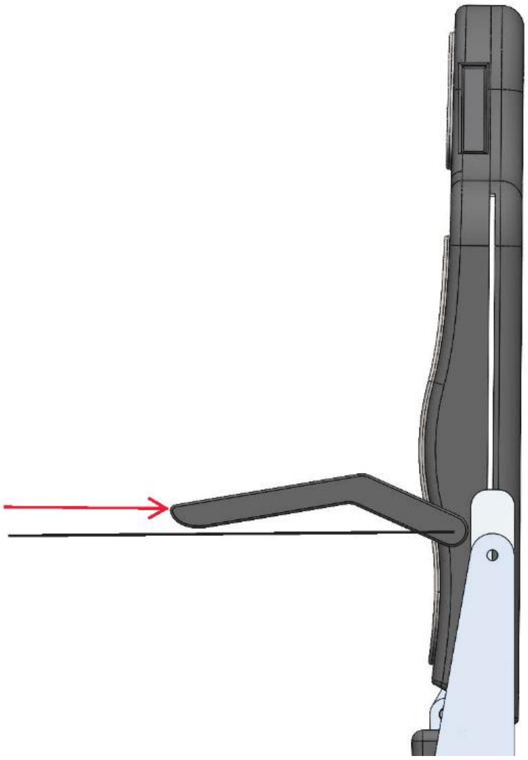


Figure 65. Armrest Passive Folding Design

The last component is the track and latch cover, located at the base of the seat. This is proposed to be a plastic molded cover that encloses all the latch mechanisms, fasteners, and articulation connections as shown in Figure 66. Since this is a location passengers may put their feet or bags, we would not want any exposed moving components or hardware there. For installation it will likely be a two-pieced shell that will clip together around the base and be secured to the base plates via automotive body bolts.

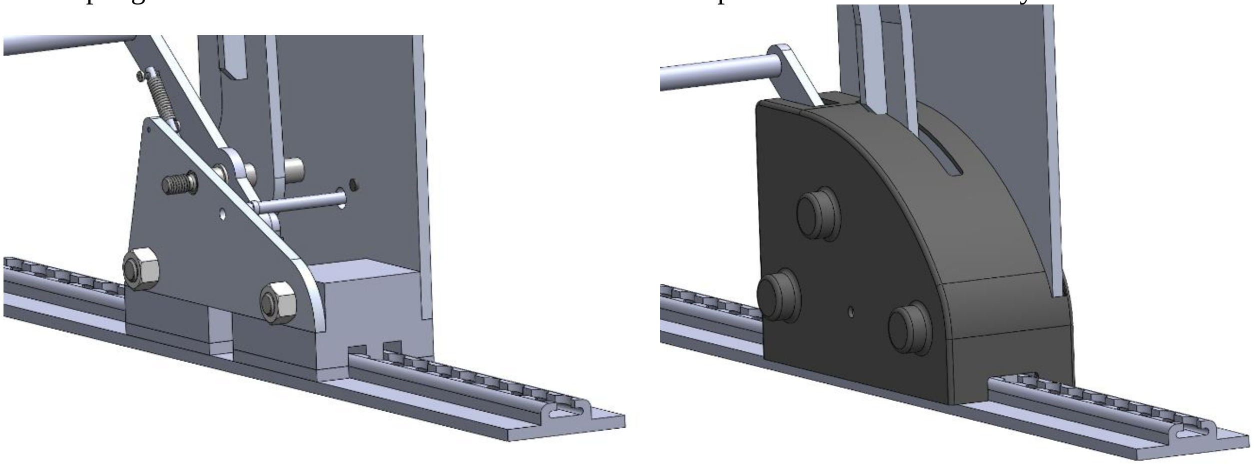


Figure 66. Track and Latch Cover

From the structural prototype, we were able to compare the seat and the articulating base in size and confirm that the proportions and dimensions are reasonable as shown in Figure 67. We were also able to qualitatively evaluate the material, polyethylene, and make sure it is strong and light to fulfill our specifications. From the structural prototype, we decided that it would be best to have ribbing on the inside to maximize support and minimize weight as the purchased seat did not have ribbing and was too flimsy for our needs. Overall, this gave us insight into the manufacturing process for molded parts and gave us confidence in our selected material choice of polyethylene.

Figure 67: Structural Prototype Placed on Top of the Articulation Prototype

6.1.2 Functionality and Engineering Evidence

In analyzing how and where our design could fail, we compiled a Failure Modes and Effects Analysis, which can be seen in Appendix P. This led to the investigation of FMVSS loads on the seat, frame, and seatbelt. The analysis for the frame was completed by the articulation team, but the loading on the seat bottom and seat belt were analyzed in this section.

A lap seat belt will be attached to either side of the base of the seat as shown in Figure 68. Seat belt analysis was performed for this placement in order to confirm that our design will pass the FMVSS 209/210 regulatory standard. These calculations can be found in Appendix Q. The base was simplified and a force approximation of 5680 lbf was used to simulate the force applied on the seatbelt in the event of a crash in which the passenger weighed 284 lbs. This weight is the 95th percentile of men in the U.S. The seatbelt is required to withstand a minimum force of 3000 lbf so this approximation is appropriate. From these the calculations, we found that the Von Mises stress does not exceed the failure stress of the steel that makes up the base. So long as the track can withstand a normal stress of 13.9 MPa and a shear stress of 8.3 MPa the seat belt itself and how it is mounted will be more than sufficient in the event of a crash.

Figure 68. Seatbelt Attachment Location

We also performed calculated to determine the structural integrity of the seat. Using a force of 600 lbf (in order to have a high factor of safety) applied at the tip as shown in Figure 69, and knowing the material, dimensions, and support points of the seat bottom, it was found that the seat will not fail but will have a vertical displacement of .46 inches. These calculations can also be found in Appendix R. With these calculations supporting the strength of our design, we feel confident moving forward with it.

Figure 69. Tip Load on Seat Bottom

Additional factors such as nesting, ergonomics, and manufacturing processes were considered in proving the feasibility of this product, as outlined in the following paragraphs.

The amount of space this seating system will save through nesting is a huge part of this project. This is measured by taking the difference between the space the seating position takes up and the space the stored position takes up as shown in Figure 70. The first senior project in 2016 set a goal of reducing space by at least 50% through nesting but did not show confirmation that their project did so. The second project in 2019 set their nesting specification to fitting two seats within 24", which they confirmed with their design. Our proposed design only has two 2 tracks, compared to the previous 4 in the second project. From our nesting analysis on the 3D model seen in Figure 70, we see that our design also surpasses both of these requirements reducing space by about 64% and nesting three seats within just over 33".

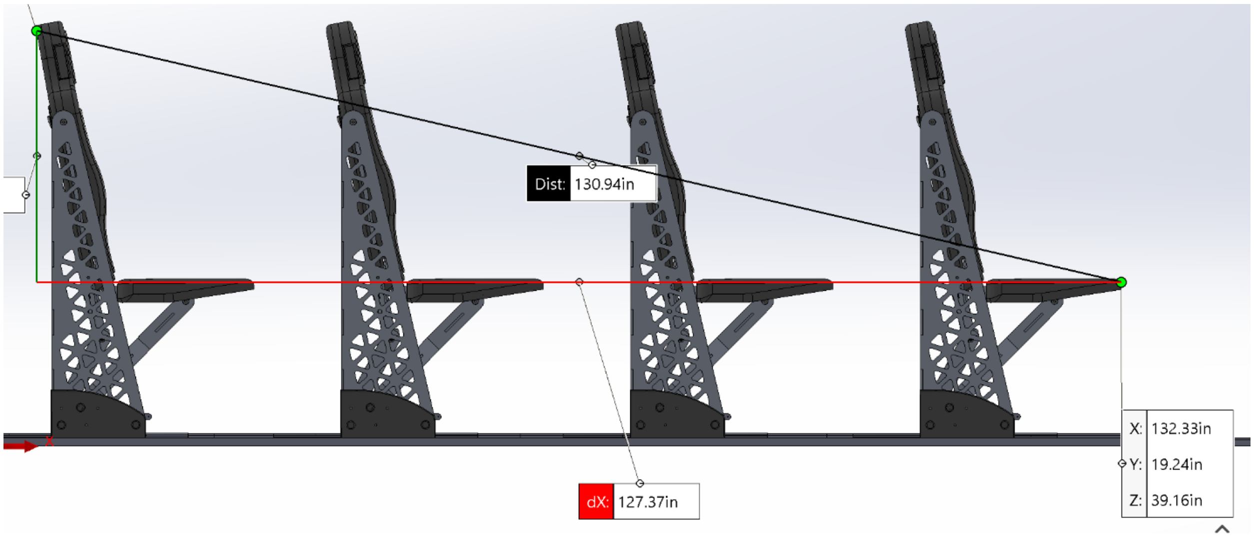


Figure 70. Floor Space Comparison of Seated and Nested Configurations

In regards to ergonomics, the seat's basic dimensions were designed for optimum comfort for people with body sizes ranging from that of 5th percentile of women to 95th percentile of men as previously defined in our conceptual design. The dimensions also took into account the functionality of the seat as it will be for short-term travel. Head rests and armrests were included for additional support. The general seat and handle ergonomic dimensions are shown in Figure 71 below. A thin cushion is included on the seat, back, and headrest to provide more comfort to the user as the seat itself is made of hard plastic.

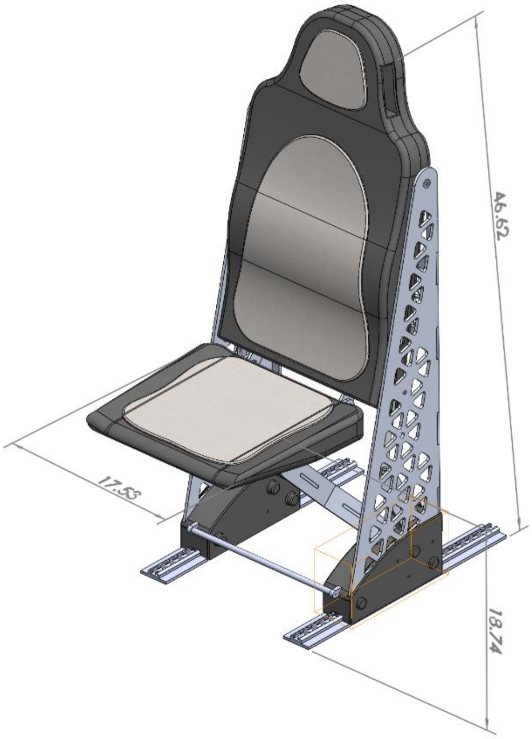


Figure 71. Basic Ergonomic Dimensions of the Seat Height, Width, and Handle Height

To mass-manufacture this seat, injection molding will be used. This will allow the seat to be made in one step. Inside the seat, ribbing will be included in order to minimize weight but still provide strength and support as previously shown. The back will also be in 2 pieces to allow for access to the articulation components hidden inside the seat. As previously mentioned, the material used will be polyethylene which is commonly used in injection molding. We do not plan to manufacture the seat ourselves using this method, and we recommend a professional mold designer review this design before it is mass manufactured. This design and manufacturing process is just what we recommend and will be performing a cost analysis for in the future.

Polyethylene was chosen as the material for our seat as it is strong, light, and adheres to safety standards. Because of these qualities, it is also used in many similar applications as our seat will be. One important standard that is met with polyethylene is the FMVSS burn rate standard. This is a flammability test required for the interiors of motor vehicles.

6.1.3 Floorplan Layout

As stated before, we would be designing with the floorplan of a Candidate II shuttle bus in mind in order to streamline our design direction. We plan to have our seating system be universal by the final product, but by using a single set of dimensions and designing for it, we can have a more concrete image of the final goal. Figure 72 below shows the floor plan of a 14 passenger layout Candidate II.

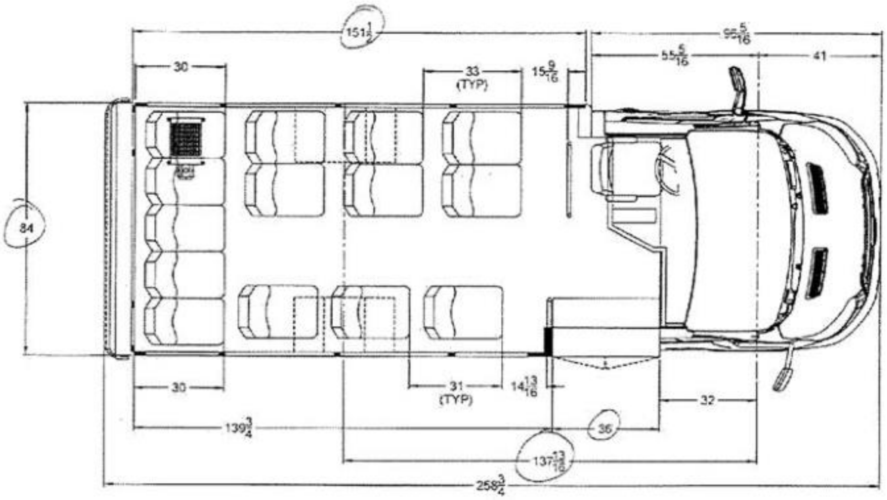


Figure 72. 14 Passenger Candidate II Layout

Our final proposed floor plan will be 4 rows comprised of 3 seats, for a total of 12 seats. The rows will also be split, with 2 seats on one side, and 1 seat on the other. This will allow for walking space to access both the front and back of the shuttle bus. As of now, the walking aisle will be 15in wide, however this is subject to change depending on changes in seat width or space needed to accommodate the track and latch system. Measured from the back of the bus to the front, the seats will be allowed a pitch of approximately 34in which is above the airline standard of 28-33in. The proposed floorplan of our configurable seating system is outlined in Figure 73 below.

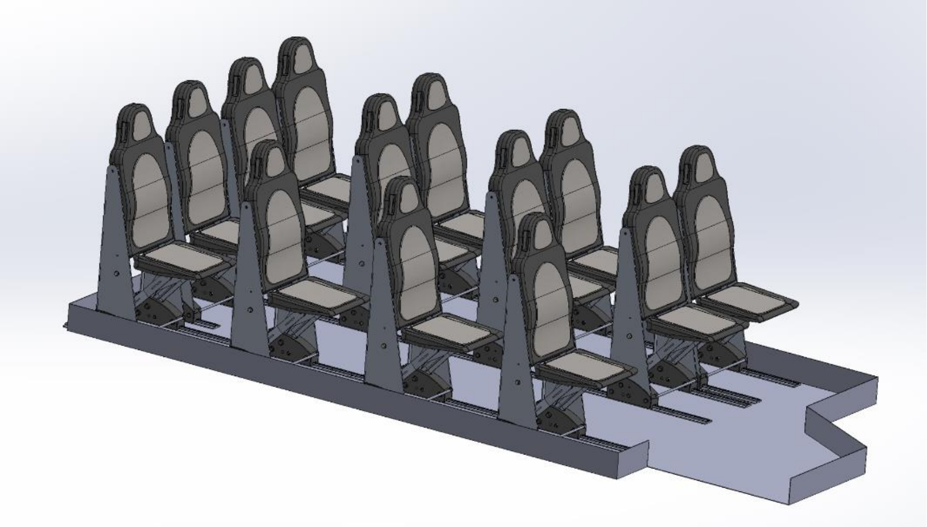


Figure 73. The Proposed Configurable Seating System Floorplan

While the proposed floorplan may be only able to seat 12 people, rather than the 14 people from the original layout, our design will be able to handle luggage entities much better. The configurable seating system will be able to stow away and make much more open floorspace available for a variety of loads. The original layout only includes static seats, which will only allow for luggage to be stored underneath the seat or take up a passenger's legroom. The configurable seating system will be a much more versatile design, allowing the transportation of people and baggage. With this system if a customer wants a shuttle bus that fits less people and have more storage, they do not have to buy a completely different shuttle bus, but can reconfigure their own as they please to meet their needs

6.1.3 Safety, Maintenance, and Repair Considerations

In regard to safety, the main hazards the system team needed to address were pinch points, abnormal movements, and sharp or protruding edges as covered in the Design Hazard Checklist in Appendix S. All other safety considerations, like having a large moving mass, falling under gravity, and unsafe usage, are addressed by the other teams. Pinch points were minimized by housing the main articulation system inside the back of the seat, enclosing a majority of the sliding and moving components. The track and latch components were also covered with a plastic cover at the foot of the seat base. The only exposed moving components are the diagonal brace attached to the bottom of the seat cushion and the hinge connecting the seat cushion and seat back. However, when these parts are moving, the operator won't have their hands near them, since the handles are at the top of the seat, so it is reasonable to have these few exposed moving parts.

To counter any abnormal physical posture or effort when operating the seat system, handles were placed at an ergonomic height for the operator to use when articulating the seat. A gas spring was also added to dampen any sudden movements and aid the operator in lifting the seat up. Also, a locking foot petal was added to the track and latch system so the operator would not have to bend down to move the seats back and forth on the track.

The covers mentioned previously also cover any sharp edges or exposed bolts where a user's feet or hand may normally be. We propose that all other exposed metal will be powder-coated, to cover any sharp edges that may exist on the metal plating and also give it a professional, clean finish.

Regarding maintenance and repair, the main components that may need to be replaced or have scheduled maintenance are the ones that are moving in the track and articulation assemblies. This includes the latching mechanism of the track and the gas spring and sliders of the articulation. In designing the placement and covers for these systems we made sure they were easily accessible and used standard fasteners to house them. For the track and latch cover, they are housed in a plastic casing that is connected to the seat base via automotive body bolts, which are easily removable and cheaply replaceable parts. For the sliders and gas spring, they are housed in the seat back which can be removed with a standard ¼" Allen key. Once the back casing is removed the gas spring is exposed and easily removed with standard tools, similarly to the sliders. These components are standard parts and can be reordered on sites like McMaster Carr. If a seat needs to be removed for maintenance the entire seat assembly is removeable from the vehicle off of the ends of the track, however, all other seats in front or behind that seat must also be removed to take it off of the track.

6.1.4 Discussion of Design Concerns

One of the main concerns is that this seat was originally designed the seat for sprinter van, but our scope recently changed to a shuttle bus, so some aspects of our seat are not completely tailored to a shuttle bus. Our seats were originally designed for user comfort over compactness, regarding the dimensions of the seat and extra features like armrests. From looking at shuttle bus interior layouts and seats, we realize that they are much smaller width wise and a lot simpler shapes with no armrests. This contrast between sprinter van interiors and shuttle bus interiors in Figure 74. The current design still can comfortably fit 3 aisles of seats side by side, but if the customer requests to increase the capacity in their vehicle, then the seats themselves can be simplified with a smaller width and no armrests to fit an additional aisle. The only factor limiting the width of the seat is user comfort since the track and articulation will work at any thinner widths.

Figure 74. Contrast Between Sprinter Van and Shuttle Bus Interiors

This also raises concern about if the current seatbelt chosen is sufficient for a shuttle bus. The current two-point seatbelt was chosen based on pictures of existing shuttle buses as seen above, but we have been unable to find laws or safety standards that specify if a two-point seatbelt is sufficient for this size of vehicle. Additional research will be done on these laws, but we may have to switch to a three-point seatbelt in the future.

In addition to this, our seat sits at a seat height an inch higher than originally designed. This issue was introduced when the track and latch was integrated with the articulation system. The additional height from the attachment point to the track was unaccounted for, making the seat slightly higher than our ergonomic goals. The problem could be solved with some adjustments to the length of some articulation linkages, but that would require new hand calculations, to check if stresses do not change drastically. The seat bottom could also be made thinner, but this would not account for enough height change.

Another slight ergonomic concern arose when we investigated the realistic seating and nesting layout within a shuttle bus. Specifically, if the seats were all nested in the back of the bus, the foot pedal that allows the seats to slide along the track system would be awkward to reach as shown in Figure 75. The user would have to reach their foot underneath from the front of the seat to actuate the pedal, which is not the most ergonomic movement, but it is definitely feasible. On the other hand, if the seats were all nested at the front of the vehicle, this problem would not exist and the track-latch system could be used from behind as intended. This is not a major concern that would warrant redesign, but will definitely be a more awkward movement than anticipated.

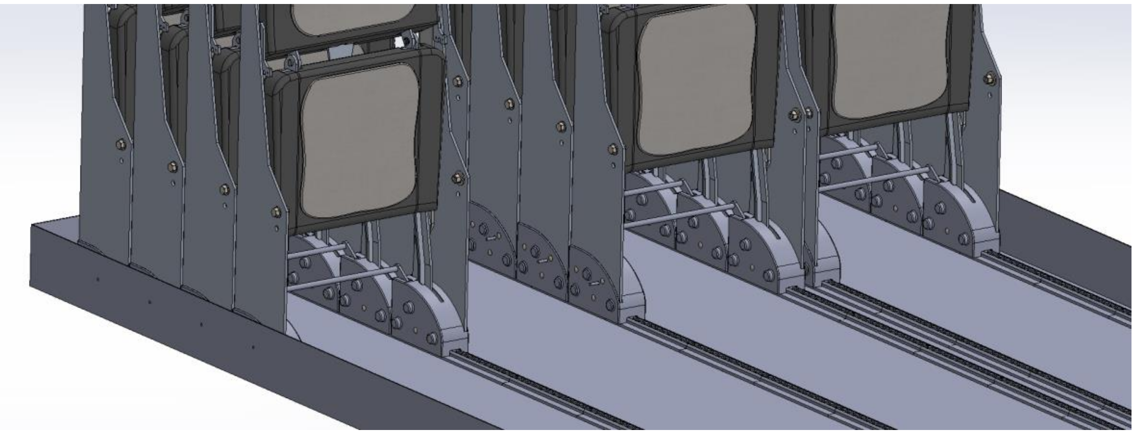


Figure 75: Foot Pedal Ergonomic Concern

Lastly, we have concerns with elegantly incorporating the seat with the linkage system to minimize used space and ensure durability during use. Without a full-size working prototype to use for design tests, it will be hard to ensure whether the seat meets safety standards. Dr. Mello has reassured us that after our senior project, if it goes well enough, they will hire engineers to do load testing for us before pitching the seats to transit companies. However, as of now, the actual method of mounting is still uncertain. Articulation team wants to design a frame that attaches onto their linkages, on which we attach our seat to the frame. The seat will most likely be bolted onto the new frame. Without the frame designed yet, it is still a concern how the seat will physically incorporate with the linkages, but our proposed mounting will be sufficient for this stage of design.

6.1.5 Description of Final Verification Prototype

Based on feedback we received from our sponsors, we have decided to create a 3D printed, 1/4 scaled desktop model. The end goal for this senior project is to have a prototype, which will be able to demonstrate the seats articulation ability, and space saving efficiency to transit companies. In order to do this, we will need a portable, yet functional model to pitch the product. Hence a fully functional, 1/4 scaled desktop model was chosen to represent the design. The desktop model will feature a scaled down van floorplan, with three or four seats attached. These seats will demonstrate the ability of the design to transition from a deployed to stowed position and roll along the track to show space saving capabilities. As of now, there are no intentions of showing the track locking capabilities on the final verification prototype.

In addition, we plan to make professional renderings and animations through SolidWorks to show to companies as a proof of concept. This will supplement the quarter scale model in aim to make the product easily marketable and convey the concept of reconfigurable seating clearly.

6.1.6 Cost Analysis Summary

We will be manufacturing two prototypes: one will be the quarter-scale 3D printed system and the other will be a full-scale seat back and cushion shaped out of foam. For a breakdown of the assemblies for both of these prototypes, see the indented bill of materials and drawing package in Appendix T.

For the 3D printed model, the materials used will be the PLA filament the components will be printed out of, sandpaper and an epoxy coating to finish the parts, and glue to assembly the prototype. Approximate costs can be found in the Table 16 below.

Table 16. Cost Analysis of 3D Printed Prototype

Material	Approximate Cost
PLA Filament	$46
Sandpaper	$6
Epoxy Coating	$25
Glue	$7
Total	**$84**

For the full-scale prototype, the materials used will be EPS foam which the seat back and cushion will be shaped out of, electric wire tools to shape the foam, a hardening coating that will mimic plastic that will be applied to the foam, and a spray adhesive. Table 17 below shows the costs of these materials.

Table 17. Cost Analysis of Full-Scale Foam Prototype

Material	Approximate Cost
EPS Foam	$40
Electric Wire Cutting Tools	$28
Plastic Coating	$30
Spray Adhesive	$19
Total	**$117**

The approximate cost of both prototypes will be $201 which is well within our budget of $1000. For a more in-depth breakdown of the materials we will be purchasing, see Appendix U for the budget.

6.2 Track and Latch Final Selected Design

6.2.1 Description of Final Design

The goal of the final design of the track and latch subsystem is to support the weight of the seat and to entirely restrict movement when locked or restrict movement to a single degree of freedom when unlocked. These goals are accomplished through three separate sub-assemblies: the latch system, the track system, and the actuation system. The system's weight is supported, and vertical movement is contained by the latches, which slide freely along the track. The system is restrained horizontally via the double pin between the latches. The pin actuates to a locked and unlocked position via the CAM actuation system. The user interacts with the actuation system via the foot bar. Figure 76 shows our team's final design of these three combined subassemblies. Figure 77 highlights each system and the hardware.

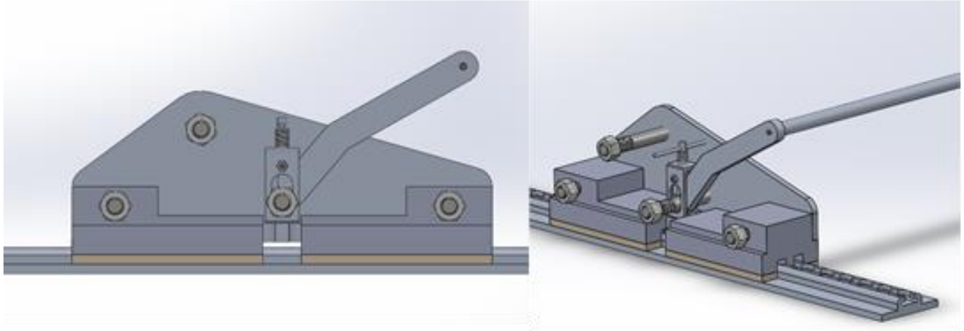


Figure 76. Full Assembly View of Track and Latch System, Side View (Left) and Isometric View (Right)

6.2.2 Functionality and Engineering Evidence

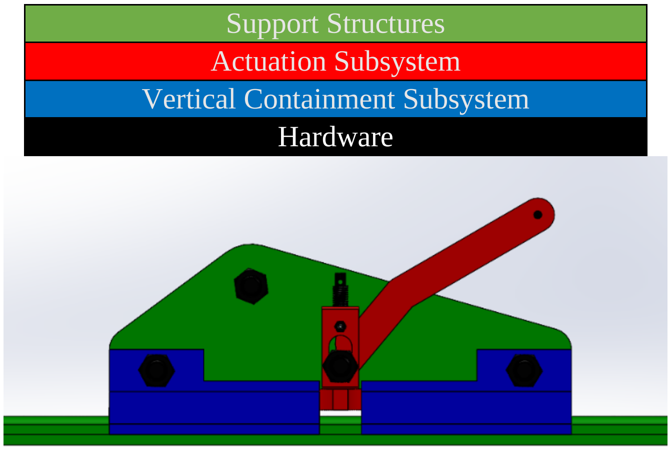


Figure 77. Color Coded Track and Latch Sub-Systems

The track and latch system was divided into three subsystems, uniquely colored above. Featured in green are the support structures. These support structures were the grounding point for the two movable subsystems. Included in the support structures are the two side plates and the modified track. The two side plates allow for the track and latch system to be integrated with the articulated chair via three 3/8” bolts. The modified track consists of a Logistical Airline Track from Aircraft Extrusion Co. with a ¼” aluminum plate. This Logistical Airline Track is currently approved for integration with existing commercial vehicles, making it an advantageous feature to design around.

The actuation subsystem is shown above in red. The primary purpose of this subsystem is to achieve horizontal containment. The subsystem consists of a lever arm with an integrated cam, a spring-loaded follower, follower frame, and locking double pin.

The vertical containment system is shown above in blue. The primary purpose of this subsystem is to contain the system vertically to the track and within the plane of the track. The subsystem consists of the latches and attached Delrin slides. The Delrin slides are secured to the underside of the latches via fasteners.

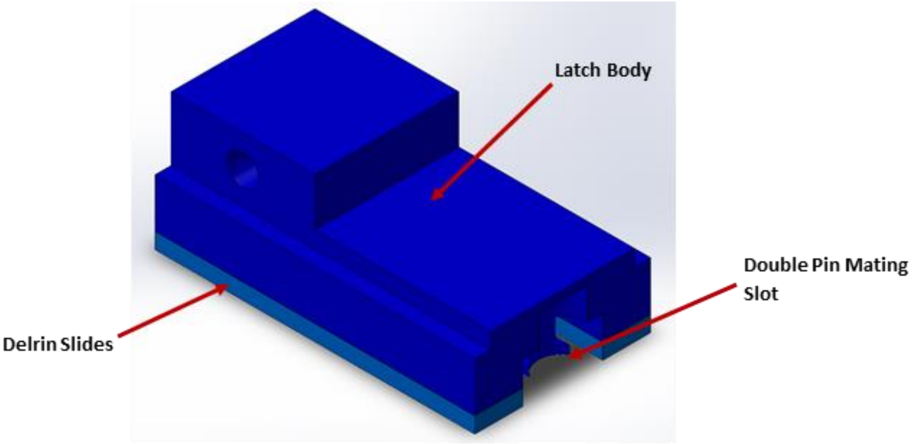


Figure 78. Isometric View of Latch Body

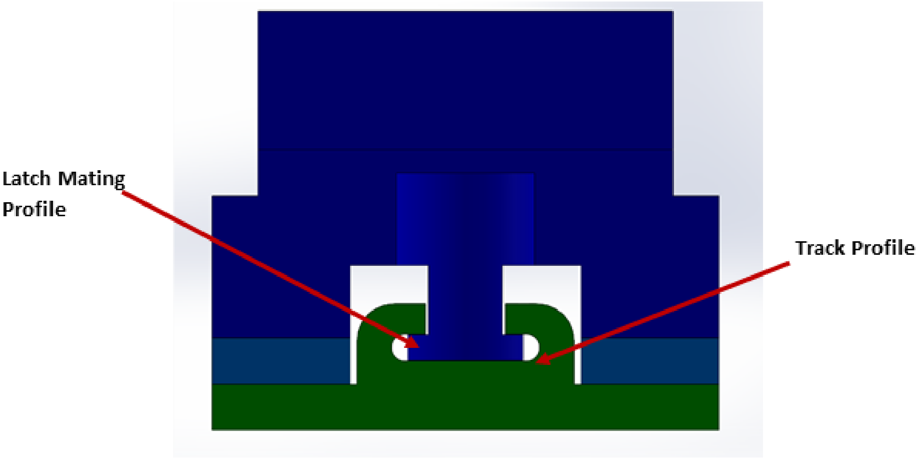


Figure 79. Front View of Track and Latch Mating

These subassemblies are broken down in Appendix V, the indented bill of materials (iBOM). The iBOM also breaks down the cost of each part. The iBOM follows the same subsystem scheme as outlined above.

The latches, shown in Figure 78, slide into the track and contain the seat vertically via the profile highlighted in Figure 79. These mated profiles contain the seat vertically and also handle applied moments to the system. Each side of the system has two latches mirrored across the centroid of the seat, allowing for excellent handling of applied moments to the track and latch system. The system is designed to work nominally in clearance for these mated profiles, although interference may occur during normal operation.

The wings on the sides of the latches slide along the aluminum plate with the help of Delrin. Delrin eliminates the need for bearings or wheels as it allows for smooth motion along metal. Delrin has a published friction coefficient of 0.15 between itself and aluminum which allows the system to translate horizontally with minimal effort. The latches also feature a mating slot for the double pin which extends over the double pin to restrict its motion to only vertical translation. The mating slot limits the travel distance of the double pin to a desired maximum.

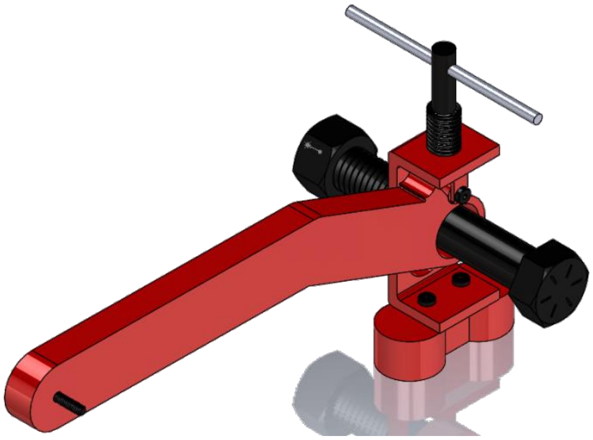


Figure 80. Isometric View of CAM Actuation Sub-System

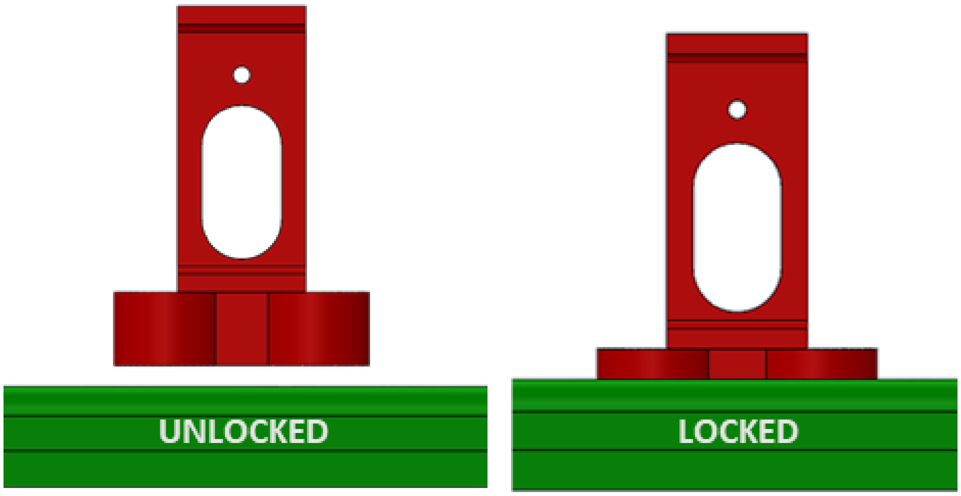


Figure 81. Double Locking Pin Unlocked Left and Locked Right

The double pin holds the seat horizontally in a locked position (Figure 81). When the pin is engaged with the track, the seat cannot translate horizontally along the track, and the system is considered to be in the locked position. When the pin is out of the track, it is in the unlocked position and the seat can move freely along the track.

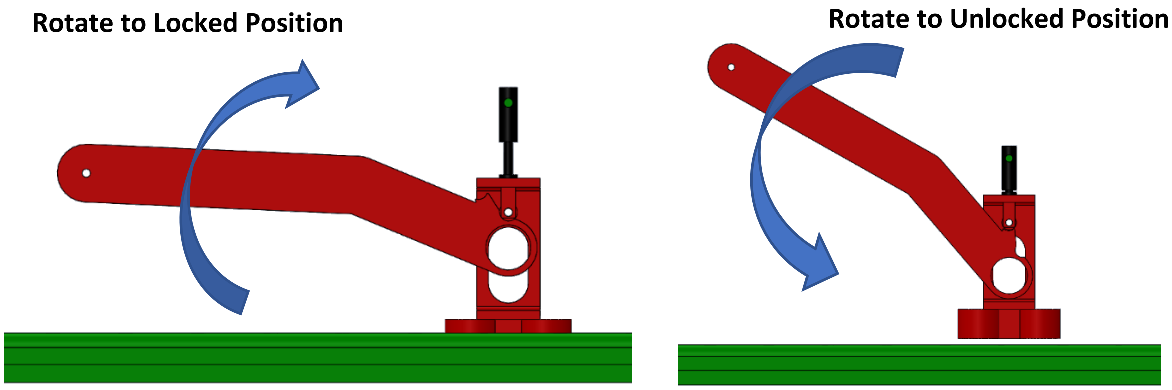


Figure 82. CAM Assembly in the Locked (Left) and Unlocked (Right) Positions

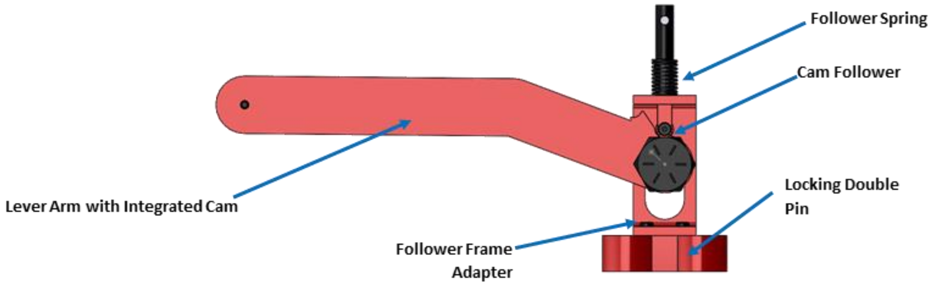


Figure 83. Labeled CAM Assembly

To actuate the double pin, the user pushes up on the front bar with their foot to interact with the CAM assembly (see Figure 83 for a labled view of this system). This action pulls the double locking pin out of the track via a spring-loaded cam system. The two positions of the actuation system are shown in Figure 82. These two positions correspond to the two indented positions on the integrated cam. To lock the seat, the user steps on the bar. This takes very little force as this is in the direction of the spring force of the Follower Spring. The Follower Spring also keeps the Cam Follower in contact with the Integrated Cam at all times. The cam action is routed around the mounting pin by the Follower Frame Adapter to the locking double pin. The follower frame is considered a rigid body that simply translates the motion of the follower to the locking double pin.The cam is designed with detents to prevent normal operating conditions from dislodging the locking pin. Further, the locked position is the lowest energy position of the cam and double pin system, meaning the likelihood of accidental unlocking is extremely low.

We performed various hand calculations to verify the designs of our pins, track, and latch body profiles. The hand calculations found in Appendix W include the load cases on the track, latch, and double pin.

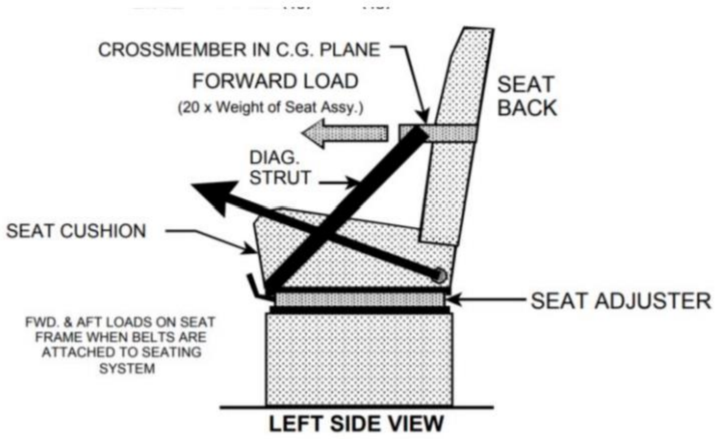


Figure 84. Crash Loading Cases

The driving loading case is a horizontal crash load. This load is derived from SAE standards, but was also used in previous verification work done with this project. The loading case is graphically represented from the SAE standard in Figure 84. The loading derived from a master's thesis completed by Zachary Wiltshire was translated to three critical components: the track, latch mating profile, and double pin. This point load was statically equated to each of the critical components. These calculations may be viewed in Appendix W. A summary of critical safety factors is shown in Table 18. The minimum safety factor refers to the smallest safety factor for any failure mode of the component that would compromise system integrity. All safety factors are derived from the driving loading case (horizontal crash load).

The latch and double pin geometry were methodically adjusted for manufacturing while checking the appropriate safety factors. Initially, hand calculations were performed using minimum areas and estimating stress concentration factors with traditional methods. Then, independently, finite element analyses of the latch and double pin were conducted. A mesh convergence study was completed with the guidelines set forward by the master's thesis completed by Zachary Wiltshire. The results of these finite element analyses are visible in Figure 85 and Figure 86. The results of these simulations matched the predictions made by the traditional hand calculations, as seen by the convergence of the safety factors in Table 18. This allowed us to move forward with confidence in our FEA, such that we could make changes to geometry and reevaluate the FEA without recalculating the hand values. These geometry changes included strategically placed fillets on the latch body. This design change greatly reduced the stress concentrations at the sharp edges with the added benefit of user safety.

Because the track is a prefabricated component, analyses were conducted but iteration could only occur between commercially available sizes and materials. Two calculations were performed on the minimum track area (referred to as the track "teeth"): horizontal and vertical stripping. Horizontal stripping placed the entire crash load on the face of the double pin, such that it is trying to move in the plane of the track. Vertical stripping hung twice the weight of the seat and a 95th percentile male from the track. Vertical stripping was realized as the limiting case. In order to meet the demands of this load, the Logistical Airline

Track, made of 7075 aluminum, was selected. This track is also commercially rated for 6000 pounds, ensuring that it is suitable to take the predicted load case extremes. This differs from the initially considered 6061 aluminum track used for the structural prototype. As such, the latch mating profile was slightly redesigned after this selection.

Table 18. Critical Compenents

Component	Analysis Method	Minimum Safety Factor
Latch Body	Hand Calculations	3.27
Latch Body	Finite Element Method	3.10
Locking Double Pin	Hand Calculations	4,85
Locking Double Pin	Finite Element Method	4.2
Track	Hand Calculations	1.89
Track	Finite Element Method	

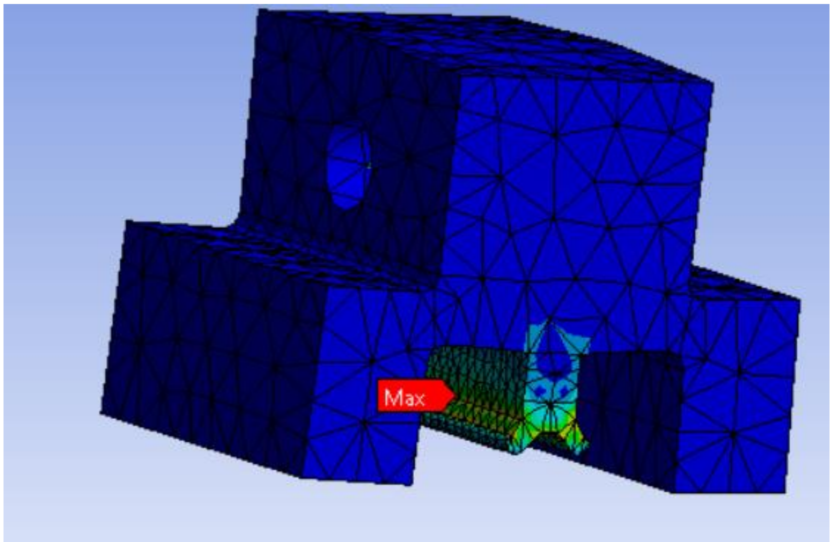


Figure 85. Latch FEA Analysis Results

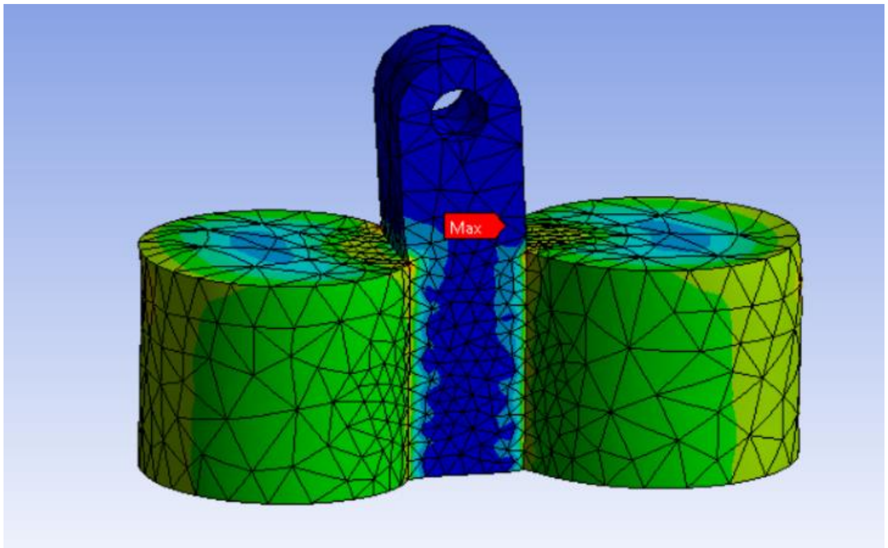


Figure 86. Double Locking Pin FEA Results

6.2.3 Safety, Maintenance, and Repair Considerations

The safety of the user is of the upmost importance. To address this, we created a hazard checklist to make sure our design was safe. This checklist is attached in Appendix Y. We reviewed these hazards and expanded upon them to create a Failure Modes and Effects Analysis (FMEA), which is attached in Appendix Z. This process investigated the design's methods of failure, considered how these failures might affect the user, and helped us focus on the most critical potential issues. The FMEA led us to focus on our latch and lock confirmation as our most critical sites of error. If these areas fail the user could potentially be in a high-risk scenario as the seat would either be free from the track, or the system would appear locked despite being unlocked. The latch needs to remain in the track profile, and the lock needs to stay locked when in motion. For these reasons, we selected a minimum safety factor of 1.5 on yielding that would release the seat from the track during the SAE derived horizontal crash load. Further, the selected track has a failure load of 6000 pounds, meaning that failure of the system will only occur in loading scenarios far behind those estimated by SAE standards.

Another error arose with the possibility of double pin misalignment. The latch body was redesigned such that the latch extends over the double pin and has a carved profile to guide the pin to keep it straight. After conducting an FEA analysis and kinematic predictions on the locking double pin in the system, we found it rocked and popped out under high load cases. The latch body prevents this failure method by restraining the locking double pin to a single degree of translational freedom.

Other safety precautions include: the track and latch system weighing less than 15lbs, all exposed sharp edges are rounded, any pinch points are placed inside system teams skirt/casing. A graphic user manual (see Appendix AL) helps the user actuate and articulate the seat correctly.

Our latch system and actuation system are enclosed in a covering designed by the Systems team to prevent dirt and grime from damaging the system. However, the exposed sections of track are still subject to dirt and wear. We designed our system such that the seat could still move and lock under these conditions as the weight of the system and rigidity of the Delrin slides largely prevent particulates from coming under the slides and adding more friction to the move. It is still recommended to regularly clean off the track with water and avoid moving seats over dirty sections of track to keep seat movement smooth and easy.

We designed the whole system to outlast the vehicle. Our system components will not need to be replaced due to normal operation as long as the vehicle is in service. However, the system should be retired after being involved in an automobile accident.

6.2.4 Structural Prototype

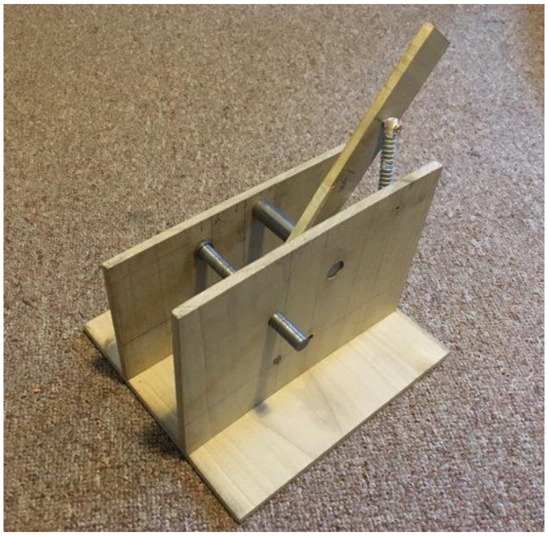


Figure 87. Structural Prototype

The latches and vertical containment for this system have been designed with enough confidence that prototyping efforts were focused on the actuation subsystem. A structural prototype was made from ¼" plywood as seen in Figure 87. Custom metal pins and a locking bar were then made, along with wooden links to complete the actuation model, and it was fitted with a compression spring.

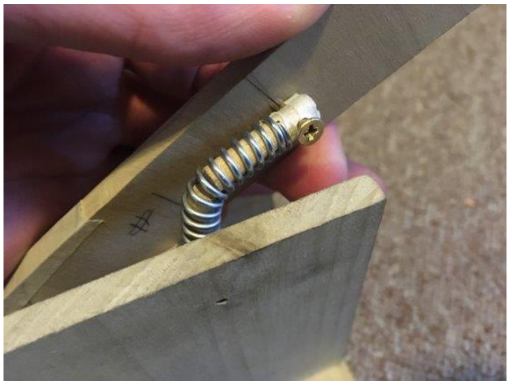


Figure 88. Spring Bending

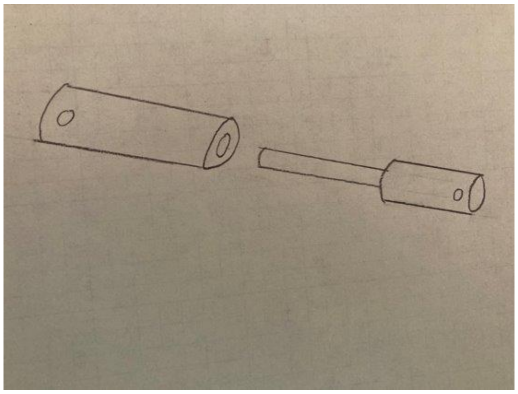


Figure 89. Modified Spring Guide Pin

From building the structural prototype, two key areas for improvement were noticed. The first fault is that the spring guide pins fail to prevent the spring from bending when the system is actuated, seen in Figure 88. To fix this, the spring guide pins will be modified to interlock with one another, as shown in Figure 89. This new design still allows for extension and compression of the spring, but to prevents it from bending.

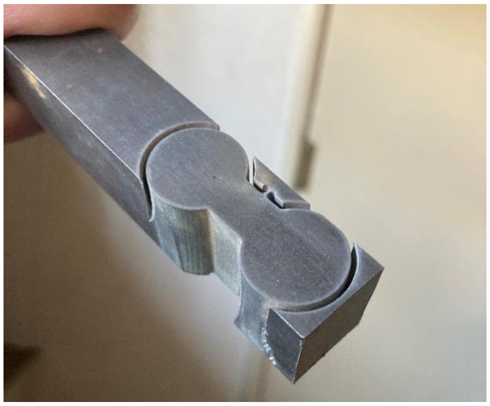


Figure 90. Double Pin Waterjet Manufacturing Error

The second major failure from this model was the manufacturing of the double pin. While on waterjet, the jet walked off the side of the stock, causing it to lose its location, and preventing it from being properly manufactured, as seen in Figure 90. To fix this moving forward, properly sized stock will be used to prevent a repeat occurrence.

6.2.5 Cost Analysis Summary

After sourcing materials and compiling prices for the track and latch system, the total cost for the final verification prototype came out to approximately $484. The bulk of the system cost came from buying stock metals to make all our components. The new 7075 Aluminum track from Aircraft Extrusion Co (as prescribed by the current weight of the system estimated by the articulation team) is a total of $150, which is a fairly large portion of the overall cost. It is currently under sponsor approval whether we may design our verification prototype off the previously purchased track. Doing so would eliminate this cost. After adding in the aluminum base plate and fasteners, the track subsystem totaled $210. The materials for the double pin and latch body subsystem totaled $171, which is much more expensive than the locking pin and latch actuation subsystem, totaling about $80. The remaining $23 consist of the main latch fasteners.

The three teams combined have a total budget of $3000. This means each team is allocated approximately $1000. Given the anticipated cost of the structural prototype, we will remain underbudget. Table 19 lays out a summary of approximate costs for the track and latch system verification prototype. For a more detailed cost analysis of the verification protype, refer to Appendix V, the indented bill of materials. The total cost of all actual and planned purchases for the entire project are listed in Appendix AA, the Purchased/Planned Materials Budget.

Table 19. Component Costs

Component	Approximate Cost
Latch Body	$131.70
Double Pin	
Delrin Slide	$29.27
Spring Guide Pin	$1.19
Locking Pin	$4.62
Linkage Pins	$6.18
Back Bar	
Lower Linkage	$36.10
Upper Linkage	
Mounting Plate	
Screws (Total)	$20.43
Springs	$4.98
Bushings	$16.24
Bolts (Total)	$23.04
Nuts	$9.66
Logistic/Airline Track	$150.00
Aluminum Sheet	$50.00
Total	**$483.41**

6.3 Articulation Final Selected Design

This section discusses the final design of the seat articulation function for the configurable seat. Also reviewed in this section are safety, maintenance, repair considerations; why specific geometry and materials were chosen; and a cost analysis summary associated with the final design.

After presenting the concept design to our sponsors, concern was expressed over the usage of pin/slot joints to guide the seat motion. Because slots lead to complicated analysis and excess wear, our team decided to simplify the concept design moving forward. This included the removal of both slots in the support frame and seat bottom frame. Because of this, the additional downwards movement when stowing the seat was eliminated.

Following the Critical Design Review, our sponsors requested additional refinement of the design. This resulted in a number of changes, including a reduction of seat width, relocation of the rotary latches, development of the rotary latch remote actuation system, and adjustment of the waterjet-cut components to allow tab-and-slot joints, eventually culminating in our final design from which we manufactured a verification prototype.

6.3.1 Description of Final Design

The final selected design for our seat articulation allows for the seat to be stowed vertically and deployed into a comfortable seating position. The design consists of a set of linkages, seat frames, and support frames. The arrangement of linkages allows for the seat back to tilt to accommodate ergonomic metrics set forth from the Demo System team while maintaining a purely vertical arrangement when stowed. The linkages are pinned together using clevis pins and pinned/fixed to two supporting side frames that interface with the track. Additionally, these linkages are connected to the seat back and bottom frame that interface with the Demo System team. For reference, all labelled components can be seen in Figure 91. These component labels will be used to refer to the components for the remainder of this report. All plate components are to be cut on the waterjet from ¼” inch steel plate and welded or pinned together; all remaining components are stock items to be purchased.

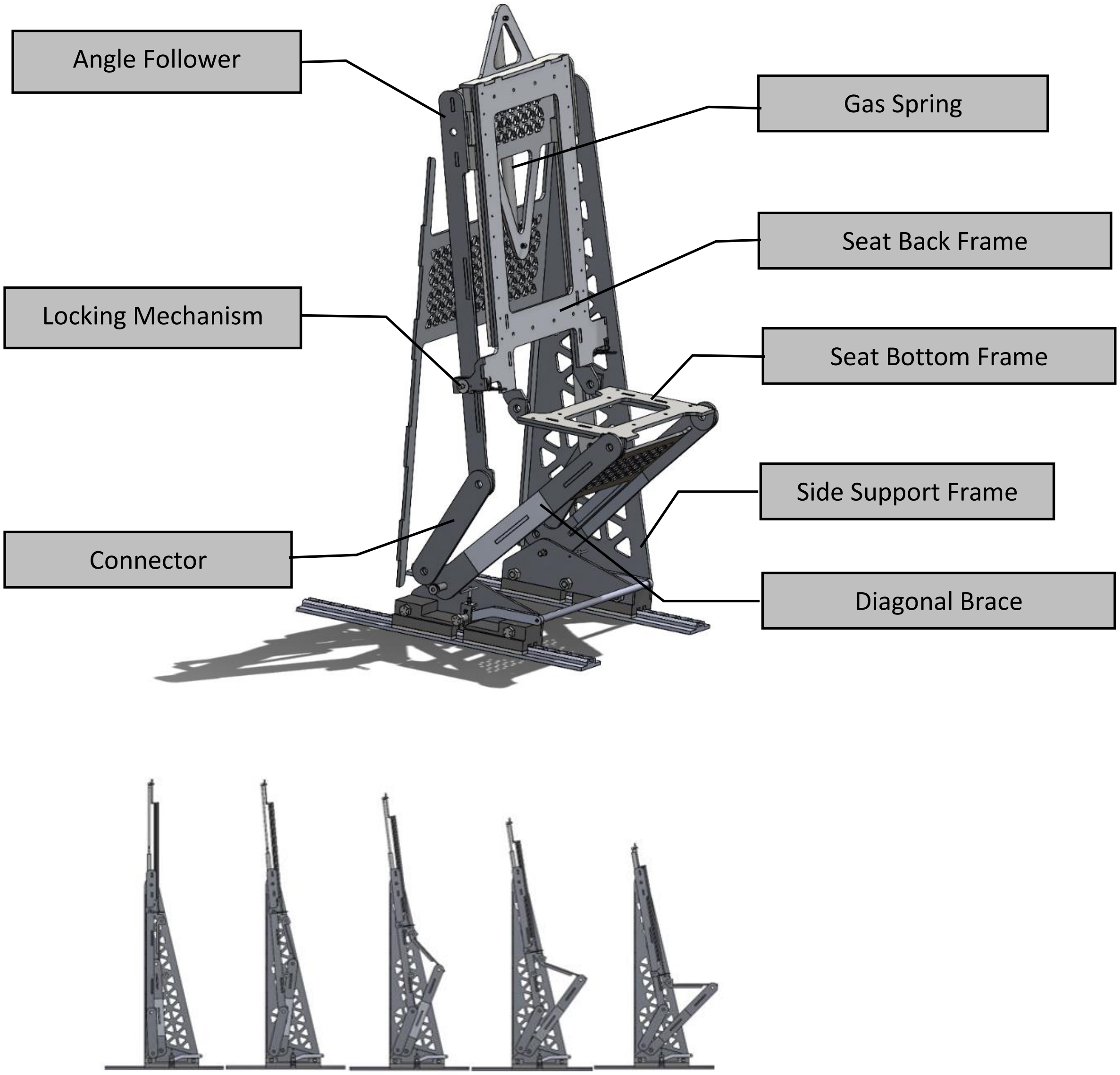


Figure 91: Labelled Isometric View of Seat Articulation System & Seat Movement Overview

The movement path of our articulation (Figure 91) is defined by our linkage assembly which consists of the angle follower, diagonal brace, and connector. The angle follower is attached to the seat back frame via a linear carriage and rail system. This attachment will be hidden behind a plastic back covering. The bottom of the angle follower is attached to a connector piece that translates rotation to the diagonal brace. The diagonal brace supports the seat bottom and consists of two side linkages and a cross web that spans between them. This cross web was implemented to reduce possible buckling and prevent binding. Another revision made to this component since CDR was the addition of small 5° bends that prevent and conceal pinch points by moving them further into the seat bottom.

The seat frames are made up of our seat bottom frame and seat back frame. These exist to interface with the Demo System team and provide additional structural support. The overall articulation system is grounded via two side support frames. The linkages pin into this side frame at the diagonal brace and the angle follower. The side frame also serves as our connection point with the track and latch team.

Additional augmentations made to our design include a gas spring to help aid the operator lift and store the seat and a mechanism to lock the seat in the deployed position. The locking mechanism is composed of two rotary latches mounted to the seat back mating with two pins protruding from the inside surface of the side frames. These locking mechanisms hold the seat in place when deployed, constrain the seat to make it rigid, and take loads off the linkage. Furthermore, the rotary latch system is comprised of modular components manufactured by SouthCo, allowing for ease in replacement and configuration.

Additionally, there was supplemental design and analysis work that was conducted in response to our CDR feedback. This included the implementation of a cross brace to increase stiffness, a redesign of the articulation latch to a remote release system, and some triangular cut-outs to reduce weight.

6.3.2 Geometry Justification

The PDR linkage geometry was no longer valid after deciding to move forward with our design change. The stowed height of the seat was now taller, and parts were still colliding. Thus, we worked to finalize these linkage lengths to minimize the vertical height of the stowed seat and eliminate interference, while still providing sufficient structural support. The SolidWorks iterative design sketch utilized to do this is depicted in Figure 92.

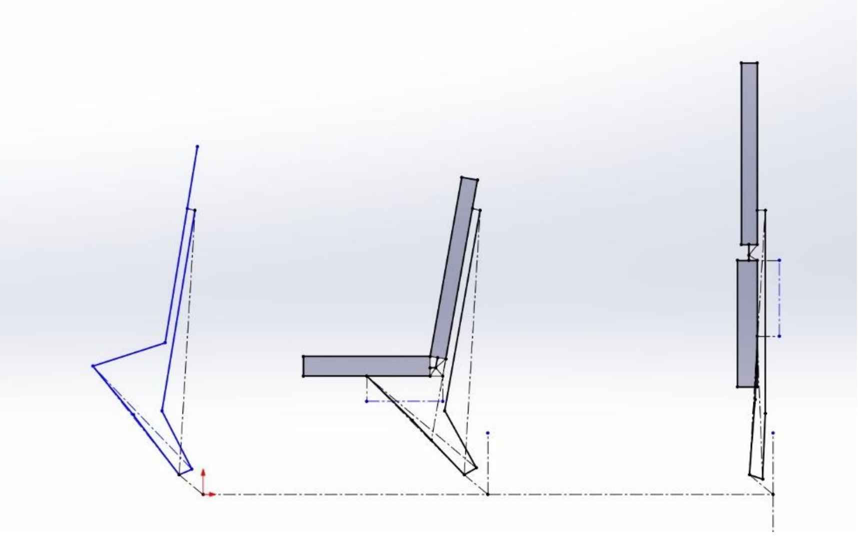


Figure 92: SolidWorks Sketch used for Graphical Linkage Synthesis

To further verify our geometry and to facilitate load calculations, a MATLAB script was developed to plot the seat positioning using vector-loop equations. This tool was used primarily for identification of precise pin locations and link angles for load computations but is also capable of outputting a graphical representation of the seat at various positions to verify geometric functionality (Figure 93).

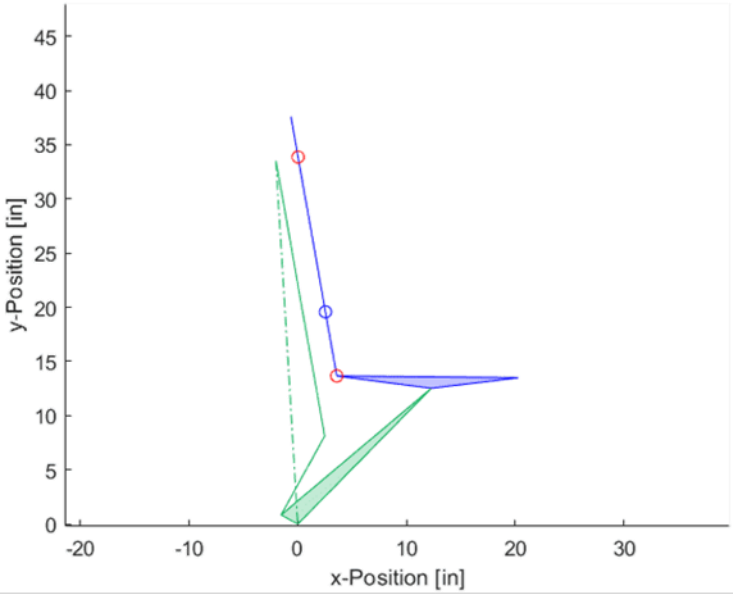


Figure 93: MATLAB Positional Verification Plot

6.3.3 Material Justification

In order to justify our material and thickness selection for our linkages, static loads and stress computations were executed. The static loading was simulated in MATLAB to test for various possible seating load cases (Appendix AC). As the system is statically over-constrained, several simplifying assumptions were required to analyze the system with rigid body statics (Figure 94). To prevent the need for complex deformable body mathematics, it was assumed that the linkage (the short leg of the diagonal brace, the connecting link, and the back slider link) would be sufficiently deformable that the linkage loads would be negligible for small angular deflections of the diagonal brace. This maintains structural integrity due to the addition of the locking mechanism to our system, which acts as an additional pin constraint on the seat back (Figure 95). For simplicity, it was assumed that the locking mechanism pin was assumed to be located in the same location as the pin connecting the seat back to the seat bottom; this allows the analysis to be considered as a linear combination of two triangular trusses. As each truss has a force of constrained direction (the diagonal brace modeled as a two-force member and the seat back reaction force from the slider), these assumptions allowed for the computation of the load cases. See Appendix AC for more details.

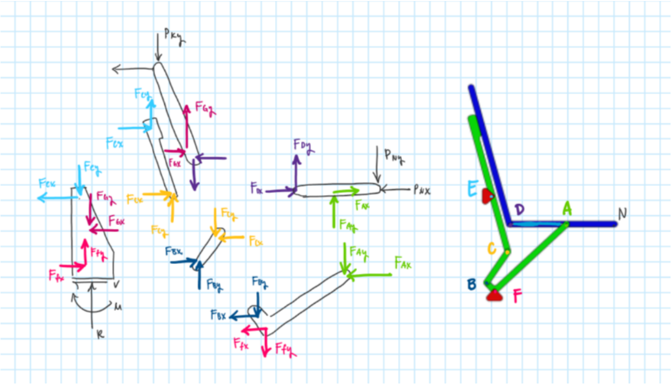


Figure 94: Static Load Derivation

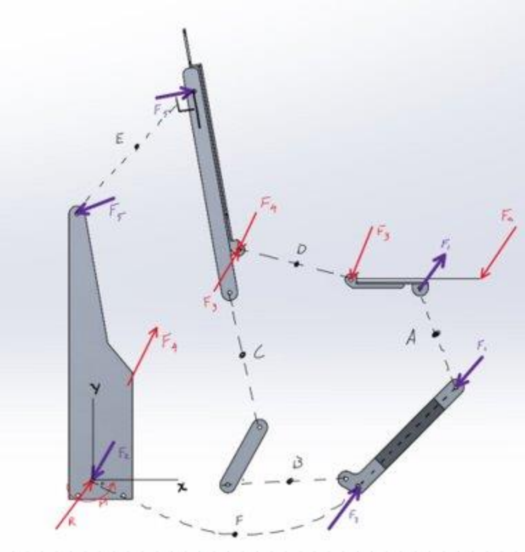


Figure 95: Static Load Derivation

Moving into stress-strength calculations, the worst-case stresses occurred when the overhanging load was placed at the tip of the seat. Thus, all stresses were calculated for a loading case of 600lbs placed at the tip of the seat bottom (factor of safety of 4). Under this loading case, the seat bottom stresses consisted of bending, axial, and transverse shear. The diagonal brace (modelled as a two-force member) experienced compressive axial stresses. Since the diagonal brace was in compression, the out-of-plane buckling was also checked for this member. The stresses calculated for the side frame included axial, bending, and transverse shear. The derivation of these stress governing equations can be seen in Appendix AD. These governing equations were additionally inputted into MATLAB for iterative use. The bending stresses were assumed to be the most likely failure mode of the system, this assumption was reinforced by our calculations as the transverse shear stress came out orders of magnitude smaller than the normal stresses. Thus, upon interpreting the analysis, more focus was directed towards the combination of normal stresses in the members. Note that many assumptions were made to simplify the stress computations. All components were modelled as simple beams with a constant cross section, for optimization further refinement of our analysis tool is required.

To reduce the weight of our prototype our team desired to have the components made of aluminum where possible. Our team utilized our stress-strength calculations to verify the material selection for our given linkage geometry. Referencing our analysis of the individual linkages, the ones most susceptible to failure included the seat bottom in bending and diagonal brace due to buckling. With the combined effects of the axial and bending stress in the seat bottom for a loading case of 600lbs, the stress exceeds the yield strength for Aluminum (40,000psi) but remains under the yield strength for steel (71,000psi). Because of this, our manufacturing plan and current design were carried out for all steel components. However, given our extremely conservative loading case (only one side of the linkage supporting 600lbs of cantilevered load) our team determined that aluminum components are feasible with slight adjustments and further analysis. The component that is currently our only limiting factor is the seat bottom which experiences the largest bending stress that exceed the yield stress for aluminum. When the calculations were run with a more realistic loading case (still a factor of safety of 2), all the components pass for aluminum. Refer to Appendix AD for the MATLAB script and outputs for theses stresses.

Our team plans to conduct additional loading cases and analysis to assess the possibility of replacing the steel components with aluminum. While the stresses are likely small enough for aluminum, we plan to assess the potential deflections of components before committing to a change in material. If it is deemed to be reasonable, however, we will switch the plate metal components from steel to aluminum as it would significantly reduce the mass of the seat.

6.3.4 Safety, Maintenance, and Repair Considerations

A full list of hazards is presented in Appendix AE in our Design Hazard Checklist. The main concerns regarding safety are pinch points. Due to our linkage design pinch points are present under the seat and along the sides. The pinch points under the seat due to the diagonal braces were concealed by moving them further into the seat bottom. Additionally, the pinch points on the sides were mitigated by covering them with a plastic shielding. Another concern for safety includes if the linkages bind or break. This concern was addressed and accounted for in our preliminary structural strength analysis and will be tested for in the future with our verification prototype. A full list of our possible failures modes, causes, and methods of prevention can be seen in Appendix AF in the Failure Modes and Effect Analysis (FMEA).

Regarding maintenance and repair a few design considerations were made. The gas spring in the back of the seat was made easily accessible to allow for a simple replacement procedure. Similarly, many mechanical components are easily accessible by simply removing the back plastic seat cover of the seat back. In addition, any bearing surfaces in the production design should not require routine lubrication as they should utilize self-lubricating plastic bearings. A full description of safety, maintenance, and repair considerations can be seen in the user manual (see Appendix AL).

6.3.5 Cost Analysis Summary

The construction of this prototype required the purchase of several materials and components. The most expensive individual component was the steel plate metal to construct the body of the prototype; all of our parts were cut out of a single 4’ x4’ sheet of 1/4“ steel plate, costing approximately $325, quoted from local suppliers. This was followed by the rail and carriage system to constrain the linear motion between the seat back and angle follower, which costed $257.86 on McMaster. The remaining components consisted of the latches, the gas spring, the rotary latch, and hardware, which totaled to approximately $300. Overall, we anticipate the articulation subsystem will cost approximately $888.44. For a detailed breakdown of our component costs see the Indented Bill of Materials in Appendix AG., and for a generalized breakdown, refer to Table 20.

Table 20: Articulation Cost Summary

Material	Cost
Stock ¼" Steel Plate 4'x4'	$325
Gas Spring	$27.91
Rotary Latch	$74.40
Linear Slider Carriage	$145
Linear Slider Rail	$112.86
Nylon Flat Washer	$8.03
Low Profile Shoulder Screw	$89.36
Short Alloy Steel Shoulder Screw	$6.48
Long Alloy Steel Shoulder Screw	$6.48
Total:	**$888.44**

Note that this should be significantly more than the unit cost of a production model – this is the next iteration of the prototyping and design process, not a final design to be manufactured. In a final design, raw material would be purchased in bulk, reducing total cost. Additionally, more efficient manufacturing methods would significantly simplify some of the design components – for example, the linkage system may be composed of stamped steel links with built-in pins, reducing the required material (making the link thinner by optimizing the cross-section) and simplifying the manufacturing and assembly process. Such optimizations on the structure, materials, and manufacturing processes would reduce the unit price of each seat to a more reasonable level. In addition, we can reduce costs further by sourcing fasteners from a local supplier in SLO instead of online at McMaster.

6.3.6 Structural Prototype

In order to gauge the structural integrity and manufacturability of this design a full-scale structural prototype was made. This prototype also aimed to address binding and stiffness concerns. We decided to build a full-scale prototype made from ½" prefinished Baltic birch plywood (Figure 94). Additional materials included wood staples, bolts, and wood glue. To evaluate the prototype our team conducted an operational test to ensure it articulated smoothly and to gauge the relative stiffness. In addition, in order to assess compatibility with Demo System's seat design, their seat prototype was attached to our base frame.

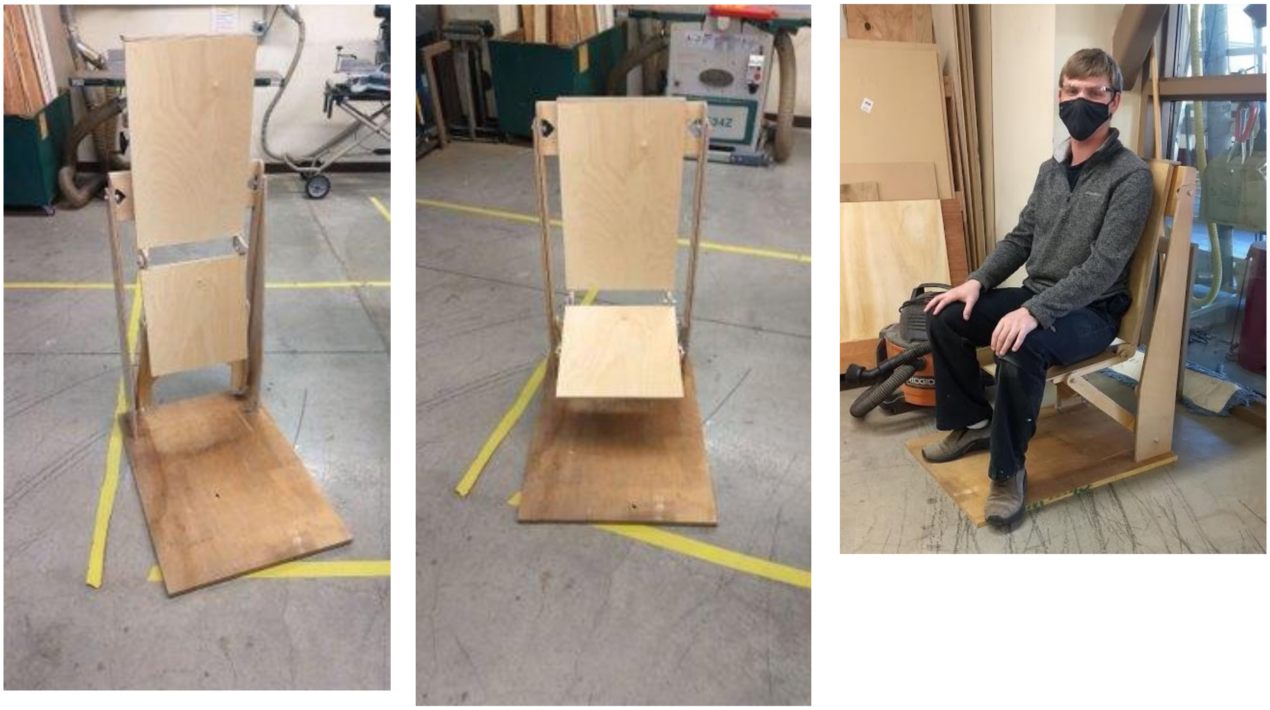


Figure 96: Structural Prototype

There were several key conclusions developed from our prototype. The most important concern addressed was the potential for binding in the seat movement. The structural prototype proved that this would not be an issue as the seat articulated very smoothly. Additionally, the dimensions of the seat were verified to be reasonable. To verify structural integrity, the prototype was put under load. Upon sitting on the prototype, it was immediately noted that the seat was not properly supported horizontally – the seat supported the applied weight vertically, but horizontal loads resulted in deflections of up to an inch in either direction. This led to the conclusion that the system was sufficient to support vertical loads but needed an additional constraint to support horizontal loads. To address this concern, we redesigned our locking system to be located on the bottom edge of the seat back such that a pin in the frame would take up the excess load.

7.0 Manufacturing Plans

Once the final designs and the verification prototypes were finalized, each team planed the manufacturing processes necessary for the prototypes. This included procurement of materials needed, the manufacturing steps for each component, and assembly of the prototypes.

7.1 System and Demo Manufacturing

As mentioned before, the final system and demo verification prototype will consist of two separate models. The first will be a quarter-scale model that is 3D printed with a simplified articulation and track. The purpose of this model is to show the system as a whole and to show the system as a marketable product. The second model will be full-scale and made to attach to the articulation team's verification prototype. This model will be made of foam and used to show the articulation with an accurately dimensioned seat.

In addition to the two prototypes, one of our final deliverables will be creating a manufacturing plan for the seat to be manufactured in large quantities. Since we are not constructing a full-scale seat using the injection molding process earlier described but it is inside of our scope to make the system manufacturable, this deliverable will ensure that the system is competitive in pricing and ease of manufacturability.

7.1.1 Procurement

The materials for the quarter-scale model will be primarily PLA filament to be 3D printed as well as an epoxy coating to finish the surface after printing. For the full-scale model we will be purchasing shaping foam, a set of electric foam cutting tools, and plastic coating. All these materials will be bought on Amazon. Any fasteners or adhesives needed for either model will be purchased in person at a local hardware store.

7.1.2 Quarter-Scale Model Manufacturing and Assembly

The quarter-scale model will be composed of a van floor and four seats with two seats in two rows. We are planning on individually 3D printing the van floor, four seat backs, four seat bottoms, and eight armrests based on the drawing package found in Appendix T. This will mean 3D printing the frame of the seat, the articulation linkages, four tracks, and latching mechanisms for each seat. Although the goal is to print the exact full-scale system we currently have at a quarter of the size, we are prepared to adjust the system to have a more simplified articulation and nesting movement due to any problems we run into when sizing down the system. Some smaller components and attachment hardware may have to be taken out as well.
After all the components are 3D printed, we will post-process all the components to have a more professional finish before assembly. Firstly, each piece will be hand sanded to smooth the PLA after printing and get rid of any small irregularities. An epoxy coating will then be applied to each piece to give them a smooth finish and improve durability of the components.

To assemble the model, super glue will be used to attach components where hardware would be used in the full-scale system. The tracks will be attached to the van floor to create two columns and three seats will be assembled onto each pair of tracks to create three rows of seats.

7.1.3 Full-Scale Model Manufacturing and Assembly

To manufacture the foam seat, we will start with two pieces of upholstery foam. Since the goal of this prototype is to show the contour of the seat, the foam must be shaped very precisely to our specified ergonomic design. This will start by using an electric foam cutting wire to cut the foam down to the general dimensions and shape needed for the back and base of the seat. We will then use a smaller and more precise foam shaping tool to shape the back and base of the seat to the contour we have designed. The seat will then be coated with plastic coating to have a hard, plastic finish on the seat surface. Since this seat will be attached to the articulation team's steel frame and linkage system, we will also need to shape the surfaces attaching to the frame with the same geometry shown in the CAD model. The seat back and base will be assembled with the articulation system using an adhesive.

7.2 Track and Latch Manufacturing

7.2.1 Procurement

Our final track and latch system is made of aluminum and Delrin.

Table 21 and Table 22 lay out the parts of our product and sourcing plans for the materials. A more in-depth breakdown of cost and parts can be found in Appendix V, the IBOM.

Table 21. Track and Latch Component Sourcing Part 1

Component	Stock material	Source	Build Processes
Latch Body	2”x3”, 2’ long 6061-T6511 Aluminum Bar	Online Metals	Cut to length, Mill Features
Double Pin	2”x3”, 2’ long 6061-T6511 Aluminum Bar	Online Metals	Waterjet
Delrin Slide	12”x12”, ¼” thick Delrin Sheet	Online Metals	Cut to length, Drill holes
Spring Guide Pin Female	¼”, 12” long round 6061-T6511 Bar	Online Metals	Drill hole in stock, Cut to length
Spring Guide Pin Male	1/8”, 12” long round 6061-T6511 Bar	Online Metals	Cut to length, create external thread
Spring Guide Spacer	¼”, 12” long round 6061-T6511 Bar	Online Metals	Cut, turn on lathe, drill
Spring Mounting Pin	1/8”, 12” long round 6061-T6511 Bar	Online Metals	Cut, drill
Cross Bar	1/2", 24" long, round 6061-T6511 Aluminum Bar	Online Metals	Cut to length, tap holes
Follower Frame	6" x 6" x 1/8" 6061-T6511 Aluminum Plate	Online Metals	Waterjet and Brake
Follower	¼”, 12” long round 6061-T6511 Bar	Online Metals	Lathe
Mounting Plate	12”x12”, 0.25” thk 6061-T6511 Aluminum Plate	Online Metals	Waterjet
Aluminum Sheet	12”x12”, 0.25” thk 6061-T6511 Aluminum Plate	Online Metals	Cut to length, Drill mounting holes

Table 22. Track and Latch Component Sourcing Cont.

Component	Source	Build Processes
Logistic/Airline Track	Aircraft Extrusion Co	Cut to length
Screws (Total)	McMaster	
Springs	McMaster	
Bushings	McMaster	
Bolts (Total)	McMaster	
Nuts	McMaster	

As seen in Table 21 and Table 22, a variety of operations are required to build the various components of the system. Most complex shapes, however, are formed using waterjet cutting. This allows the other operations to include only simple passes of milling, turning, or drilling. The most complex operation beyond the waterjet processes is the t-slot milling for the latch mating profile.

7.2.2 Manufacturing

To begin our manufacturing process, we cut several pieces of stock material to size using the overhead saw so they could be sent to the water jet to be cut to shape. The parts which required the waterjet included the double pin, the follower frame, and the mounting plate. After the mounting plate and double pin were cut, we drilled and reamed properly sized holes depending on the hole's tolerance. After we cut and drilled the follower frame, we bent it as shown below in Figure 97.

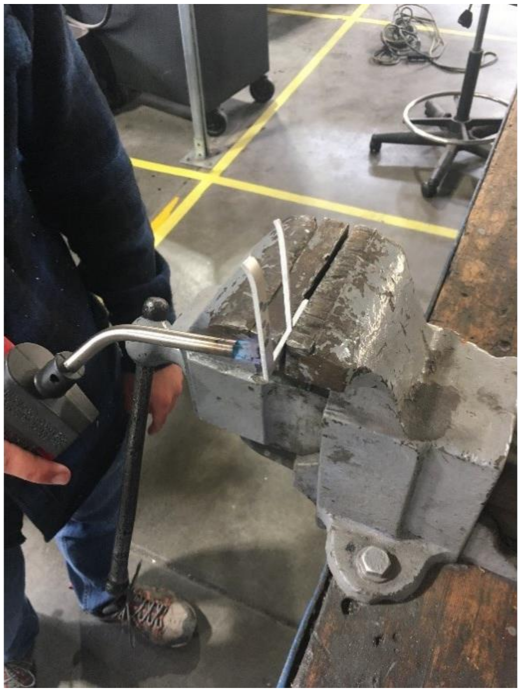


Figure 97. Alex Preheats Follower Frame to Prevent Cracking during Bending

Before bending the metal, we heated it up so it would not snap during the bending process. It was too thick and brittle without a heat treatment. This heat treatment was the first step in all bending trials for this part.

Figure 98. Test Bends of the Follower Frame

Figure 99. Bending of Follower Frame with Welding Wire

Figure 97 and Figure 98 show trail runs for bending the follower frame on the finger break. From these tests we learned in order for a successful bend we needed to heat treat the metal first, then use a thin wire to get a uniform straight bend.

Next, we manufactured the male and female follower pins. We used a mill to flatten the face and circumference of the pins. Once we milled a flat surface on the round area, we drilled the mating hole in each pin.

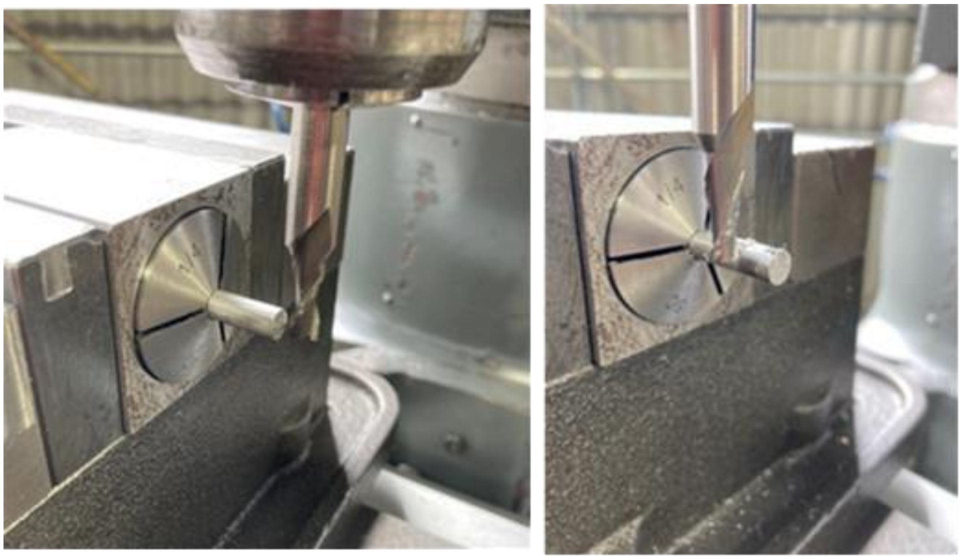


Figure 100. (Left) Mill Flattening Operation for face of female follower pin. (Right) Flattening circumference of female follower pin to prevent drilling errors.

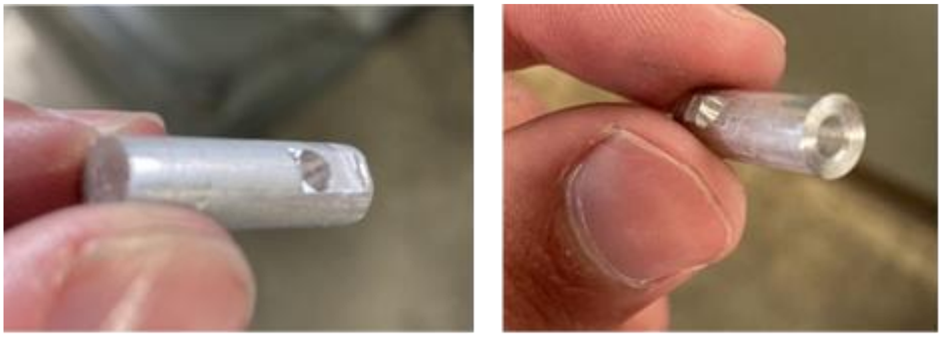


Figure 101. (Left) Female Follower Pin Showing Mounting Hole. (Right) Female Follower Pin Showing Mating Hole

Next, we drilled and milled the follower mount. This piece was then cut to size on the band saw.

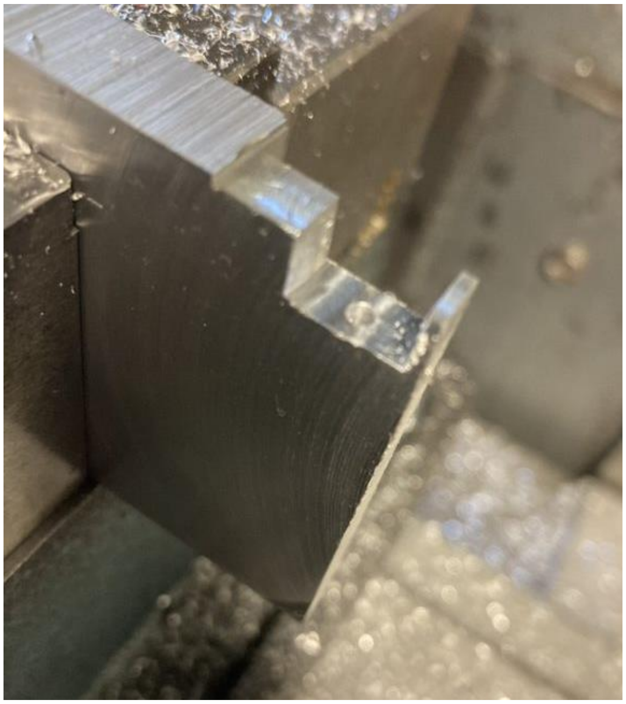


Figure 102. Follower Mount Stock after being drilled and milled using a manual mill

The most difficult operation involved making the latch body. We completed many different operations to complete the part. Figure 103 through Figure 108 show the sequence of cuts and drills necessary to complete the part.

Figure 103. Initial cut from stuck to rough latch shape

The initial cut for latch body used a mill to cut material off both sides of the stock aluminum. Nearly all cuts were done with two latches conjoined so fewer passes and holds were needed on the mill. As such, we performed each operation twice rather than four times.

Figure 104. Initial pass for forming of track-latch profile

The second cut for the latch removed material from the bottom of the stock bar. Here, we used an end mill to cut material off the bottom of the latch to get the beginning of the track mating profile.

Figure 105. Milling the Double Pin Guide Slot on the Latch

Next, we milled the double pin guide slot on the latch. A larger drill bit created the guide slot on the inside of the latch. This process was done on both sides of the long latch material.

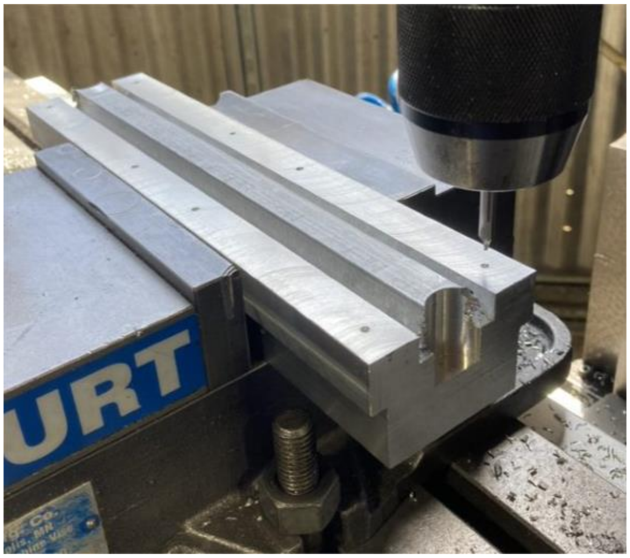


Figure 106. Drilling Holes for Delrin Attachment Screws

Next, we drilled holes for the Delrin set screws. Once the guide slot was milled, we used a drill press to create the holes for the set screws that would hold the Delrin in place.

Figure 107. Drilling Frame Mounting Holes onto Latches

Next, we drilled the two bolt holes that attach the latch to the frame of the seat. Each bolt hole is for one latch to attach the seat articulations design. The holes were measured from the edge of the material such that when the block was cut in half, they were correctly placed.

To complete the manufacturing on the latches, we used a T-slot end mill to create the track profile. Figure 108 shows the t-slot end mill cutting the last cut for the track mating profile. This cut removed a lot of material, so it required a lot of time and coolant.

Figure 108. Milling the Mating Profile Using a T-Slot End Mill with Coolant

7.2.3 Assembly

The assembly of our design was divided into three parts: the latches and track, Cam design, and the integration with the seat articulation design. Each of the sub-assemblies had difficulties and challenges to overcome.

The easiest sub-assembly, the latch sliding onto the track, took two easy steps. First, we attached the Delrin to the bottom of the latches with the set screws (see Figure 109).

Figure 109. Completed Single Latch with Delrin Slides Attached

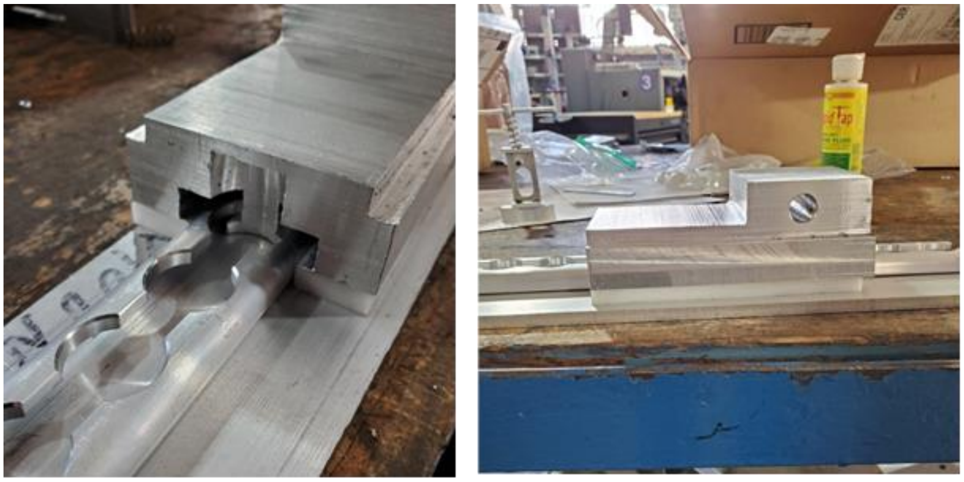


Figure 110. Completes Latch in Track Demonstrating Profile Mating

Next, we lined up the track mating profile from latch with the track and slide it in as seen in Figure 110. The motion of the latch sliding along the track was not smooth due to imperfect cutting, so we took a file and filed the inside profile of the latches down. This gave the track and latch mating profiles more clearance, such that they moved smoother.

Next, we assembled the Cam follower as seen in Figure 111. The first components for this sub assembly included the double pin, spring guide pin female, follower frame, follower, and follower mount. We started the assembly by attaching the follower frame to the double pin via the two black screws. Once the double pin and the follower frame were attached together, we attached the follower mount to the underside of the of the follower frame with a screw. Next the follower was placed in the follower mount and held in place with screw. Finally, the spring guide pin-female was attached to the top of the follower mount. The Cam lever arm is attached later when we connect the track and latch system to the seat articulation system.

Figure 111. Complete Follower Subassembly with Double Pin

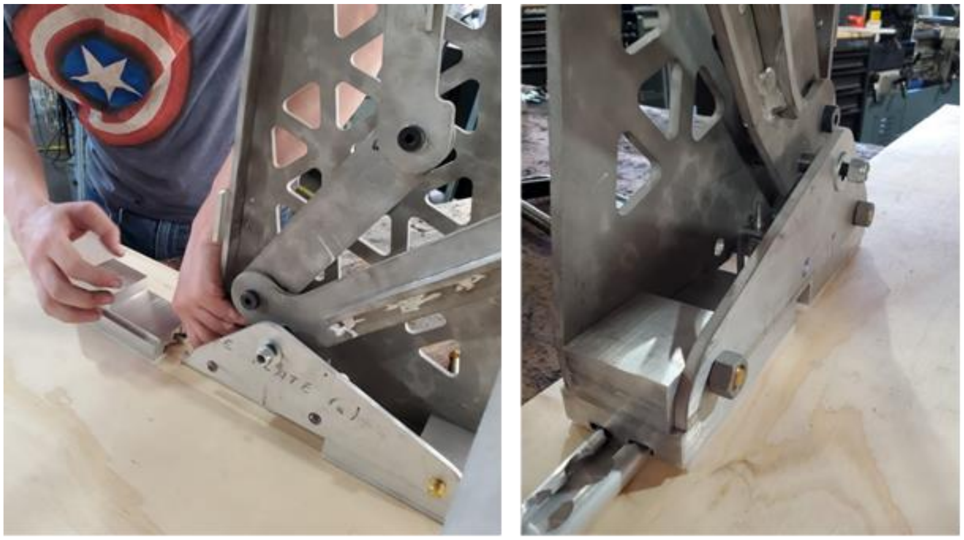


Figure 112. Attaching the Latch to Seat and Track

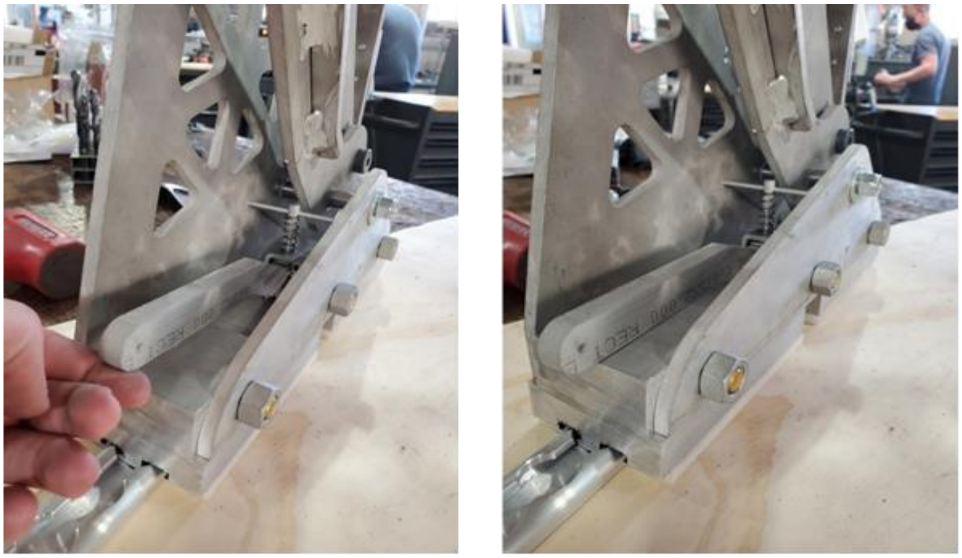


Figure 113. Attaching the CAM System to the Assembly

Next, we combined the track system and seat actuation system. We slide the track with one latch on it underneath the sides of the seat on both sides as shown in Figure 112. We then placed the Cam follower system with the double pin into the track as shown in Figure 113. We made sure to mate the double pin with the guiding profile of the latch already attached.

Once the two latches and the pin with the cam follower system were in the correct places, we slide the bolts through holes to create a rigid connection. The bolt slide easily into the front latch, but the bolts for the cam follower system and the back latch were more difficult. We had to file the guide slot in the cam follower, so the pin didn’t create friction when the pin moved in and out of the track. Once we finished filing, the pin went in much easier. The back latch bolt caused much difficulty. We had to take a mallet and hammer the bolt through the hole. Once it was hammered in, it was near impossible to remove, but the connection was sturdy. Now that the system was locked into place, we finished assembling the Cam system.

To finish the assembly, we attached the spring, spring guide pin-male, spring guide spacer, and spring mounting pin. We placed the spring over the female guide pin and mated the male guide pin with the female guide pin inside the spring. Next, we slide the mounting pin through the support plate, male guide pin, and outside plate. With the follower firmly set in place, we attached the Cam lever arm. We first slide out the bolt holding it in place so that we could slide the bolt through the Cam lever arm. We lined up the Cam follower to the lever arm and locked the bolt in place by sliding it through the support place and locking it with a nut.

Finally, we attached the front bar to the two Cam lever arms to complete the assembly (see Figure 114).

Figure 114. Final Assembly

7.2.4 Challenges, Lessons Learned and Future Recommendations

Our largest challenge was due to further misunderstandings with the required space for waterjetting the double pin. While we learned from our structural prototype error and purchased larger stock for this process, the larger stock still had insufficient surface area for the waterjet's toe clamp to hold the material. Luckily, we were able to quickly procure appropriately sized stock and this lesson did not cause any delays in production. Most importantly, this notes that the double pin should use a different stock size than the latch stock. The size of the follower frame and tight bend radii introduced problems with cracking the 0.125” thick aluminum. This continued to be a problem despite heating the part prior to bending. Therefore, we recommend manufacturing this part out of C-Channel stock, or if allowed by stress analyses, use a thinner sheet metal stock. Another problem relating to the follower frame is that in the current design, the foot pedal- cam lever assembly can slide back and forth. To solve this, we recommend including some cheap plastic spacers on the cam mounting bolt or do a slight redesign of the follower frame to be made from rectangular tube stock. Additionally, during production of the follower frame, we discovered that the called tolerances are insufficient due to the interface with the follower frame bend radius. This issue would be resolved if the follower frame were to be made from a C-channel or rectangular tube stock as described above.

The latches are a complex part but have a basic base shape. Instead of manufacturing the latches purely using an end mill (as was done for the verification prototype), the team recommends initially casting the base shape of the latch and then complete finishing touches on an end mill. This will greatly reduce material waste and increase production efficiency of the latches. Upon completion of the latch machining, it was discovered that the t-slot endmill used to create the mating profile was improperly sized. The correct endmill is now included in the manufacturing plan and described above. Contact between this mating profile and the track was slightly higher than expected upon assembly, causing a large sliding resistance when moving the seat along the track. Therefore, we recommended editing the design to have a significantly larger clearance between the latch T-profile and the track profile. Uneven sliding between the latches on either side of the seat also contributed to the large sliding resistance. To combat this, we recommend welding (or otherwise attaching) a rigid plate between the two mounting plates. Furthermore, the double pin actuation mechanism did not function entirely as designed. It was impossible to disengage the double pin from the track with the current design of the cam, and thus we recommend a full redesign of the cam lever arm component. During operation of the actuation mechanism, it was noticed that the male spring guide pin would sometimes fully disengage from the female guide pin, resulting in binding. Thus, we recommend the male spring guide be designed to be slightly longer. Finally, we initially specified only standard hex nuts. During assembly, we discovered that locking nuts should have been used instead. The iBOM and drawings have been updated to reflect this.

All these changes are reflected in the updated manufacturing plan attached in appendix AJ. While these processes could be further optimized in mass production, single entity production is optimized in this way.

7.3 Articulation Manufacturing

This section details how all the components were procured, as well as a description of how each component was made and assembled for the full confirmation prototype.

7.3.1 Procurement

A full Bill of Materials can be seen in appendix AF, which includes the procurement for every component. The metal was bought from McCarthy Steel in San Luis Obispo, CA, the carriage and rail system were purchased from McMaster Carr, the latching system was bought from SouthCo, and the majority of the fasteners were ordered from McMaster-Carr or purchased in person at an Ace Hardware. The stock ¼” plate from which the seat was manufactured from are shown below in Figure 115.

Figure 115. Raw Aluminum Plate Sheet, displayed in truck (Left) for perspective and vertically (Right)

The total expense of our project was $852.56, placing us under budget for the manufacturing of the verification prototype. The breakdown of each major expense can be seen in Table 23. The remaining balance of $147.44 could be placed towards future iterations of this verification prototype, as discussed in Section 9.2.

Table 23. Final Budget Summary

Final Budget Summary:	
Items Purchased	Cost
1/4" Aluminum Plate - 4' x 6' Sheet	$ 323.25
Rail/Carriage System and Miscellaneous Hardware	$ 366.65
Rotary Latches and Latch Hardware	$ 162.66
Total expenses:	$ 852.56
Budget:	$ 1,000.00
Remaining Balance:	$ 147.44

7.3.2 Waterjet Cutting

The first step in this process involved converting all the plate metal piece profiles – for the linkages and framework pieces – to a .dxf file. Once this .dxf file was made, the plate metal was then loaded onto the waterjet in Mustang60 to be cut (Figure 116).

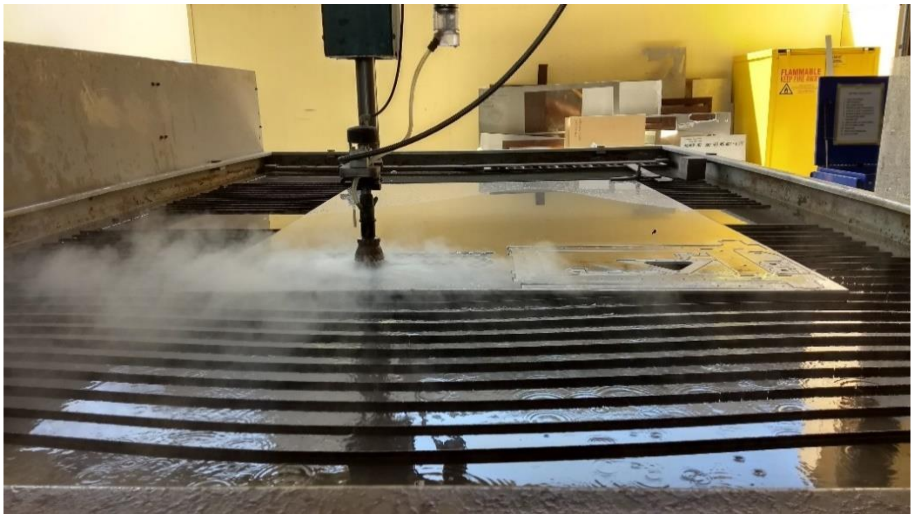


Figure 116. Waterjet piercing the plate to initiate a cut

Due to the small triangular cut outs for system weight reduction (Figure 116), the waterjet had to be constantly monitored to ensure none of the cut trinagles interfered with the path of the waterjet; they occasionally did not fall through into the water, resting just above the surface of the plate. Often such triangles had to be manually removed to continue cutting.

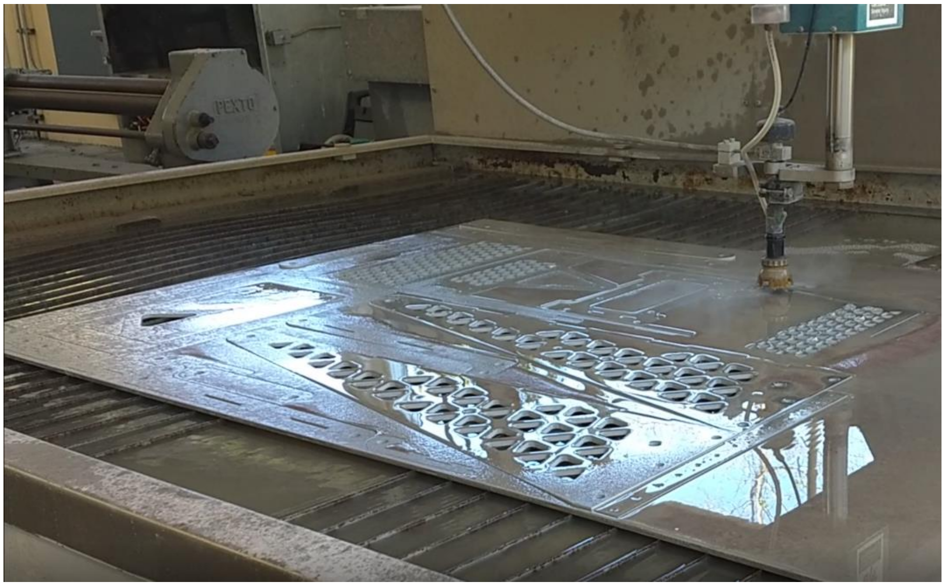


Figure 117. Final cut on the waterjet

After just over 3 hours of cutting, the plate components of the design were completed and ready for post-processing (Figure 117 and Figure 118).

Figure 118. All parts displayed by the waterjet after removal from the plate

7.3.3 Post Processing

After the overall profiles were cut on the waterjet, the parts went through postprocessing. While the waterjet is remarkably accurate in its tolerances, the cut edges do not have a surface finish sufficient to be used as a bearing surface. As such, all holes were undersized to be reamed to the correct diameter to ensure cylindricity of the holes and to aid in concentricity of holes across the two sides. The holes were carefully marked to indicate the desired diameter in order to speed up the drilling process (Figure 119).

Figure 119. Holes were carefully marked to minimize the duration of the drilling operation

All holes were drilled on a drill press to maximize perpendicularity. Additionally, a number of holes needed to be tapped to attach purchased hardware (Figure 120).

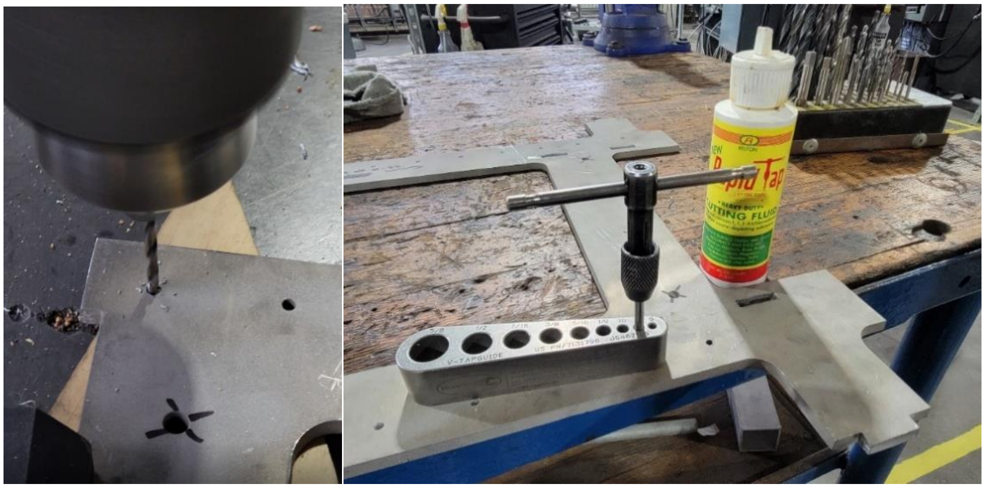


Figure 120. Drilling out (Left) and Tapping (Right) the holes

To clean the parts (prior to welding) and provide a more aesthetic surface finish each of the plate components were sandblasted. Finally, remaining sharp surfaces were deburred and the components were filed to ensure the tab-joints mated properly (Figure 121). Due to tolerancing errors with the waterjet, this process took a significant amount of time. These processes were also done at the Cal Poly Mustang60 facility.

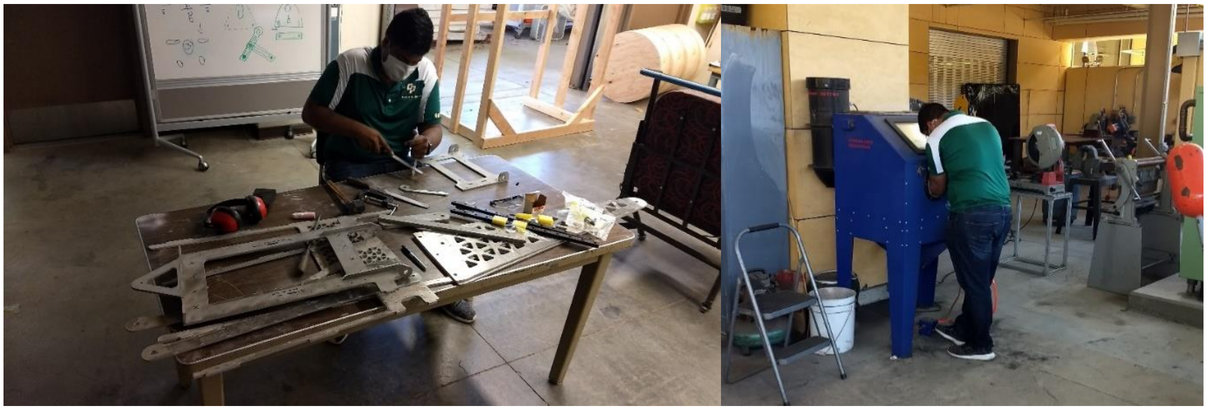


Figure 121. Deburring and filing the parts (Left) and cleaning them with a sandblaster (Right)

7.3.4 Welding Subassemblies

After all the parts were cleaned and refined in postprocessing, all the necessary subassemblies were tig-welded together in the Aero Hangar. A dry fit of each component was conducted prior to welding (Figure 122) to ensure the components could be assembled to tolerance (no excessive gaps and all components perpendicular).

Figure 122. Seat Bottom Frame Unwelded Test Fit

Various fixtures were used to maintain alignment of components during welding. For most components, a steel bar was run between concentric holes to ensure proper alignment (Figure 123). To avoid excessive warping due to heat, short stitch welds were used rather than continuous welds.

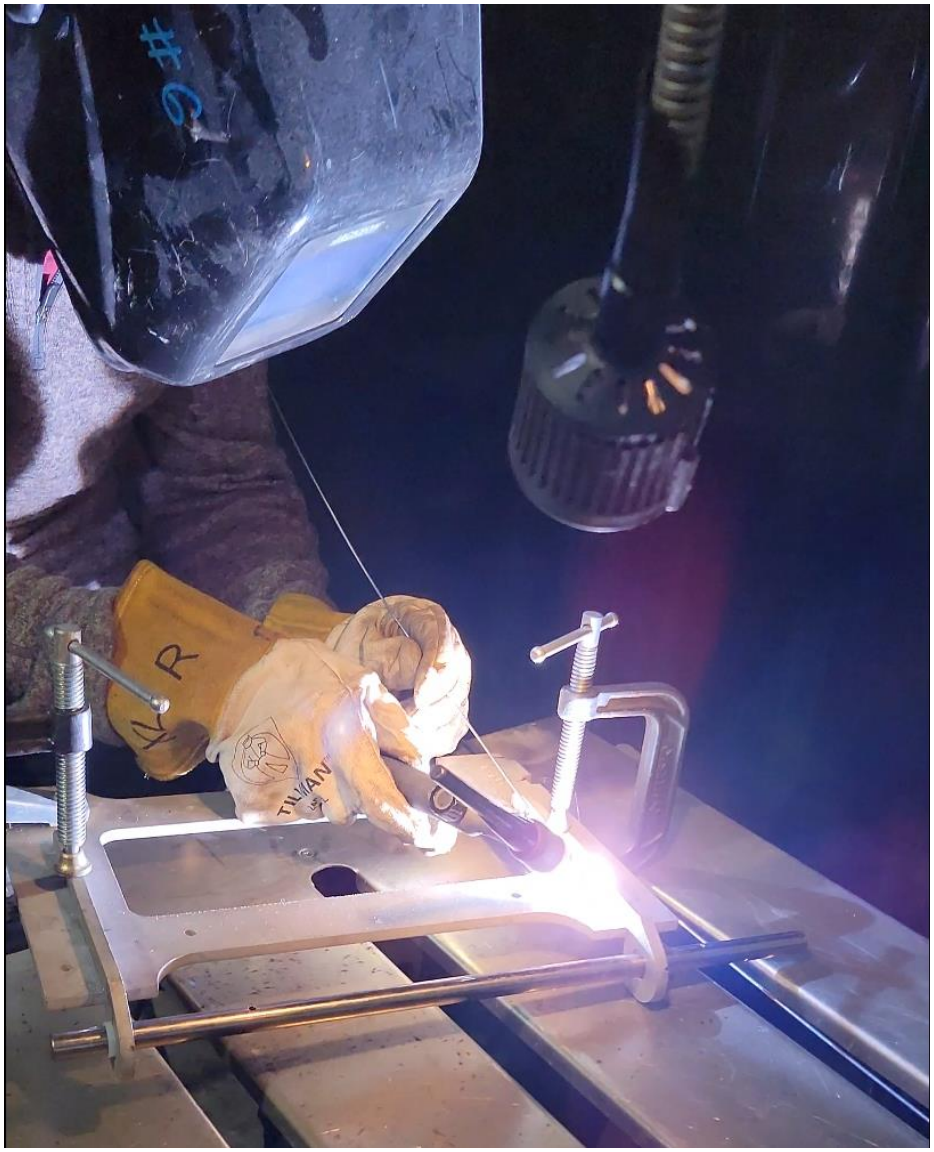


Figure 123. Tig Welding on the Seat Bottom with Supporting Bar

Upon completion, each component was tested to ensure integrity of the weld by manually applying a light load on the part. Several completed welds are shown in Figure 124.

Figure 124. Completed welds on the seat back

Due to tolerancing or aesthetic concerns, many of the welds were ground into a filleted profile (Figure 125).

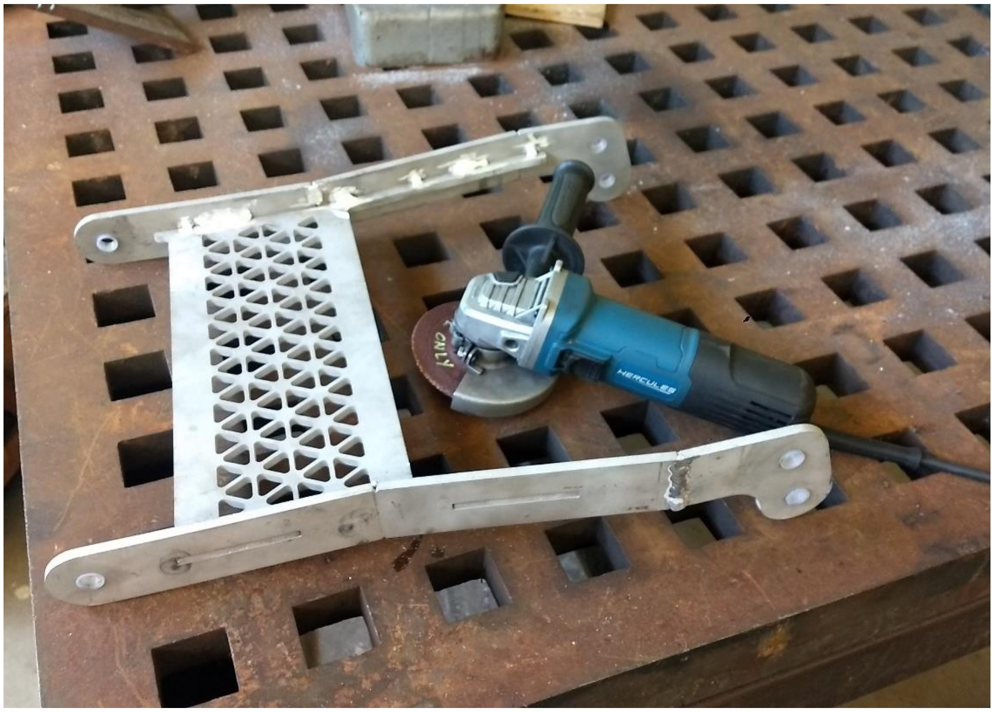


Figure 125. Ground welds on the diagonal brace

7.3.5 Final Assembly

After all the subassemblies were welded, the two larger assemblies were assembled via shoulder bolts and brackets in Bonderson. This is seen in Figure 126 and Figure 127.

Figure 126. Side Frame and Seat Assembly

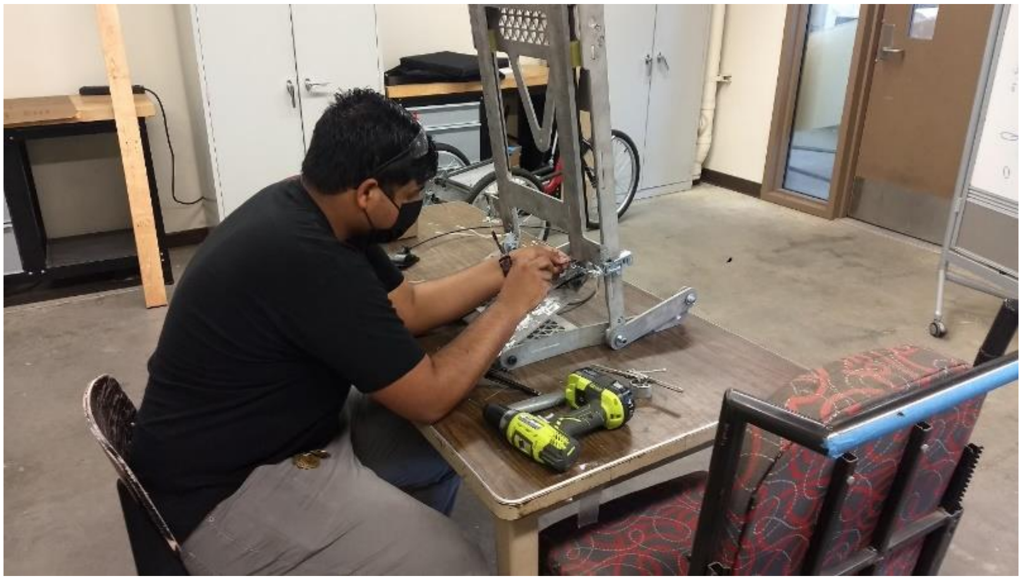


Figure 127. Installed Fasteners

Once the seat frames and linkages were put together the latch and gas spring were retrofitted to the seat. Once the clearances were verified on the side frame, the left and right latches were mounted with accompanying sticker pins. The cables were then attached and routed to the remote actuation system. Lastly, the gas spring was then bolted on to the seat back.

7.3.6 Challenges and Recommendations for Future Production

Challenges associated with this project stemmed mostly from misalignment due to warping from welding, and the subsequent tolerancing issues that resulted. For example, incorrect welding settings led to an early snapped component that needed to be recut on the waterjet. In addition, warping from the welded components led to a need for troubleshooting and clearance adjustment in the final stages of assembly due to friction interference restricting articulation movement. Clearance issues also required that we buy new, more applicable shoulder bolts and locknuts to prevent interference and binding.

In total, I believe deflection could have been accounted for more heavily during the design process. It was possible to fix excess deflection manually after assembly, but it could perhaps be avoided in the design process with more cross bracing and more comprehensive tabbing before welding to prevent warping.

8.0 Design Verification Plans

In order to meet each team's design specifications, tests will be conducted on the verification prototypes to ensure that each individual specification is met. These tests will verify that the designs will meet the customers' wants and needs and will give insight into recommendations for future designs.

8.1 System and Demo Design Verification

With the two prototypes of our quarter scale, 3D-printed model and articulation's full-scale model, testing will be done to verify the feasibility and marketability of the design. Various tests including surveys, demonstrations, and force analysis will be done to verify that the target specifications are met.

8.1.1 Specification Discussion

Below is a table of the specifications which will be tested using our structural prototype to verify the design will be feasible and a brief description of each underneath the table. Due to additional insights that we have gained throughout the design process, these specifications have been updated from our initial specifications. These specifications more accurately describe the necessary requirements for our system design that will be tested with our verification prototypes (Table 24).

Table 24. System Verification Prototype Specifications

Spec. #	Specification Description	Requirement or Target
1	Nesting Efficiency	Increases floor space 70%
2	Manufacturing Cost Analysis	$1000/Seat
3	Seatbelt Safety Standards	Pass FMVSS 209/210
4	Transit Company Satisfaction Survey	60% satisfaction
5	Customer Ergonomic/Aesthetic Survey	80% satisfaction
6	Intuitive Design Survey	20 sec to articulate and nest one seat

Spec 1: When in the stowed position, all the seats should take up a maximum of 30% of the floor space, leaving 70% of the space empty for storage of luggage entities. This test will only be considered for the seats in the nested and not in the deployed position.

Spec 2: Total cost of each individual seat should not exceed $1,000. This price was provided by Ritch Hollingsworth in order to keep our seat priced competitively so transit companies will consider choosing our design.

Spec 3: Integrated seatbelt for the final design should meet FMVSS 209/210 requirements. FMVSS 209 specifies the loading requirements for the seatbelt assembly and FMVSS 210 specifies the loading requirements for the seatbelt anchorage point. Both of these safety requirements must be met with our seatbelt design.

Spec 4: The goal is to have a 60% satisfaction or approval rate from transit companies that would be potential buyers of this system since our goal is for this to be a marketable product to transit companies.

Spec 5: A survey that will be given to potential passengers of the vehicles that would the seat installed. This survey will be measuring whether the passengers liked the ergonomics and aesthetics of the seat.

Spec 6: This is a survey which will be given to users who have no previous knowledge of the seat. The survey will test how intuitive operation of the seat will be. The goal of this specification is to have 80% of new users be able to operate the seat with no previous knowledge.

8.1.2 Description of Testing

The following is a description of each individual test we will be conducting to verify each of the six specifications described above. Additionally, a summary of our design verification testing plan for the verification prototypes can be found in Appendix AI.

Spec 1: Using our quarter-scale model, we will be measuring the space saved when the seat is nested versus when it is deployed. Since this model will include four seats, we will also be able to measure space saved when multiple seats are nested together to provide a more comprehensive measurement of the space saved on a van using our configurable system.

Spec 2: Using our mass manufacturing plan we will use the DFM software available on campus to give us the cost to manufacture one seat. This may be an iterative process if our original manufacturing plan does not meet our spec of $1,000/seat.

Spec 3: A force of 5000 lb. will be applied to the seatbelt anchorage points on the full-scale verification prototype since this is the approximate load a 95th percentile man would apply on the anchorage during a crash. The prototype will be checked for any deformation to see if the system can withstand this load to meet the seatbelt safety standards. This would be done with a ¼” steel plate and the seat belt anchorage point placed in Cal Poly’s load testing facilities. If this is not available then hand calcs and FEA should be sufficient.

Spec 4: A survey will be sent to local transportation companies since they are representative of the entities we want to convince to buy our product. This survey will be an initial gage of satisfaction of the system to see if this is an appealing product to our target audience. An average satisfaction rate of 60% as our goal, and we hope to hear feedback from these companies for future iterations as well.

Spec 5: A survey will be given to transit users and potential passengers of the transit vehicles the seat would be installed in. This survey will measure satisfaction of the seat overall, as well as satisfaction of the perceived ergonomics and aesthetics of the seat. The goal is to have an 80% satisfaction rate on each of these individual markers as well as hear feedback to improve the seat and the seating system.

Spec 6: A test will be given to a random population of 50 people who have no previous knowledge of the seating system. Each person will be given the quarter-scale model and told to articulate the seat to a vertical position and nest it with the seat in front of it. They will be timed on how long it takes them to complete the articulation and nesting functions of the system directly after hearing the instructions. The goal is to have an average operation time of 20 seconds across the 50 samples.

8.2 Track and Latch Design Verification Plan

The final design verification prototype was tested for a variety of safety critical parameters. These parameters, their goal values, and their tested values are displayed below in Table 25. A complete discussion of testing procedures and analyses are available in Appendix AJ. We completed all tests in the Senior Project Rooms inside the Bonderson Project Center.

Table 25. Track and Latch Testing Results

Parameter	Goal Value	Tested Value
System Weight	60 lb Maximum	46 lb
Force to Actuate Lock with no system fouling	5 lb	9.26 lb
Force to Actuate Lock with System Fouling	10 lb	11.87 lb
Force to Move System along track with no fouling	10 lb	15.74 lb
Force to Move System along track with fouling	15 lb	18.44 lb
Effective System Friction Coefficient	-	0.3323

To measure the system weight, we placed all components of the system on a common household scale. This was necessary due to limitations on available equipment and acceptable as the resolution of the measurement is not critical. The system weight was measured to be 46 lbm +/- 0.5 lbm. This fell well within the goal value of 60 lb. This reduced system weight also aided the effective system friction coefficient. No processing was necessary with this data.

For all parameters requiring the measurement of forces, a force gauge (the device seen in Figure 128) was used. The manual force gauge allowed the test administrators to apply a visibly measurable force to various components in a controlled fashion.

Figure 128. Force Gauge

First, the force required to actuate the locking system was measured by using the hook extension of the force gauge to pull on the crossbar. This testing setup can be seen in Figure 129. Using this method to measure the actuation force, the average actuation force of the unfouled system was found to be 9.26 lb. This test is corrupted due to issues in manufacturing preventing the movement of the CAM system. Therefore, this test is simply a maximum possible value for the poor design as at this value, deformation of the follower frame began. This test revealed that the CAM must be redesigned to have a less step angle of rotation such that it may be actuated. It also demonstrated that the follower frame lacks lateral stiffness and should be redesigned out of rectangular tubing to prevent deformations. This recommended design changes are detailed in the Conclusion and Recommendations.

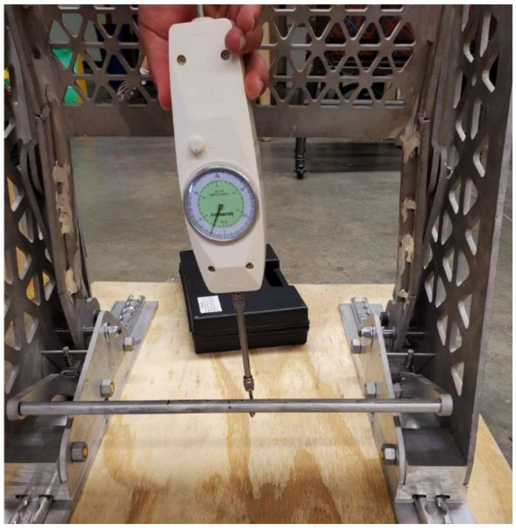


Figure 129. Testing Set up for Actuation Bar

Using the same procedure as described above, we measured the force required to actuate the locking system while the system was fouled. System fouling was accomplished by grinding common dirt and other debris into the track and actuation system. The dirty system can be seen in Figure 130. After the system was fouled in this manner, we repeated the testing procedure above. This test was largely inconclusive due to the same reasons described above.

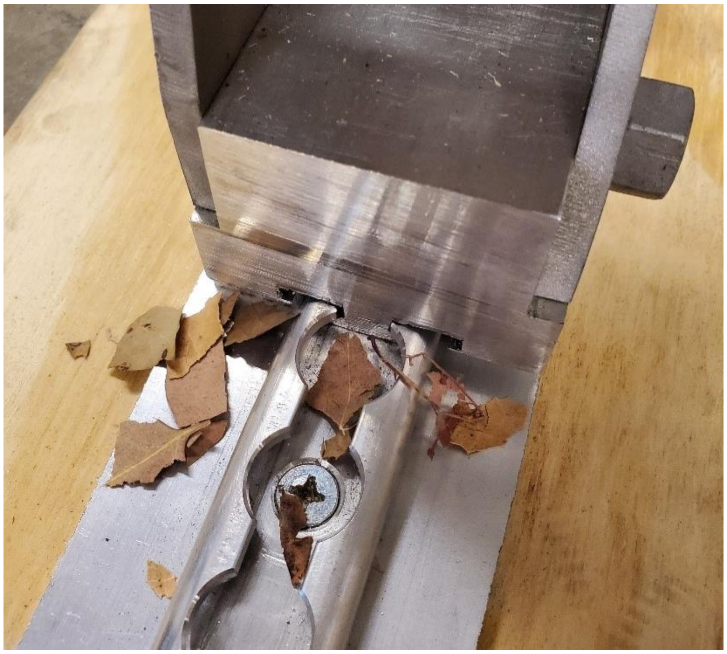


Figure 130. Dirty Conditions for Track Testing

Next, a test to determine the ideal effective system friction factor was executed. We placed a crossing brace board so that the force applied from the force gauge was uniformly distributed, as seen in Figure 131.

Figure 131. Testing Set up for Push Force Test

This prevented one side of the seat to move without the other. If one side moved without the other, binding occurred, which greatly increased the force required to push the seat. With the system in the unlocked position, we applied a force to the force gauge into the back brace. We measured the force measured once the system began moving. The average value of this force was 15.74 lb. This force was then used to calculate the friction coefficient between the latch and the track. The calculated friction coefficient was 0.3323 +/- 0.0098. We performed uncertainty propagation on this calculation to find the uncertainty of 0.04 in the value. This calculation can be found in Appendix AJ, the DVP&R.

We performed the same test under fouled conditions. We used the same fouling man show in Figure 130 above. Under these conditions, we found the average force required to move the seat was 18.44 lb.

All the forces measured during testing did not meet their goal values. A simple redesign of the cam system would fix the force to actuate the locking mechanism. With a less steep Cam route, the force needed to lift the pin out of the track would be lower and meet our goal of five pounds. There are a few solutions to lower the force required to push the seat while in the unlocked position. First, give the latch track mating profile a larger clearance. Occasionally, the latch mating profile got caught on the track, causing a hitching problem that increased the average force value. A quick fix for this issue is to deburr the inside latch profile. If the inside is efficiently deburred, the catching problem is mitigated. Another issue that increased the required force to slide the seat was binding. One side of seat would move while the other remained in place. To fix this issue we recommend adding a rigid plate welded between the mounting plates such that they much move together. This would drastically reduce the required force to slide the seat.

8.3 Articulation Design Verification & Testing

The purpose of manufacturing a verification prototype was to verify that the proposed design meets all engineering and design specifications in a manner that is directly observed in a controlled environment instead of in a simulated or modelled environment. As such, the design and performance of physical testing on the verification prototype was necessary to achieve this goal. This section outlines the details and procedures used in each test, as well as the results and analysis that prove that the proposed design meets all engineering and design specifications.

8.3.1 Test Description

The tests conducted to verify that the verification prototype met the outlined specifications are as follows:

1) Operation time test to determine how long a user would take to move the seat from a stored position into a deployed position and vice versa.
2) Operation effort test to determine the amount of force required to move the seat from a stored position into a deployed position and vice versa.
3) Linkage stiffness test to determine the amount of deflection experienced by the seat in both in plane and out of plane loading conditions.
4) Miscellaneous testing to verify engineering specifications that require no quantitative analysis, but rather, are observationally based.

All tests were performed in Bonderson Test Center. Sections 7.1.1 – 7.1.4 below provide details on the nature and design of these four tests, and section 7.2 discusses the results of each test. In addition, further details can be seen in the design verification plan & report, referenced in Appendix AK.

8.3.1.1 Operation Time

This test was conducted to gauge the intuitiveness and ease of use of our final design. The scope of this test included timing how long it took a testing participant to stow and deploy the seat. Facilities used included the Bonderson test center and equipment used for this test included a timer to time how long a user took to articulate the seat. Figure 132 below delineates the general motion of stowing the seat, and depicts what users had to decipher during testing.

Figure 132. Testing of Seat Folding Operation

8.3.1.2 Operation Effort

As stated above, this test is designed to determine the amount of force required to move the seat from a stored position into a deployed position and vice versa. This test is necessary in proving our design goal of requiring minimal user effort to actuate the seat into different positions. By measuring the amount of force required to actuate the seat, and comparing it to a maximum threshold, the test technician can verify that minimal user effort (force input) is required to actuate the seat.

The test setup is shown below in Figure 134, and shows a force being applied to the seat from the top of the seat back downward in a parallel fashion to the seat back. This applied force required to move the seat was observed and recorded using a force gauge. The specific force gauge used in this test was acquired from Mustang 60, and can be seen in Figure 133. The force gauge provided an analog dial reading of lb_f on the device in compression or tension. For this test, the device was used in both compression and tension to measure the deployment and stowing of the seat respectively.

Figure 133. Model of Force Applied for Testing

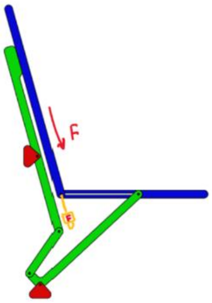


Figure 134. Force Model Used for Testing

The test procedure is as follows:

1. Set up verification prototype in stowed configuration, and attach Force Gauge at hinge point between seat bottom and seat back
2. Articulate seat into deployed configuration by moving the seat back down. Measure the force required to pull the seat down against the gas spring using the Force Gauge.
3. Record values and repeat for 2 trials across 3 team members

The target specifications and test results are discussed in section 7.2.2.

8.3.1.3 Linkage Stiffness

This test was conducted to develop a model of seat deflections under static loading conditions. This was necessary in order to ensure the deflection experienced in common loading conditions would not exceed our maximum deflection specification. Three load cases were considered, summarized by Figure 135 below. As indicated in the figure, the three loading directions will be defined as the Vertical, Axial, and Transverse load cases, respectively.

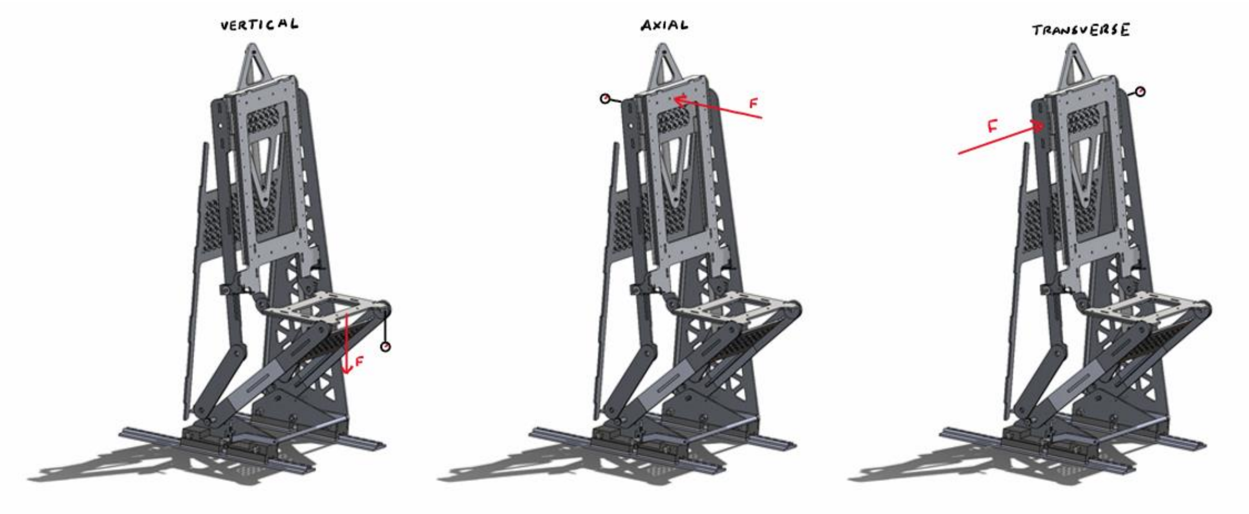


Figure 135. Loading Cases for Stiffness

For both the Axial and Transverse load cases, the following procedure was utilized.

1. Mount the dial indicator securely on a steel frame using the magnetic base.
2. Adjust the indicator to zero out the reading.
3. Manually apply load to the force gauge, hold at a steady force value, and record deflection.
4. Repeat steps 2 and 3 for several levels of force.

The test setup used for these two cases is displayed below in Figure 136. The transverse case is displayed to visualize the setup more easily; for the axial case, the seat is rotated 90 degrees.

Figure 136. Testing Setup for Transvers Loading Case

For the vertical case, a slightly different procedure was utilized. The test setup was altered to allow a mass to be hung from the seat by raising the entire assembly on sawhorses and cutting a hole in the plywood base below the edge of the seat. The mass utilized was a bucket filled with water hung using a ratchet strap (see Figure 137 below). Using this setup, the procedure was as follows:

1. Place the dial indicator under the edge of the seat and manually stabilize.
2. Adjust the dial indicator to zero out the reading.
3. Add water to the bucket and weigh with a scale.
4. Hang the bucket under the seat, taking care to minimize movement of the dial indicator base.
5. Repeat steps 2 through 4 for several weights.

Figure 137. Testing Setup for Vertical Load Case

8.3.1.4 Misc. Testing

Several additional tests were conducted to verify the engineering specifications that did not require extensive testing. These tests require either one data point or simple inspection. The miscellaneous tests are as follows:

1. Measure seat floorplan dimensions.

2. Weigh the seat.
3. Check for exposed machinery.

The seat floorplan dimensions were measured to verify our seat compatibility. The weight of the seat was verified for track and latch team and correlate to our load calculations. The exposed machinery was checked safety and aesthetic reasons.

8.3.2 Test Results

After completing testing, the raw data was compiled in an Excel spreadsheet for analysis. The raw data and refined data/analysis can be seen in Appendix AK.

8.3.2.1 Operation Time

The operation time data was reduced to average time required to stow and deploy the seat, then combined to determine the average total articulation time (summarized in Table 26 below). The measured average of 3.6 seconds is notably less than the specified 5 second target.

Table 26: Average Operation Time Results

Average Operation Time		
Stow	Deploy	
[s]	[s]	Total:
1.27	2.31	3.58 Seconds

8.3.2.2 Operation Effort

The average force (in lb$_f$) required to move the seat and hold the seat in a fixed, statically balanced midpoint was recorded for several scenarios, including deploying and stowing the seat, as well as with and without the gas spring. The reason for the latter is due to a manufacturing constraint, where the gas spring fixed to the seat was overbalanced at 50 lb$_f$. The reason for this was simply due to purchasing constraints, as this was the only spring that fit our budget. As such, the test was conducted with and without the gas spring in order to measure the effect the overbalance had on operation effort. Table 27 outlines the average results of the operation effort test for each scenario. Because the gas spring is designed to hold the seat in a stowed position, measuring the force required to deploy the seat without the gas spring engaged would be a trivial test requiring no effort. Similarly, the seat stows itself with no user effort when the gas spring is engaged, and measuring the effort required to stow the seat would also be a trivial test. As a result, the two scenarios shown are the only two cases where a user would have to apply force, with the deploying of the seat with the gas spring being the only 'consumer applicable' case.

Table 27: Average Operation Effort Results

Average Operation Effort			
Deploying - Gas Spring Engaged		Stowing - Gas Spring Disengaged	
Hold	Move	Hold	Move
[lb$_f$]	[lb$_f$]	[lb$_f$]	[lb$_f$]

48	67	12	17

Overall, the test yielded predicted results. Because the gas spring is sized for 50 lb$_f$, the combined user effort with the weight of the seat yields a force requirement of 48 lb$_f$ to hold the seat, and with resistance, 67 lb$_f$ to move against the gas spring. When stowing the seat without the aid of the gas spring, the force required to hold the seat statically was 12 lb$_f$, and 17lb$_f$ was required to move the seat upwards against friction and the weight of the seat back.

The maximum target specification for user effort was 5 lb$_f$, and obviously the required force for the verification prototype with the incorrectly sized gas spring of 67 lb$_f$ vastly exceeds this. However, the test is not in vain and yielded interesting conclusions for future iterations of this design. For example, when first estimating the force requirement for the gas spring, we assumed the required force would approximately be the weight of the seat plus 5 lb$_f$ to achieve upward mobility. Weighing the seat during the testing phase of this project indicated that the seat weighed 46 lb$_f$, which would initially lead the designer to believe that a 50 lb$_f$ would be ideal. However, this obviously was not the case. Future iterations of this project should instead perform the test seen in the second scenario, there the force required to move the seat up into a stowed position was measured. In this design, 12 lb$_f$ was required to hold the seat statically, indicating that the required force to actuate the seat upwards by a gas spring would be around 17 lb$_f$ (confirmed by the average force of exactly 17 lb$_f$ in this test to move the seat upwards).

8.3.2.3 Linkage Stiffness

From the recorded stiffness data, a plot was developed to determine the equivalent stiffness for each load case. Linear trendlines were utilized to determine an equivalent ‘spring constants,’ assuming linear elastic behavior, that were then utilized to project the deflection of the seat for a range of load values (Figure 138, below).

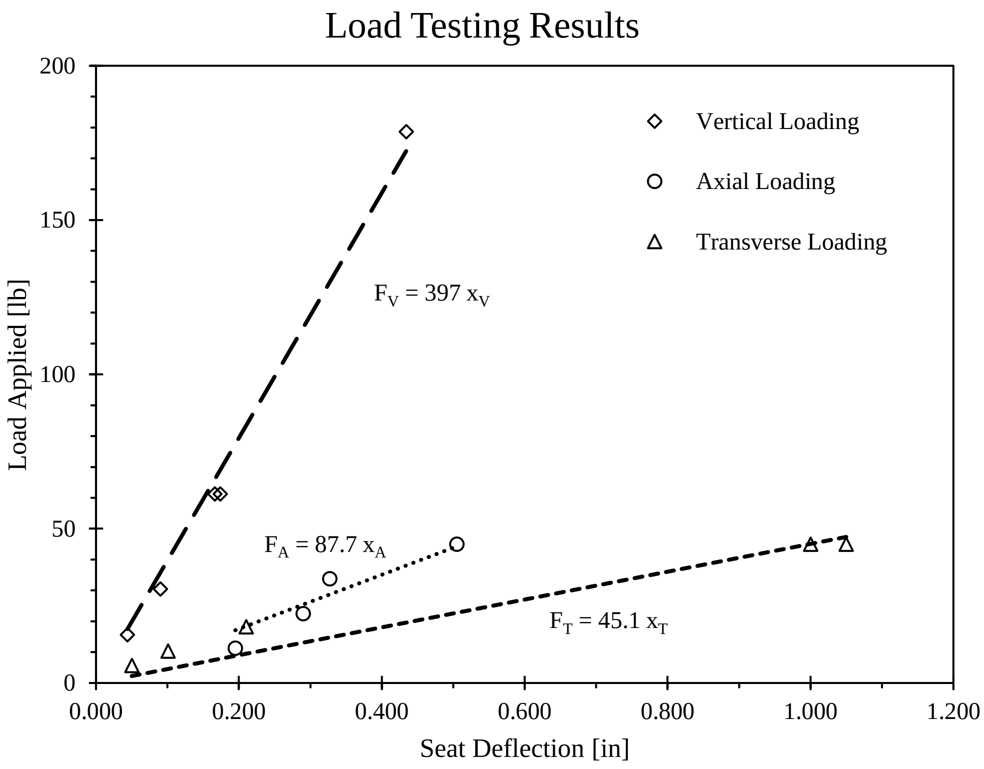


Figure 138. Loading Test Results Graphed

Based on a projection from the vertical stiffness value, the target maximum deflection of 0.25 in would be exceeded by only 100 lb_f of force. As this is notably less than the projected static load applied to the seat during normal use, the seat did not meet the stiffness criteria.

8.3.2.4 Misc. Testing

The target specification for the seat floorplan dimensions was 8” x 24”, and the measured verification prototype dimensions was 11” x 19”. As the design scope and criteria changed, the target specification changed in response to demo team requirements for more space. As such, the design was altered to intentionally not meet the original design specification. However, our current design and verification prototype both meet the new guidelines set by the demo team.

The target specification for the weight of the seat was originally 50 lb_f. This later changed to 60 lb_f in response to track & latch team requests for a lighter seat in order to meet crash test force requirements outlined in FMVSS standards. The verification prototype weighs only 46 lb_f, meeting both requirements.

Finally, the last test was observationally required to ensure no exposed pinch points could injure a user. However, due to the demo team being unable to manufacture the plastic cover for the seat, the entire internal frame of the seat is exposed to the user, exposing numerous pinch point locations. We anticipate this will not be an issue with completed production of the seat, as these pinch points would be covered by the cosmetic exterior plastic cover.

An overview of our final testing results and if they met our predetermined design specifications is summarized in Table 28.

Table 28. Articulation Testing Results

<table>
<tr><th colspan="5">Engineering Specification Verification Summary</th></tr>
<tr><th>Spec. #</th><th>Specification</th><th>Target</th><th>Measurement</th><th>Result</th></tr>
<tr><td>1</td><td>Single Seat Storage Space</td><td>8” x 24”</td><td>11” x 19”</td><td>Fail*</td></tr>
<tr><td>2</td><td>Strength</td><td colspan="2">See Notes Below**</td><td>N/A</td></tr>
<tr><td>3</td><td>Stiffness</td><td>0.25”</td><td>0.38”</td><td>Fail</td></tr>
<tr><td>4</td><td>Operation Effort</td><td>5 lb_f</td><td>67 lb_f / 17 lb_f</td><td>Fail</td></tr>
<tr><td>5</td><td>Operation Time</td><td>5 s</td><td>3.6 s</td><td>Pass</td></tr>
<tr><td>6</td><td>Weight</td><td>50 lb_f</td><td>46 lb_f</td><td>Pass</td></tr>
<tr><td>7</td><td>Exposed Machinery</td><td colspan="2">See Notes Below***</td><td>Fail*</td></tr>
<tr><td colspan="5">* Impacted by overlapping team scope.
** Unable to test; could not apply sufficient load in a safe and accurate manner.
*** Components required to cover exposed machinery were not constructed for this prototype.</td></tr>
</table>

8.3.4 Future Testing Recommendations

There are several testing modifications that our team would consider in the future. For the deflection testing, better test fixturing should be implemented to firmly bolt the base of seat in order to avoid any discrepancies due to the seat not being properly secured. Additionally, proper mounting points for applying load on the seat would have allowed us to test at multiple locations thus expanding our range of data. Regarding the operation effort testing, maintaining a steady force by hand was difficult to maintain. A more precise state could be achieved by integrating a linear actuator to put out a prescribed amount of force. The operation time testing could also be improved by testing with a larger pool of participants to generate more data.

9.0 Project Management

Our overall design process can be categorized into define, create, evaluate, specify, build, and test. The first undertaking each team underwent was to sufficiently research the design challenge to help define our problem statement and develop a list of customer needs and wants. After the Scope of Work document was completed, our team moved forward with ideation. This eventually led to design ideas that aimed to best solve our problem definition. Next our team created a functional decomposition tree, ideated on those functions with rudimentary concepts models, combined those functions via a morphological matrix, and prioritized those designs via a weighted decision matrix. Our design process will be slightly unique since our team is split into three main design sub-systems. This will require us to work in tandem with each other to make sure that our designs work well with together. The overall major project deadlines are shown in Table 29.

Table 29. Major Project Deadlines

Date	Action
2/19-2/25	Finalize design
2/26-3/5	Order materials for verification prototype
3/5-3/12	Develop test procedures
3/12-3/26	Build verification prototype
3/29-4/2	Gather test equipment
4/6-4/26	Test prototype
5/18	Final Design Review
6/4	Senior Project Expo

9.1 Articulation Team’s Take on Project Management

The overall design process that our team followed roughly centered around three main milestones: our Preliminary Design Review (PDR), Critical Design Review (CDR), and Final Verification Prototype. PDR was executed in fall quarter and CDR was done in winter quarter. In preparation for our PDR, we conducted extensive background and customer research (~3 weeks). In addition, we narrowed down the best ideas through ideation sessions, selection matrices, and rapid prototyping (~ 2-3 weeks). This provided us with an initial design concept at PDR. Following this, our team entered the detailed design and in-depth engineering analysis phase (~3 weeks). This allowed us to present a fully fleshed out design at CDR.

Following our CDR, we were authorized to begin manufacturing of our Final Verification Prototype in spring quarter. In addition, a Risk Assessment, seen in Appendix AE, was conducted to identify all risks present in our design and to develop a plan for managing those risks. Following this, the actual manufacturing of our prototype began (~3 weeks), and upon its completion we conducted a variety of tests to determine if our final prototype met our design specifications (~1 week). Through our testing we verified that our design worked as anticipated. Lastly, once testing was complete a hand-off of our prototype was arranged with our sponsors. A full timeline reflecting work competed can be seen in our Gantt Chart in Appendix F.

Overall, this design process worked very well for our team. It allowed us to gain a deep understanding of our customer base and problem statement in order to iterate designs that most effectively met our sponsor's criteria. Additionally, the intermittent design reviews really helped our team incorporate valuable feedback throughout the process, thus allowing us to integrate key design changes early and often. What our team may do differently in the future is have more frequent design reviews or increase communication with our sponsors to elicit further feedback.

10.0 Conclusion

10.1 Track & Latch Conclusions and Recommendations

10.1.1 Design Evaluation

Our largest challenge was due to further misunderstandings with the required space for waterjetting the double pin. While we learned from our structural prototype error and purchased larger stock for this process, the larger stock still had insufficient surface area for the waterjet's toe clamp to hold the material. Luckily, we were able to quickly procure appropriately sized stock and this lesson did not cause any delays in production. Most importantly, this notes that the double pin should use a different stock size than the latch stock. The size of the follower frame and tight bend radii introduced problems with cracking the 0.125" thick aluminum. This continued to be a problem despite heating the part prior to bending. Therefore, we recommend manufacturing this part out of C-Channel stock, or if allowed by stress analyses, use a thinner sheet metal stock. Another problem relating to the follower frame is that in the current design, the foot pedal- cam lever assembly can slide back and forth. To solve this, we recommend including some cheap plastic spacers on the cam mounting bolt or do a slight redesign of the follower frame to be made from rectangular tube stock. Additionally, during production of the follower frame, we discovered that the called tolerances are insufficient due to the interface with the follower frame bend radius. This issue would be resolved if the follower frame were to be made from a C-channel or rectangular tube stock as described above.

10.1.2 Design Recommendations

The first major design recommendation regards the manufacturing of the latch body. Instead of manufacturing the latches purely using an end mill (as was done for the verification prototype), the team recommends initially casting the base shape of the latch and then complete finishing touches on an end mill. This will greatly reduce material waste and increase production efficiency of the latches. Upon completion of the latch machining, it was discovered that the t-slot endmill used to create the mating profile was improperly sized. The correct endmill is now included in the manufacturing plan and described above. Contact between this mating profile and the track was slightly higher than expected upon assembly, causing a large sliding resistance when moving the seat along the track. Therefore, we recommended editing the design to have a significantly larger clearance between the latch T-profile and the track profile. Uneven sliding between the latches on either side of the seat also contributed to the large sliding resistance. To combat this, we recommend welding (or otherwise attaching) a rigid plate between the two mounting plates. Furthermore, the double pin actuation mechanism did not function entirely as designed. It was impossible to disengage the double pin from the track with the current design of the cam, and thus we recommend a full redesign of the cam lever arm component. During operation of the actuation mechanism, it was noticed that the male spring guide pin would sometimes fully disengage from the female guide pin, resulting in binding. Thus, we recommend the male spring guide be designed to be slightly longer. Finally, we initially specified only standard hex nuts. During assembly, we discovered that locking nuts should have been used instead.

Moving forward, the iBOM (appendix V) and drawings (appendix W) should be updated to reflect the recommendations above. While these processes could be further optimized in mass production, single entity production can be optimized based on the design/manufacturing changes listed above.

10.2 Articulation Conclusions and Recommendations

10.2.1 Design Evaluation

The articulation mechanism achieved many of the desired design features. Most notably, the combination of the gas spring and rotary latches allowed for a high product useability. The ability to operate the seat with a single input motion was a key success of our design. Additionally, the material selection and lightweight geometry reduced the weight of the seat frame to well under our target value.

The design also fell short in a number of categories. The design stiffness did not achieve our target value in the vertical direction, in addition to significant deflections in transverse and axial directions (which were not considered in our engineering specifications). This is largely due to compounding deflection errors throughout the design; deflections in the plywood test base, the track/latch, and the joints between the links account for a notable portion of the deflection. These errors were not accounted for in the theoretical analysis of the seat deflection. In addition, a number of assumptions were made to simplify the analysis computations, the effects of which were not sufficiently anticipated in developing the design.

Further accumulating errors occurred due to multiple redesigns of the linkage system after CDR. During this design period, the remote actuation of the articulation latches was added, the seat width was reduced, the side frame geometry changed, and several other relatively small design modifications. Each individual change minimally effected the rest of the design but the culmination of minor design flaws adversely effected the stiffness of the final design. The most notable specific examples of this are the gas spring sizing (the gas spring neither extends far enough nor compresses enough, accommodated for by the slot on the bottom mounting point) and the rotary latch clearance (which required material removal from the seat back-frame).

The final element of the design that would benefit from future improvement is the manufacturing time. While cutting the parts on the waterjet allowed for construction of complex parts with relative ease, the time required to cut the components on the waterjet would not be acceptable in industry. This can be partially accounted for by increasing the size of the triangles in the weight-reduction pattern on several components or by removing the cutouts entirely, but would likely require a different manufacturing method to effectively market the design.

10.2.2 Design Recommendations

The manufacturing and testing performed on the verification prototype yielded multiple insights for improvements to future iterations of this design. The following insights represent, not only the lessons learned from manufacturing and testing, but also from discussion and feedback with our sponsor, project advisor, and industry experts.

While the construction methods utilized for our design were suitable for constructing a single prototype, waterjet cutting the frame pieces cannot be effectively scaled for production. To maintain the strength-to-weight ratio, stamped steel components may be able to replace the majority of aluminum components. If the weight of the seat needs to be reduced further without reducing stiffness, composite components should be considered.

The placement of the articulation latch, while successful in the current design iteration, required several compromises to operate correctly. In particular, the seat back frame was reduced in width to fit between the latch strikers. Combined with the spacers required on the upper support pins, this contributed significantly to the lateral stiffness problems. One possible solution is to apply extensions to the seat back frame (to eliminate the spacers). A secondary solution would be to shift from a side frame design to a back structure design (similar to the previous senior project design) to move the pins to a more stable location.

To improve the latch release, a different Southco release with a lock should be selected to prevent the seats from being actuated by passengers. Furthermore, the release should be moved to a location that is less likely to be manipulated by passengers; a flush-mount push-button release may allow more options for release location and reduce the likelihood of inadvertent articulation of the seat.

To allow for locking of the track-latch release, an additional strut should be added to the diagonal brace to interfere with lifting the release when the seat is deployed. Combined with the previous recommendation, this would allow for both the track and articulation to be locked out when the seat is deployed to prevent inadvertent motion of the seat.

If manufacturing the verification prototype again, our process would remain relatively unchanged, however, our organization of the project would. A finalized design was only fully developed after critical design review, with teams still performing ideation late into winter quarter. I believe a re-examination of the structuring of senior project teams in future iterations of this project, as well as clear definitions of scope can help optimize the ability to move through ideation into design.

10.2.3 Next Steps

Regarding next steps for our existing verification prototype, we recommend a gas spring with a bleed off valve instead of a fixed force output to tune system to exact force requirement of 5lb. The gas spring used in this verification prototype was oversized, and a bleed off valve would enable tuning of the force output to balance ease of use by the user, while ensuring necessary force for upward stowing movement. Furthermore, correctly sizing the length of the gas spring to ensure the seat undergoes a full range of travel is necessary for improvement.

Our recommendations for next steps on this project would include some additional design, manufacturing, and integration work. Regarding design, we would conduct additional analysis to improve stiffness and revise the support frame to eliminate racking. We would also advise to better define the manufacturing methods for a more robust final product and to optimize for mass manufacturing. Lastly, we would invest the effort to improve overall integration and compatibility with the track and latch subsystem.

11.0 References

Abilitrax. *Abilitrax.* Retrieved October 8, 2020

AbilityTrax. "Seating For Ram Promaster, Ford Transit & Sprinter Vans." *AbiliTrax Van Seating for Wheelchair Vans, Commercial Vans & Passenger Vans*, 2019, www.abilitrax.com/.

Badwaik, Sumit E., and Jagtap, K.R., "Natural Frequency Analysis of Automobile Seat" *International Journal of Computer Applications, Vol. 125—no. 5*, 20

Beige Metal Stackable Folding Chair. *Home Depot*, (n.d.) Retrieved October 8, 2020

Bringing Extra Friends Was Never So Easy – Action Van, LLC offers Freedman 3PT double fold-away seats, *Action Van*, (Jan 04, 2019) Retrieved October 8, 2020

Cal Poly Corp. (2019). *US Patent No. US10596934B2.* Washington, DC: U.S. Patent and Trademark Office.

Cardone, S. P., & Kerr, M. C. (2018). *U.S. Patent No. US10052974B2*. Washington, DC: U.S. Patent and Trademark Office.

Christensen, M. (2003). *U.S. Patent No. US6595142B2*. Washington, DC: U.S. Patent and Trademark Office.

ChunTung Chen, -, KuoHsiang Chen, and -, MinYuan Ma. "The Research of the Application of Quality Function Deployment in the Design and Development of All-plastic Folding Chair." *Journal of Convergence Information Technology* 7.19 (2012): 1-13. Web.

DeLucia, Jordan, and Speed 51. *Seat Track Assembly ALL98100*. allstarperformance.com/seat-track-assembly-all98100/.

D'Souza, C., "Accessibility and User Performance Modeling for Inclusive Transit Bus Design," *SAE Int. J. Commer. Veh.* 7(1):50-58, 2014, https://doi-org.ezproxy.lib.calpoly.edu/10.4271/2014-01-0463.

Dworaczyk, Z., Lewin, J., Timken, G., & Voss, E. (2019). Final Design Review Adjustable Seating Systems.

Dworaczyk, Z. (2019). "A Methodology for Verification of Structural Standards for a Seating System by Finite Element Analysis"

Freedman Seating Company. "Ford™ Transition Bracket." *Freedman Seating Company*, 15 July 2020, www.freedmanseating.com/seats/ford-transition-bracket/.

Hampton Bay Mix and Match Zero Gravity Sling Outdoor Chaise Lounge Chair in Café. *Home Depot*, (n.d.) Retrieved October 8, 2020

Hapsari, Sakya Nabila. "Designing Train Passenger Seat by Kansei Engineering in Indonesia." *MATEC Web of Conferences* 135 (2017): MATEC Web of Conferences, 2017, Vol.135. Web.

Hoeben, C., and Q. Louw. "Ergonomic chair intervention: effect on chronic upper quadrant dysfunction, disability and productivity in female computer workers." *South African Journal of Physiotherapy*, vol. 70, no. 2, 2014, p. 11+. *Gale Academic OneFile*, https://link-gale-com.ezproxy.lib.calpoly.edu/apps/doc/A455784098/AONE?u=calpolyw_csu&sid=AONE&xid=315fcead. Accessed 29 Sept. 2020.

Hollingsworth, Ritchie D. Configurable transit seating systems and methods. US10596934B2, United States Patent and Trademark Office, March 24 2020 https://patents.google.com/patent/US10596934B2/en?oq=US-10596934

Hun, Kug H. Apparatus for Back-Folding Standup Seat of Vehicle. US9358907B2, United States Patent and Trademark Office, June 7 2016 https://patents.google.com/patent/US9358907B2/en?oq=US9358907B2

Hwang, Hsiu-Ying. “Minimizing Seat Track Vibration That Is Caused by the Automatic Start/Stop of an Engine in a Power-Split Hybrid Electric Vehicle.” *Journal of Vibration and Acoustics*, vol. 135, no. 6, 2013, doi:10.1115/1.4023954.

Jie Zhou. "Convertible Furniture Design." *Computers & Graphics* 70 (2018): 165-75. Web.

Kämmerer, J. (2003). *U.S. Patent No. US6655738B2*. Washington, DC: U.S. Patent and Trademark Office.

Kargilis, E. M., Salva, J. P., Geraci, J. M., Mather, C., & Janosko, R. J. (1996). *U.S. Patent No. US5570931A*. Washington, DC: U.S. Patent and Trademark Office.

Knott, Tyler. Personal Interview. 1 October 2020.

Landbird. “Van Rental - 10-Passenger Mid-Roof Van Ford Transit.” *Landbird*, 14 Aug. 2020, rentlandbird.com/fleet/10-passenger-mid-roof-van-rental/.

Leary M., Mazur M., Mild T., Subic A. (2011) Optimisation of Automotive Seat Kinematics. In: Hung S., Subic A., Wellnitz J. (eds) Sustainable Automotive Technologies 2011. Springer, Berlin, Heidelberg. https://doi-org.ezproxy.lib.calpoly.edu/10.1007/978-3-642-19053-7_17

“Low Profile Rail.” *Koller*, www.koller.co.uk/product/rails-amp-bonded-floors/2/low-profile-rail/18/.

Márquez, M. A., Garcia, J. M., & Venezuela, S. C. T. (2004). Ergonomics of urban public passengers transportation. *9th*, *23*.

Matthaei, F.c. “Universal Positioning Seat Track.” *SAE Technical Paper Series*, 1954, pp. 331-334 doi:10.4271/540245.

McMillen, Robert J. Fold Flat Seating. US7559594B2, United States Patent and Trademark Office, July 14 2009

Mirnig, Alexander G., et al. “Capacity Management in an Automated Shuttle Bus: Findings from a Lab Study.” *12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 2020, doi:10.1145/3409120.3410665.

M Kolich & SM Taboun (2004) Ergonomics modelling and evaluation of automobile seat comfort, Ergonomics, 47:8, 841-863

Mobility Works Commercial. “SmartFloor - Custom Wheelchair Van Flooring.” *MobilityWorks Commercial*, 2 Sept. 2020, commercial.mobilityworks.com/smartfloor/.

Moffa, M. D., Mikhail, K., & Purnell, A. (2005). *U.S. Patent No. US6846044B2*. Washington, DC: U.S. Patent and Trademark Office.

Neff, J., & Pham, L. (2007). A profile of public transportation passenger demographics and travel characteristics reported in on-board surveys

NMI Safety. “V Fitting.” *V Fitting | NMI Safety Systems*, www.nmisafety.com/product/v-fitting/.

Peterson, Del. *Small Transit Vehicle Industry Study*. NDSU Upper Great Plains Transportation Institute, 2007.

Popuri, Y., Proussaloglou, K., Ayvalik, C., Koppelman, F., & Lee, A. (2011). Importance of traveler attitudes in the choice of public transportation to work: findings from the Regional Transportation Authority Attitudinal Survey. *Transportation*, *38*(4), 643-661.

Q'Straint. “QSF Seat Fixing.” *Q'STRAINT*, www.qstraint.com/qsf/.

Raynor, Noah. Personal Interview. 9 October 2020.

RecPro 60” RV Wall Mount Rollover Sofa with Adjustable Legs in Cloth. RecPro, (n.d.) Retrieved October 8, 2020

Reed, Matthew P., et al. Lear Seating Corporation, 1994, pp. 1–96, *SURVEY OF AUTO SEAT DESIGN RECOMMENDATIONS FOR IMPROVED COMFORT*.

Ruiz, Harold. Personal Interview. 30 September 2020.

Seymour, Michael W. Height Adjustable Seat. US8276220B1, United States Patent and Trademark Office, October 2 2012 https://patents.google.com/patent/US8276220B1/en?oq=US8276220B1

Sonenblum, Sharon E., et al. “Everyday Use of Power Adjustable Seat Height (PASH) Systems.” *Assistive Technology*, 2019, pp. 1–9., doi:10.1080/10400435.2019.1634659.

Tsai, Hsin-Hung. Folding chair with sliding leg structure. US7080877B1, United States Patent and Trademark Office, July 25, 2006

Varterasian, John H., and Richard R. Thompson. “The Dynamic Characteristics of Automobile Seats with Human Occupants.” *SAE Technical Paper Series*, 1977, doi:10.4271/770249.

Www.aircraftspruce.com. “SEAT RAILS FOR CESSNA AIRCRAFT.” *Aircraft Spruce*, www.aircraftspruce.com/catalog/appages/seatrails.php.

(n.d.). *US Department of Transportation*. Retrieved October 8, 2020, from https://www.transportation.gov/

(n.d.). *National Highway Traffic Administration*. Retrieved October 8, 2020, from https://www.nhtsa.gov/

(n.d.) *Federal Motor Carrier Safety Administration*. Retrieved October 8, 2020, from https://www.fmcsa.dot.gov/

https://patents.google.com/patent/US7080877B1/en?oq=US7080877B1

https://patents.google.com/patent/US7559594B2/en?oq=US7559594B2

49 CFR, § 571.3 (1970)

49 C.F.R. § 38.23 (2009)

49 CFR, § 571.0 (2014)

12.0 Appendix

Appendix AC: Articulation Stress-Strength MATLAB and Derivation

Appendix AD: Articulation Design Hazard Checklist

Appendix AE: Articulation FMEA

Appendix AF: Articulation iBOM

Appendix AG: Articulation Manufacturing Plan

Appendix AH: Articulation Drawing Package

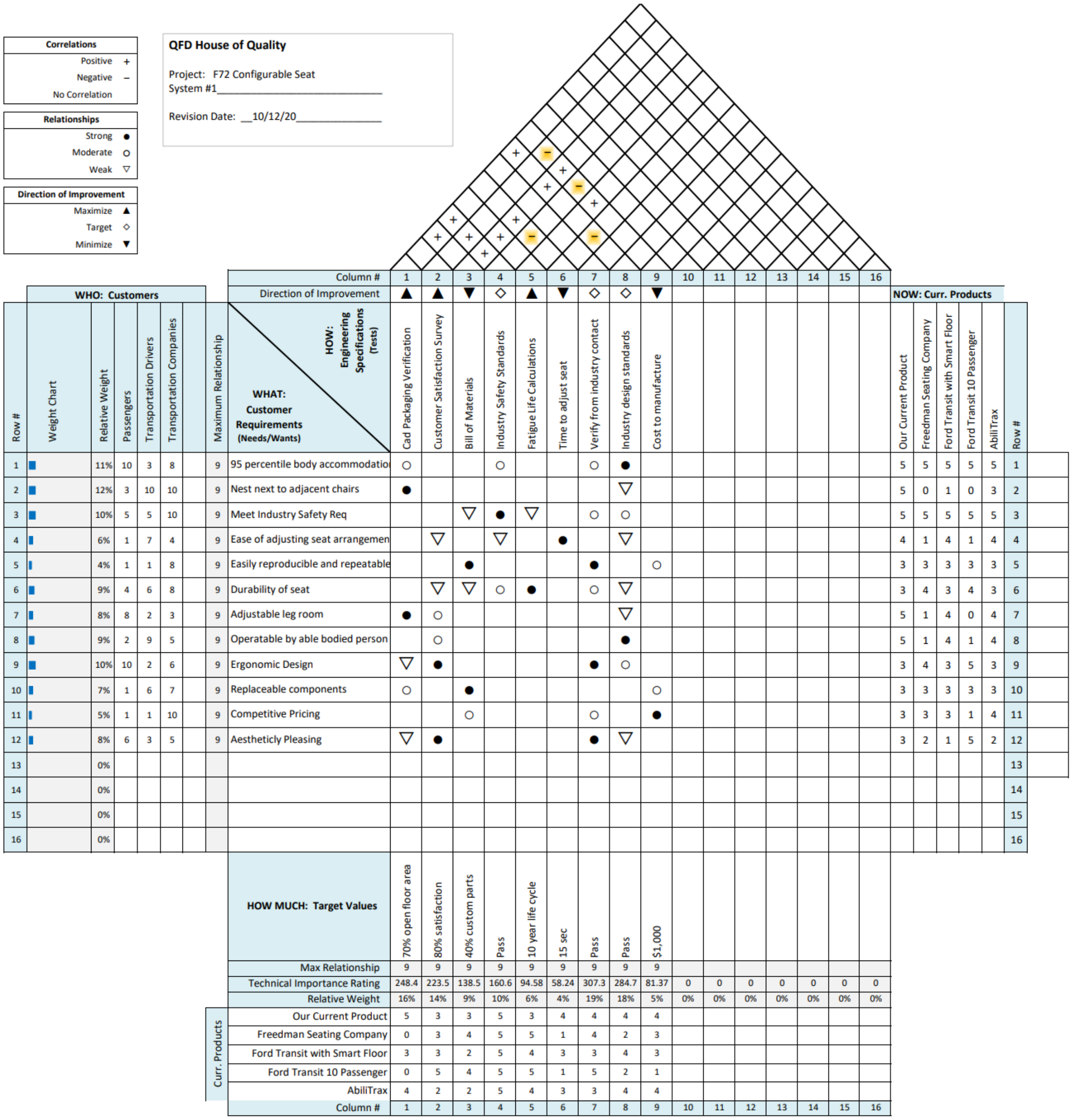
Appendix AI: System and Demo DVP(&R)

Appendix AJ: Track and Latch DVP(&R)

Appendix AK: Articulation DVP(&R)

Appendix AL: User Manual

Appendix A: System and Demo Team QFD House of Quality



Correlations
Positive +
Negative –
No Correlation

Relationships
Strong ●
Moderate ○
Weak ▽

Direction of Improvement
Maximize ▲
Target ◇
Minimize ▼

QFD House of Quality

Project: F72 Configurable Seat
System #1_____________________________

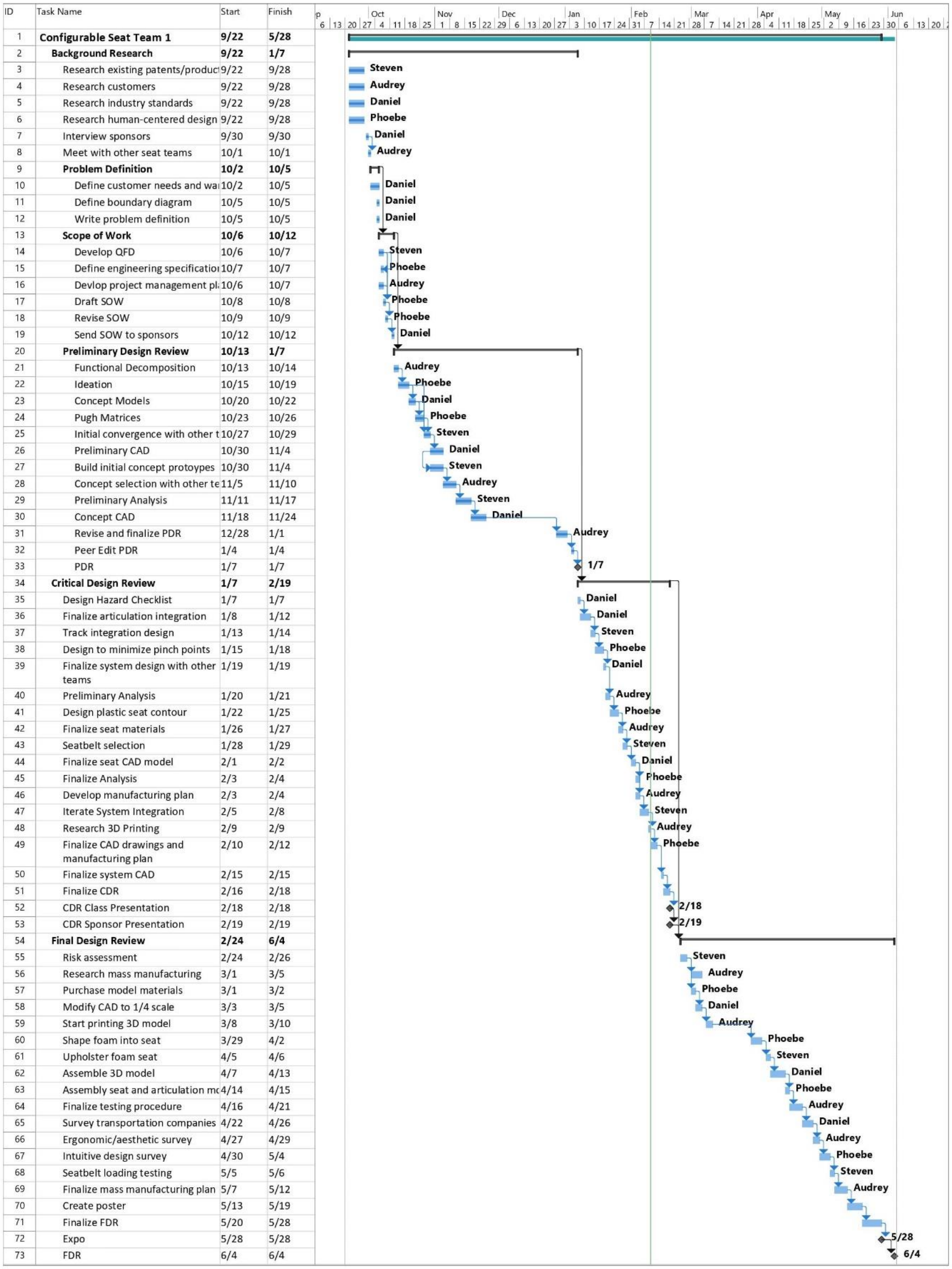
Revision Date: __10/12/20_______________

WHO: Customers / **NOW: Curr. Products**

Row #	Weight Chart	Relative Weight	Passengers	Transportation Drivers	Transportation Companies		Maximum Relationship	HOW: Engineering Specifications (Tests) / WHAT: Customer Requirements (Needs/Wants)	Cad Packaging Verification	Customer Satisfaction Survey	Bill of Materials	Industry Safety Standards	Fatigue Life Calculations	Time to adjust seat	Verify from industry contact	Industry design standards	Cost to manufacture								Our Current Product	Freedman Seating Company	Ford Transit with Smart Floor	Ford Transit 10 Passenger	AbiliTrax	Row #
								Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16						
								Direction of Improvement	▲	▲	▼	◇	▲	▼	◇	◇	▼													
1	▮	11%	10	3	8		9	95 percentile body accommodatio	○			○			○	●									5	5	5	5	5	1
2	▮	12%	3	10	10		9	Nest next to adjacent chairs	●							▽									5	0	1	0	3	2
3	▮	10%	5	5	10		9	Meet Industry Safety Req			▽	●	▽		○	○									5	5	5	5	5	3
4	▮	6%	1	7	4		9	Ease of adjusting seat arrangemen		▽		▽		●		▽									4	1	4	1	4	4
5	▮	4%	1	1	8		9	Easily reproducible and repeatable			●				●		○								3	3	3	3	3	5
6	▮	9%	4	6	8		9	Durability of seat		▽	▽	○	●		○	▽									3	4	3	4	3	6
7	▮	8%	8	2	3		9	Adjustable leg room	●	○						▽									5	1	4	0	4	7
8	▮	9%	2	9	5		9	Operatable by able bodied person		○						●									5	1	4	1	4	8
9	▮	10%	10	2	6		9	Ergonomic Design	▽	●					●	○									3	4	3	5	3	9
10	▮	7%	1	6	7		9	Replaceable components	○		●						○								3	3	3	3	3	10
11	▮	5%	1	1	10		9	Competitive Pricing			○				○		●								3	3	3	1	4	11
12	▮	8%	6	3	5		9	Aestheticly Pleasing	▽	●					●	▽									3	2	1	5	2	12
13		0%																												13
14		0%																												14
15		0%																												15
16		0%																												16

	HOW MUCH: Target Values	70% open floor area	80% satisfaction	40% custom parts	Pass	10 year life cycle	15 sec	Pass	Pass	$1,000							
	Max Relationship	9	9	9	9	9	9	9	9	9							
	Technical Importance Rating	248.4	223.5	138.5	160.6	94.58	58.24	307.3	284.7	81.37	0	0	0	0	0	0	0
	Relative Weight	16%	14%	9%	10%	6%	4%	19%	18%	5%	0%	0%	0%	0%	0%	0%	0%
Curr. Products	Our Current Product	5	3	3	5	3	4	4	4	4							
	Freedman Seating Company	0	3	4	5	5	1	4	2	3							
	Ford Transit with Smart Floor	3	3	2	5	4	3	3	4	3							
	Ford Transit 10 Passenger	0	5	4	5	5	1	5	2	1							
	AbiliTrax	4	2	2	5	4	3	3	4	4							
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Appendix B: System and Demo Team Gantt Chart



ID	Task Name	Start	Finish
1	**Configurable Seat Team 1**	**9/22**	**5/28**
2	**Background Research**	**9/22**	**1/7**
3	Research existing patents/product	9/22	9/28
4	Research customers	9/22	9/28
5	Research industry standards	9/22	9/28
6	Research human-centered design	9/22	9/28
7	Interview sponsors	9/30	9/30
8	Meet with other seat teams	10/1	10/1
9	**Problem Definition**	**10/2**	**10/5**
10	Define customer needs and wa	10/2	10/5
11	Define boundary diagram	10/5	10/5
12	Write problem definition	10/5	10/5
13	**Scope of Work**	**10/6**	**10/12**
14	Develop QFD	10/6	10/7
15	Define engineering specificatio	10/7	10/7
16	Devlop project management pl	10/6	10/7
17	Draft SOW	10/8	10/8
18	Revise SOW	10/9	10/9
19	Send SOW to sponsors	10/12	10/12
20	**Preliminary Design Review**	**10/13**	**1/7**
21	Functional Decomposition	10/13	10/14
22	Ideation	10/15	10/19
23	Concept Models	10/20	10/22
24	Pugh Matrices	10/23	10/26
25	Initial convergence with other t	10/27	10/29
26	Preliminary CAD	10/30	11/4
27	Build initial concept protoypes	10/30	11/4
28	Concept selection with other te	11/5	11/10
29	Preliminary Analysis	11/11	11/17
30	Concept CAD	11/18	11/24
31	Revise and finalize PDR	12/28	1/1
32	Peer Edit PDR	1/4	1/4
33	PDR	1/7	1/7
34	**Critical Design Review**	**1/7**	**2/19**
35	Design Hazard Checklist	1/7	1/7
36	Finalize articulation integration	1/8	1/12
37	Track integration design	1/13	1/14
38	Design to minimize pinch points	1/15	1/18
39	Finalize system design with other teams	1/19	1/19
40	Preliminary Analysis	1/20	1/21
41	Design plastic seat contour	1/22	1/25
42	Finalize seat materials	1/26	1/27
43	Seatbelt selection	1/28	1/29
44	Finalize seat CAD model	2/1	2/2
45	Finalize Analysis	2/3	2/4
46	Develop manufacturing plan	2/3	2/4
47	Iterate System Integration	2/5	2/8
48	Research 3D Printing	2/9	2/9
49	Finalize CAD drawings and manufacturing plan	2/10	2/12
50	Finalize system CAD	2/15	2/15
51	Finalize CDR	2/16	2/18
52	CDR Class Presentation	2/18	2/18
53	CDR Sponsor Presentation	2/19	2/19
54	**Final Design Review**	**2/24**	**6/4**
55	Risk assessment	2/24	2/26
56	Research mass manufacturing	3/1	3/5
57	Purchase model materials	3/1	3/2
58	Modify CAD to 1/4 scale	3/3	3/5
59	Start printing 3D model	3/8	3/10
60	Shape foam into seat	3/29	4/2
61	Upholster foam seat	4/5	4/6
62	Assemble 3D model	4/7	4/13
63	Assembly seat and articulation mc	4/14	4/15
64	Finalize testing procedure	4/16	4/21
65	Survey transportation companies	4/22	4/26
66	Ergonomic/aesthetic survey	4/27	4/29
67	Intuitive design survey	4/30	5/4
68	Seatbelt loading testing	5/5	5/6
69	Finalize mass manufacturing plan	5/7	5/12
70	Create poster	5/13	5/19
71	Finalize FDR	5/20	5/28
72	Expo	5/28	5/28
73	FDR	6/4	6/4

Appendix C: Track and Latch Team QFD House of Quality

Correlations	
Positive	+
Negative	–
No Correlation	

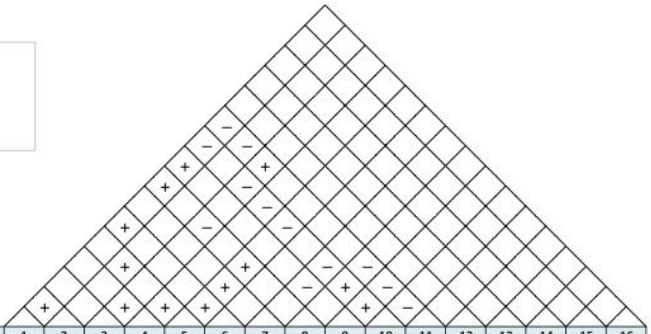
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: Configurable Seat-Track and Latch

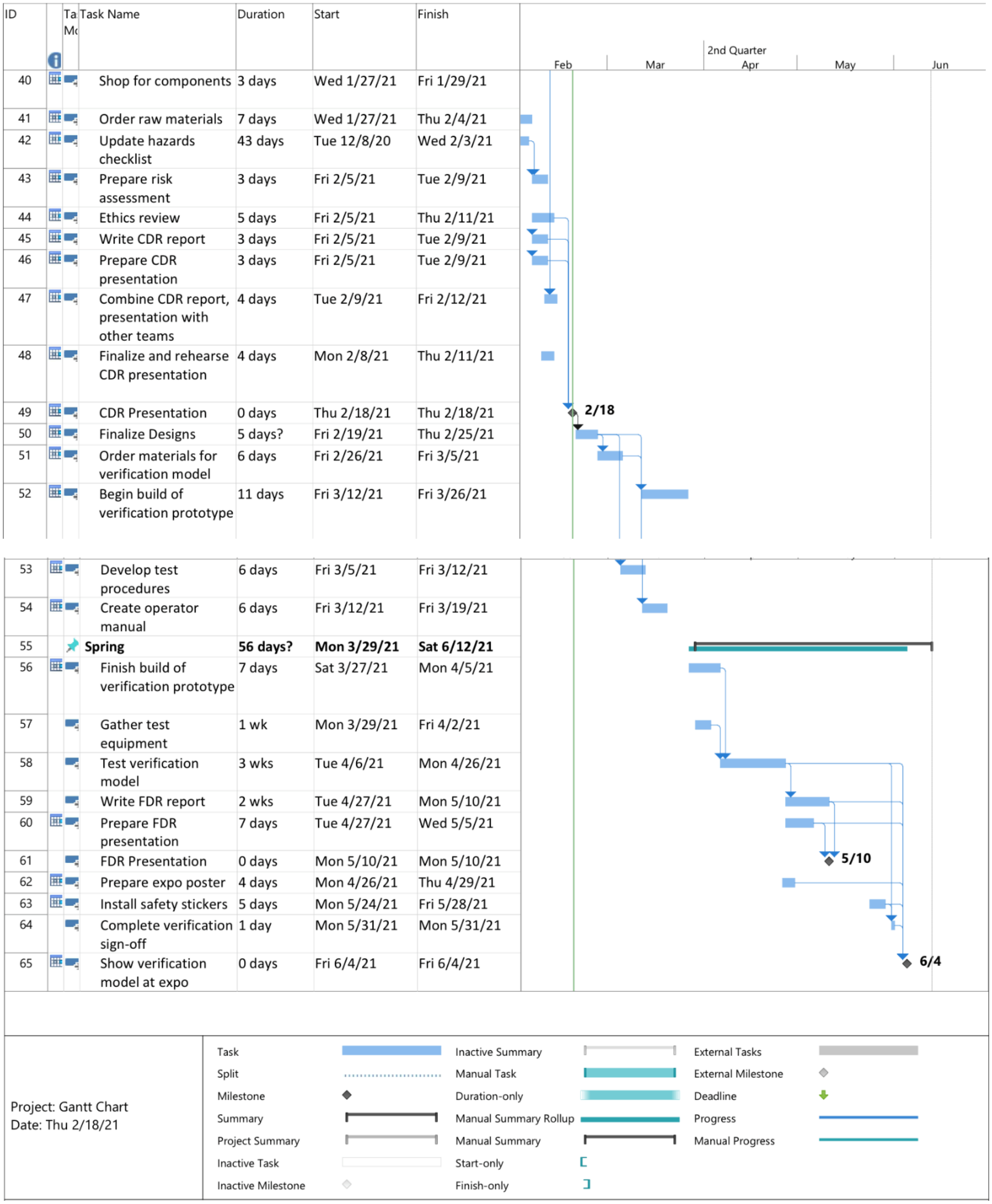
Revision Date: 10/7/20



									Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16						
	WHO: Customers								Direction of Improvement	▼	▼	◇	▲	▲	▼	▲	▼	◇	▼	▲						NOW: Curr. Products					
Row #	Weight Chart	Relative Weight	Shuttle Company Owners	Shuttle Drivers	Passengers	Patent Holders	Manufacuters	Maximum Relationship	HOW: Engineering Specifications (Tests) WHAT: Customer Requirements (Needs/Wants)	Weight	Force Required for Actuation (D	Mechanical Stress Analyses	Vibration Resistance	Customer Surveys	Force Required for Movement	Thermal Properties (Material S	Size	Only Standard Manufacturing P	Cost Analyses	Minimum Yielding Instantaneou						Our Current Product	Current Bench Seats	Aircraft Rails	NMI Safety	QStraint	Row #
1	▮	16%	8	9	10	9	1	9	Reliable			●	▽			○				●							8	10	8	9	1
2	▮	10%	9	4	2	9	4	9	Durable			●	○			○				●							7	10	8	8	2
3	▮	12%	7	1	1	6	9	9	Low Manufacturing Cost	▽	▽	▽				●		●	●								9	2	3	8	3
4	▮	9%	6	9	6	5	1	9	Ergonomic	○	●			●	●		▽										4	1	8	3	4
5	▮	11%	9	10	6	8	1	9	Safe to operate	○	●			○	●	●	○										10	6	9	4	5
6	▮	5%	4	5	1	5	1	9	Light Weight	●		▽			○	●	▽	○									1	10	2	8	6
7	▮	8%	7	2	8	3	1	9	Looks nice					●			○		▽								3	6	2	5	7
8	▮	7%	6	5	4	2	1	9	No training required to operate		▽			●	○	▽											10	1	4	6	8
9	▮	9%	2	7	6	4	3	9	Compact	▽		▽				▽	●	▽									1	7	2	9	9
10	▮	7%	3	7	4	2	1	9	Smooth operation		○				●	▽		▽	○								6	3	6	2	10
11	▮	11%	6	3	10	3	3	9	Comfortable				●	○		●			▽								1	3	6	4	11
12		0%																													12
13		0%																													13
14		0%																													14
15		0%																													15
16		0%																													16

	HOW MUCH: Target Values	$8\ lb_m$/seat	$2\ lb_f$	Minimum Safety Factor = 2.67	Natural Frequency above 200Hz	Very satisfied	$10\ lb_f$	Minimum Specific Heat = 0.09	$10\ in^3$/latch	CNC Production	Unit cost below that of compeitors	Maintains 5G's					
	Max Relationship	9	9	9	9	9	9	9	9	9	9	9					
	Technical Importance Rating	126.3	222.1	255.8	140.7	282.4	278.4	446.4	152	139.3	147.3	229.7	0	0	0	0	0
	Relative Weight	5%	9%	11%	6%	12%	12%	18%	6%	6%	6%	9%	0%	0%	0%	0%	0%
Curr. Products	Our Current Product	5	5	5	5	5	5	5	5	5	5	5					
	Current Bench Seats	5	1	5	5	1	1	2	1	8	9	8					
	Aircraft Rails	9	5	9	7	6	5	6	5	3	1	8					
	NMI Safety	1	8	6	7	7	8	2	1	2	2	6					
	QStraint	7	2	2	4	4	2	7	7	8	7	3					
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Appendix D: Track and Latch Team Gantt Chart



ID	Ta Mc	Task Name	Duration	Start	Finish
40		Shop for components	3 days	Wed 1/27/21	Fri 1/29/21
41		Order raw materials	7 days	Wed 1/27/21	Thu 2/4/21
42		Update hazards checklist	43 days	Tue 12/8/20	Wed 2/3/21
43		Prepare risk assessment	3 days	Fri 2/5/21	Tue 2/9/21
44		Ethics review	5 days	Fri 2/5/21	Thu 2/11/21
45		Write CDR report	3 days	Fri 2/5/21	Tue 2/9/21
46		Prepare CDR presentation	3 days	Fri 2/5/21	Tue 2/9/21
47		Combine CDR report, presentation with other teams	4 days	Tue 2/9/21	Fri 2/12/21
48		Finalize and rehearse CDR presentation	4 days	Mon 2/8/21	Thu 2/11/21
49		CDR Presentation	0 days	Thu 2/18/21	Thu 2/18/21
50		Finalize Designs	5 days?	Fri 2/19/21	Thu 2/25/21
51		Order materials for verification model	6 days	Fri 2/26/21	Fri 3/5/21
52		Begin build of verification prototype	11 days	Fri 3/12/21	Fri 3/26/21
53		Develop test procedures	6 days	Fri 3/5/21	Fri 3/12/21
54		Create operator manual	6 days	Fri 3/12/21	Fri 3/19/21
55		**Spring**	**56 days?**	**Mon 3/29/21**	**Sat 6/12/21**
56		Finish build of verification prototype	7 days	Sat 3/27/21	Mon 4/5/21
57		Gather test equipment	1 wk	Mon 3/29/21	Fri 4/2/21
58		Test verification model	3 wks	Tue 4/6/21	Mon 4/26/21
59		Write FDR report	2 wks	Tue 4/27/21	Mon 5/10/21
60		Prepare FDR presentation	7 days	Tue 4/27/21	Wed 5/5/21
61		FDR Presentation	0 days	Mon 5/10/21	Mon 5/10/21
62		Prepare expo poster	4 days	Mon 4/26/21	Thu 4/29/21
63		Install safety stickers	5 days	Mon 5/24/21	Fri 5/28/21
64		Complete verification sign-off	1 day	Mon 5/31/21	Mon 5/31/21
65		Show verification model at expo	0 days	Fri 6/4/21	Fri 6/4/21

Project: Gantt Chart
Date: Thu 2/18/21

Appendix E: Seat Articulation Team QFD House of Quality

Correlations	
Positive	+
Negative	–
No Correlation	

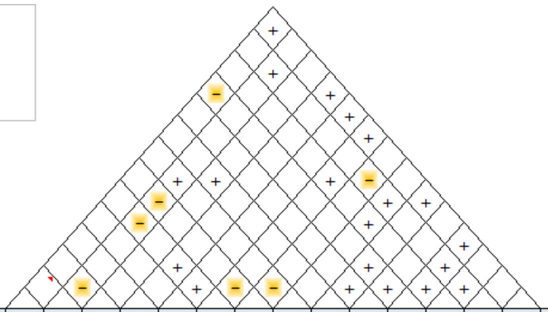
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: F74 - Configurable Seat Articulation

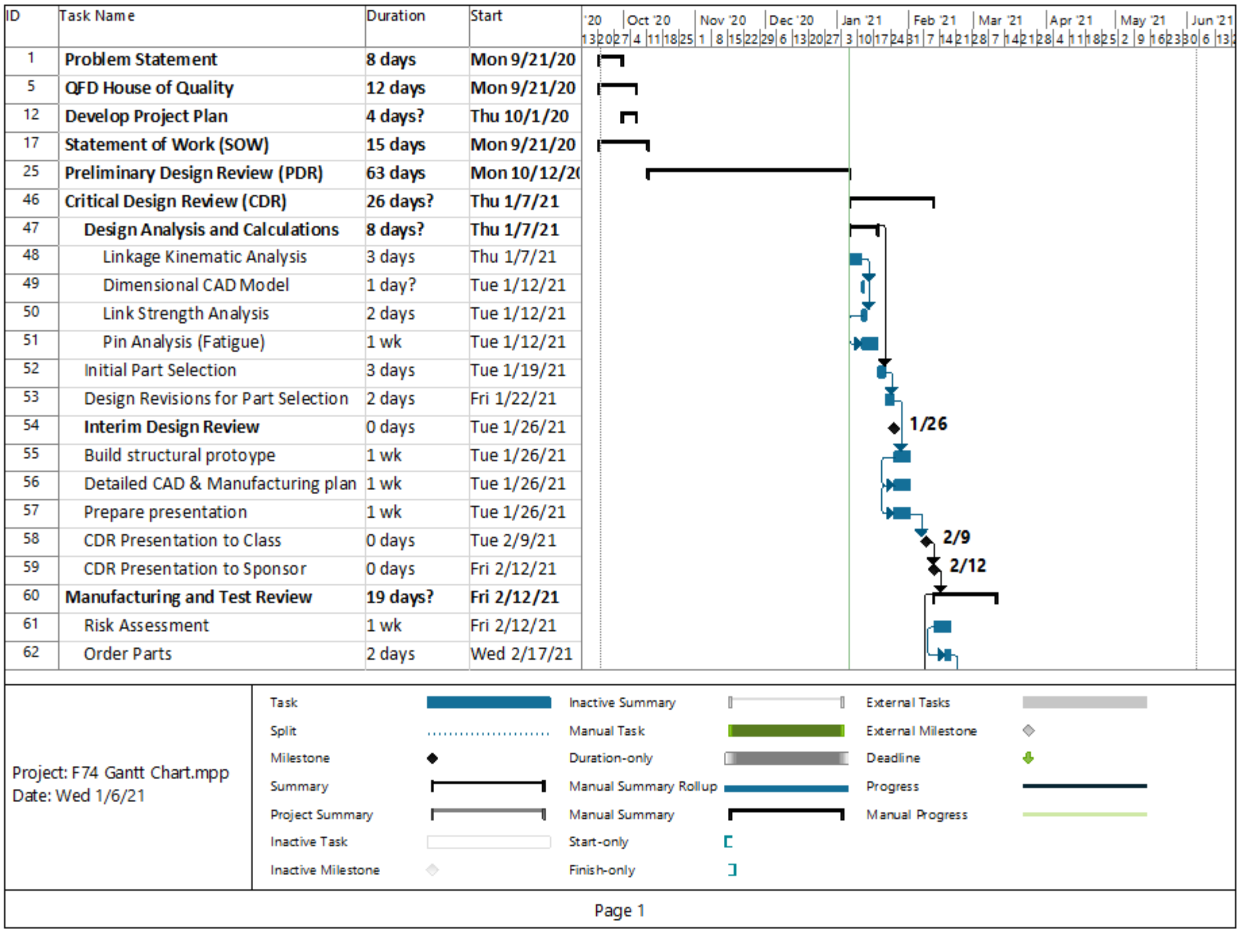
Revision Date: 10/07/2020



								Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	NOW: Curr. Products				
	WHO: Customers							Direction of Improvement	▼	▲	▲	▼	▼	▼	▼	▲	◇	▼	▼	◇	▼	▲					
Row #	Weight Chart	Relative Weight	Business (Sponsors)	Manufacturer	Airport Shuttle	DRC	Maximum Relationship	HOW: Engineering Specifications (Tests) / WHAT: Customer Requirements (Needs/Wants)	Seat Storage Space	Strength	Stiffness	Operation Effort	Operation Time	Weight	Manufacturing Cost	Lifetime	Comfort Survey	Pinch Points	Exposed Components	Operating Environment	Corrosion	Operator Survey	Existing Prototype	Abilitrax Seating	Freedman 3pt	Folding Chair	Row #
1	IIII	10%	10	4	8	9	9	Robust		○	●					●				●	●		3	3	4	5	1
2	IIIII	10%	10	4	10	10	9	Easy to Use				●	●							○	○	●	2	2	3	5	2
3	IIII	9%	8	4	10	9	9	Intuitive					●									●	2	2	3	5	3
4	IIIII	10%	8	7	9	9	9	Simple				○	▽		○	●							5	1	3	5	4
5	IIII	9%	10	4	9	8	9	Compactable	●													●	4	2	3	5	5
6	I	3%	2	1	7	2	9	Aesthetic											●			▽	2	4	3	2	6
7	IIII	8%	4	5	8	10	9	Lightweight				○	▽	●								○	3	3	3	5	7
8	IIIII	10%	8	5	10	10	9	Safe		●								●	○				2	3	3	4	8
9	IIII	10%	5	9	8	8	9	Inexpensive							●								3	2	4	5	9
10	III	8%	5	10	3	3	9	Manufacturable							●								2	3	4	5	10
11	III	7%	4	2	9	8	9	Does Not Interfere with Comfort			●						●		○			●	4	5	4	1	11
12	II	4%	8	2	2	2	9	Marketable							●							○	1	4	3	1	12

	HOW MUCH: Target Values	8" x 24"	PASS Industry Standards -	1/4" Max Deflection	TBD - Test of Similar Products Pending	5 sec	50 lb	$200 / Seat	10^5 Cycles	No Mechanism Interference	Max 2 pinch points in Low-Use Areas	0 in High-Use Areas	Wet Test/Dry Test/ Debris Test	Corrosion Resistant	80% Satisfication
	Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	Technical Importance Rating	85.5	120	147	150	197	75.6	228	180	61.1	91.4	82.3	117	117	366
	Relative Weight	4%	6%	7%	7%	10%	4%	11%	9%	3%	5%	4%	6%	6%	18%
Curr. Products	Existing Prototype	3	5	4	3	1	2	3	3	2	3	2	4	5	1
	Abilitrax Seating	1	5	5	4	2	2	1	4	4	2	2	4	5	2
	Freedman 3pt	3	5	3	5	4	4	3	4	3	3	4	4	5	3
	Folding Chair	5	2	5	5	5	5	5	5	1	2	3	5	5	4
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14

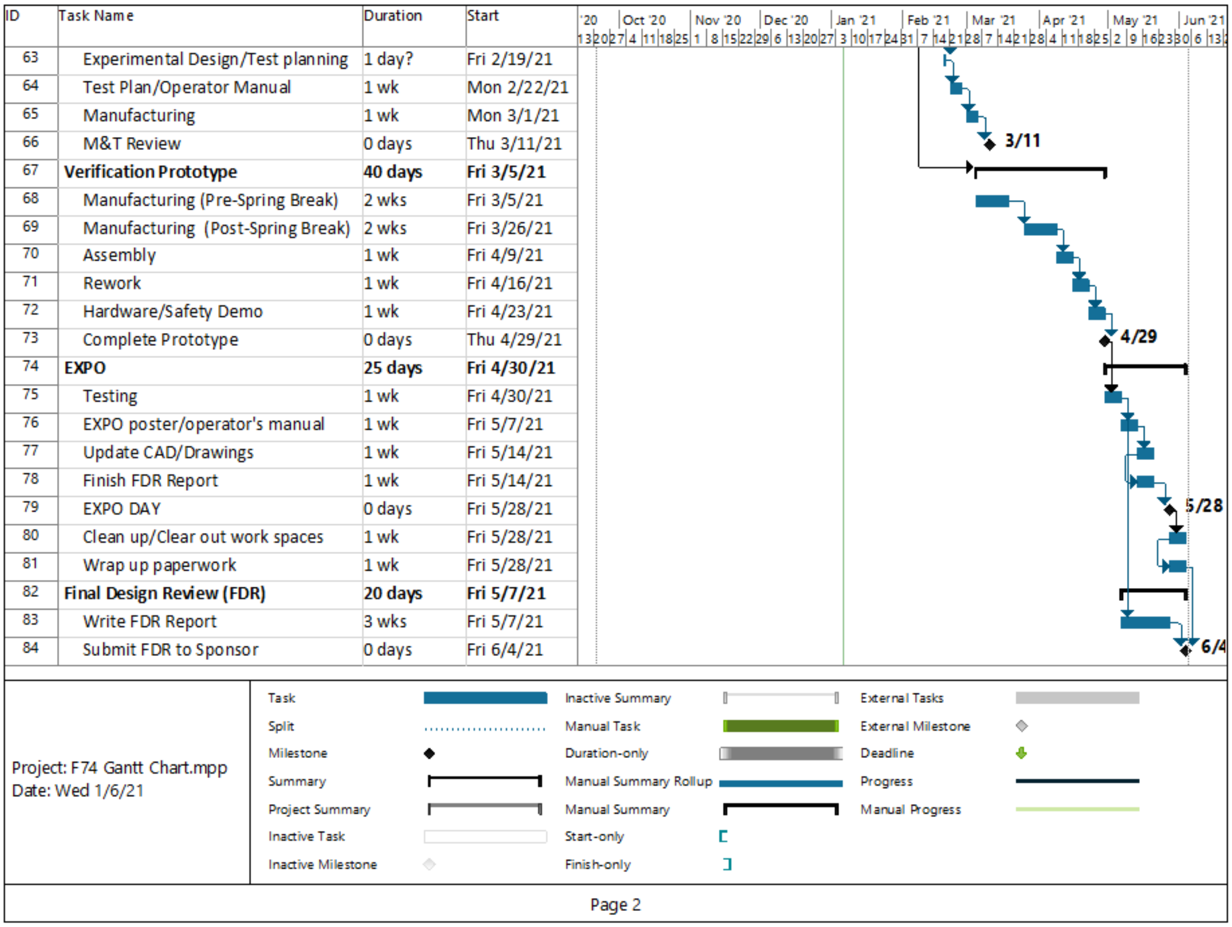
Appendix F: Seat Articulation Team Gantt Chart



ID	Task Name	Duration	Start
1	**Problem Statement**	**8 days**	**Mon 9/21/20**
5	**QFD House of Quality**	**12 days**	**Mon 9/21/20**
12	**Develop Project Plan**	**4 days?**	**Thu 10/1/20**
17	**Statement of Work (SOW)**	**15 days**	**Mon 9/21/20**
25	**Preliminary Design Review (PDR)**	**63 days**	**Mon 10/12/2**
46	**Critical Design Review (CDR)**	**26 days?**	**Thu 1/7/21**
47	**Design Analysis and Calculations**	**8 days?**	**Thu 1/7/21**
48	Linkage Kinematic Analysis	3 days	Thu 1/7/21
49	Dimensional CAD Model	1 day?	Tue 1/12/21
50	Link Strength Analysis	2 days	Tue 1/12/21
51	Pin Analysis (Fatigue)	1 wk	Tue 1/12/21
52	Initial Part Selection	3 days	Tue 1/19/21
53	Design Revisions for Part Selection	2 days	Fri 1/22/21
54	**Interim Design Review**	0 days	Tue 1/26/21
55	Build structural protoype	1 wk	Tue 1/26/21
56	Detailed CAD & Manufacturing plan	1 wk	Tue 1/26/21
57	Prepare presentation	1 wk	Tue 1/26/21
58	CDR Presentation to Class	0 days	Tue 2/9/21
59	CDR Presentation to Sponsor	0 days	Fri 2/12/21
60	**Manufacturing and Test Review**	**19 days?**	**Fri 2/12/21**
61	Risk Assessment	1 wk	Fri 2/12/21
62	Order Parts	2 days	Wed 2/17/21

Project: F74 Gantt Chart.mpp
Date: Wed 1/6/21

Page 1



ID	Task Name	Duration	Start
63	Experimental Design/Test planning	1 day?	Fri 2/19/21
64	Test Plan/Operator Manual	1 wk	Mon 2/22/21
65	Manufacturing	1 wk	Mon 3/1/21
66	M&T Review	0 days	Thu 3/11/21
67	**Verification Prototype**	**40 days**	**Fri 3/5/21**
68	Manufacturing (Pre-Spring Break)	2 wks	Fri 3/5/21
69	Manufacturing (Post-Spring Break)	2 wks	Fri 3/26/21
70	Assembly	1 wk	Fri 4/9/21
71	Rework	1 wk	Fri 4/16/21
72	Hardware/Safety Demo	1 wk	Fri 4/23/21
73	Complete Prototype	0 days	Thu 4/29/21
74	**EXPO**	**25 days**	**Fri 4/30/21**
75	Testing	1 wk	Fri 4/30/21
76	EXPO poster/operator's manual	1 wk	Fri 5/7/21
77	Update CAD/Drawings	1 wk	Fri 5/14/21
78	Finish FDR Report	1 wk	Fri 5/14/21
79	EXPO DAY	0 days	Fri 5/28/21
80	Clean up/Clear out work spaces	1 wk	Fri 5/28/21
81	Wrap up paperwork	1 wk	Fri 5/28/21
82	**Final Design Review (FDR)**	**20 days**	**Fri 5/7/21**
83	Write FDR Report	3 wks	Fri 5/7/21
84	Submit FDR to Sponsor	0 days	Fri 6/4/21

Project: F74 Gantt Chart.mpp
Date: Wed 1/6/21

Task	▬	Inactive Summary		External Tasks	▬
Split	┈	Manual Task	▬	External Milestone	◇
Milestone	◆	Duration-only	▬	Deadline	⇩
Summary	┌─┐	Manual Summary Rollup	▬	Progress	─
Project Summary	┌─┐	Manual Summary	┌─┐	Manual Progress	─
Inactive Task		Start-only	[		
Inactive Milestone	◇	Finish-only	]		

Page 2

Appendix G: System and Demo Team Ideation Session Results

Aesthetics and Ergonomics (worst idea exercise):

Aesthetics

Symmetrical

Modern-looking/ simple

looks not cheap

Looks comfortable

Clean-looking

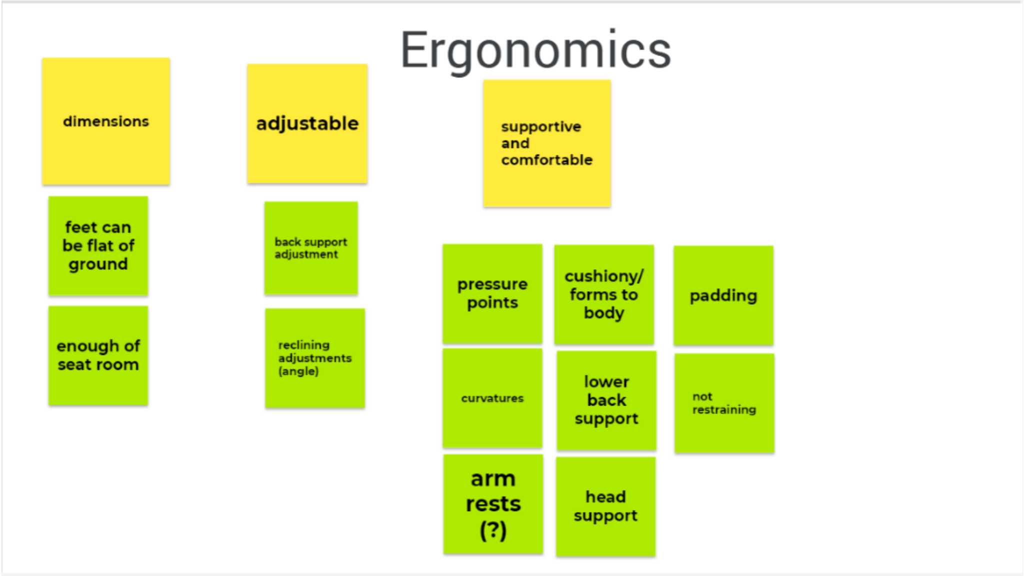
doesn't look dirty easily

stitch-lines

Solid color (or simple pattern)

bulk

curvature



Ergonomics

dimensions

adjustable

supportive and comfortable

feet can be flat of ground

enough of seat room

back support adjustment

reclining adjustments (angle)

pressure points

cushiony/ forms to body

padding

curvatures

lower back support

not restraining

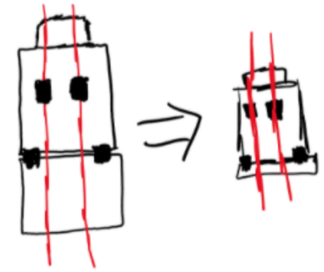
arm rests (?)

head support

Nesting Brainwriting Results:

Steven

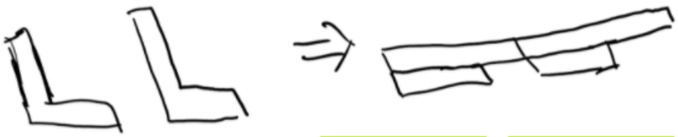
The rod idea is really great for adjusting height. Could maybe put holes in the rod so that a pin could slide through to hold a certain height. Or could be some other mechanism that does a similar locking but is safer for the operator.



this idea would be good for nesting when thinking about how the poles/undercarriage will fit into the system

This idea allows for a lot of adjustment which would be good for ergonomic considerations.

This can possibly be done vertically to save floor space. This design does create usable luggage space to put on top of the seats though which is cool



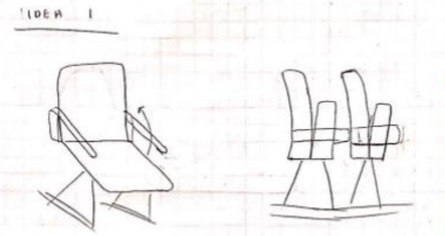
I like how this one provides a lot of vertical space even though the track might not be necessary for this design as it wont slide. Also easy to move.

Could be a toothed quick release type design, like a ratchet. This could allow for a locked height and adjustability

this one could provide more space on top when nested depending on what configuration it is in

might not be ideal for minimizing floor space

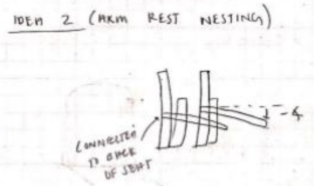
Audrey



this one would be good for a full comfort chair

Arm rest could potentially fold inward to lock new position is place and save space.

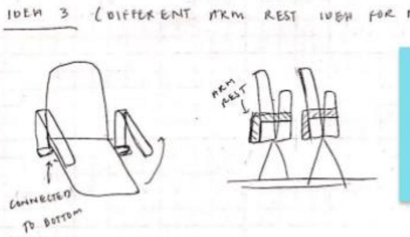
If armrest was as long as the folded chair was thick, then wouldn't need to move the arm rest at all, which is nice



shorten armrest, could also make the armrest fold halfway

Agree with steven - the arm rests should fold to maximize space. Or somehow attach to the chair in front.

The angled armrest is pretty genius, it will nest well and no mechanisms or movement needed. Would minimize pinch points and what not. Maybe the best way to nest would be with minimal movement! Could you possible

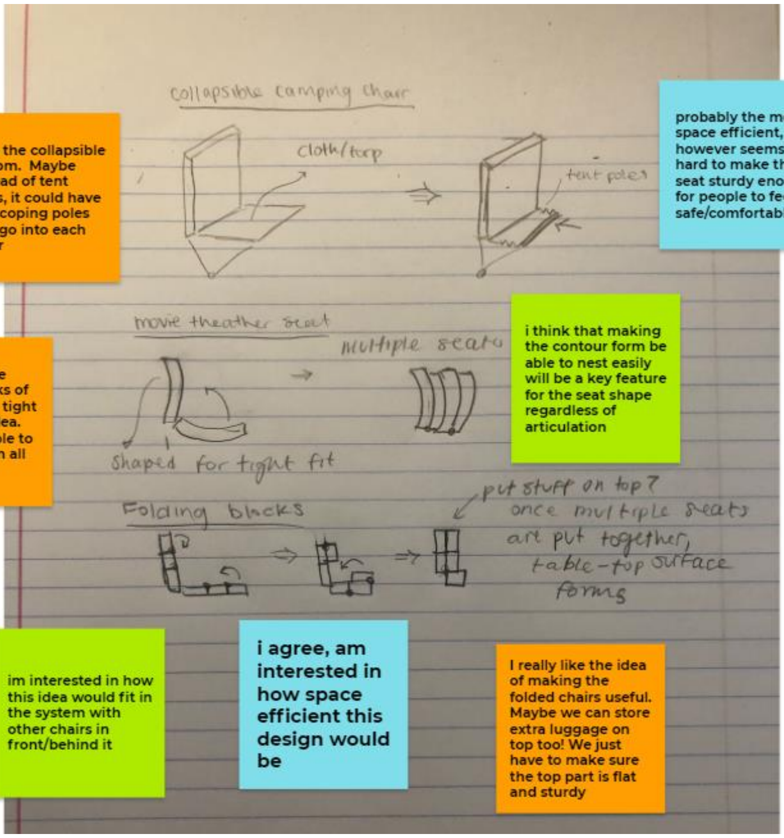


i like the consideration for the armrests, max comfort while saving space still

Maybe the armrests could fold inwards if we made a space for them to do that. would minimize the width of the whole seat when folded

Arm rests folding up from the side of the seat, just like a normal car's, may be the simplest way to do this.

Pheobe



i like the idea of telescoping poles for this one

I like the collapsible bottom. Maybe instead of tent poles, it could have telescoping poles that go into each other

probably the most space efficient, however seems hard to make the seat sturdy enough for people to feel safe/comfortable

Contouring the front and backs of the seats for a tight fit is a great idea. You may be able to just keep them all flat to nest

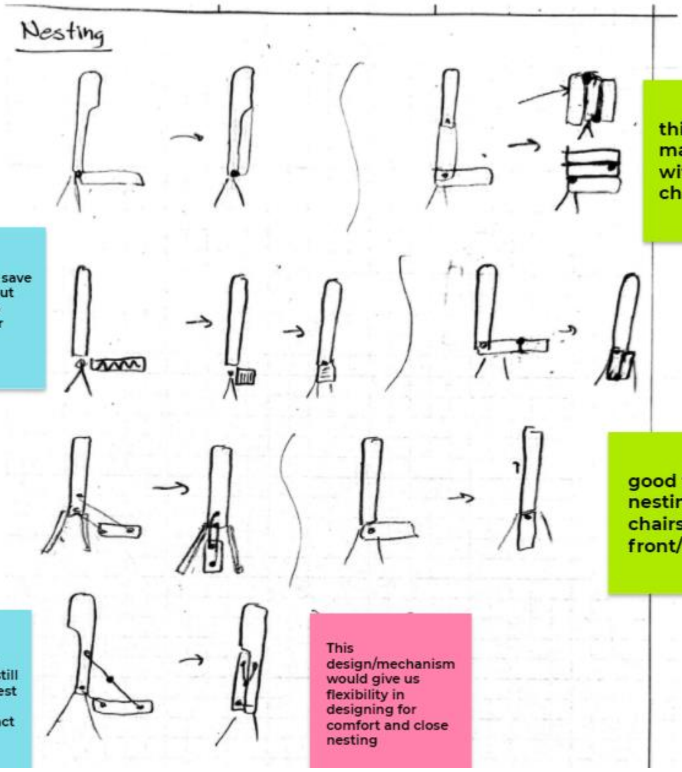
i think that making the contour form be able to nest easily will be a key feature for the seat shape regardless of articulation

im interested in how this idea would fit in the system with other chairs in front/behind it

i agree, am interested in how space efficient this design would be

I really like the idea of making the folded chairs useful. Maybe we can store extra luggage on top too! We just have to make sure the top part is flat and sturdy

Daniel



this one would be ideal for nesting

this might make nesting with another chair difficult

provides a surface for more storage

this one would save alot of space, but may be hard to make stable for sitting

good for nesting with chairs in front/behind

This would make use of the space under the chair.

i like this one for nesting, since it still makes the backrest flush but still extremely compact

This design/mechanism would give us flexibility in designing for comfort and close nesting

Concluding Ideas

Minimize movement- best for ease of use and making nesting shorter

Make vertical and seat goes underneath the space - depends on how high off the ground the seat is

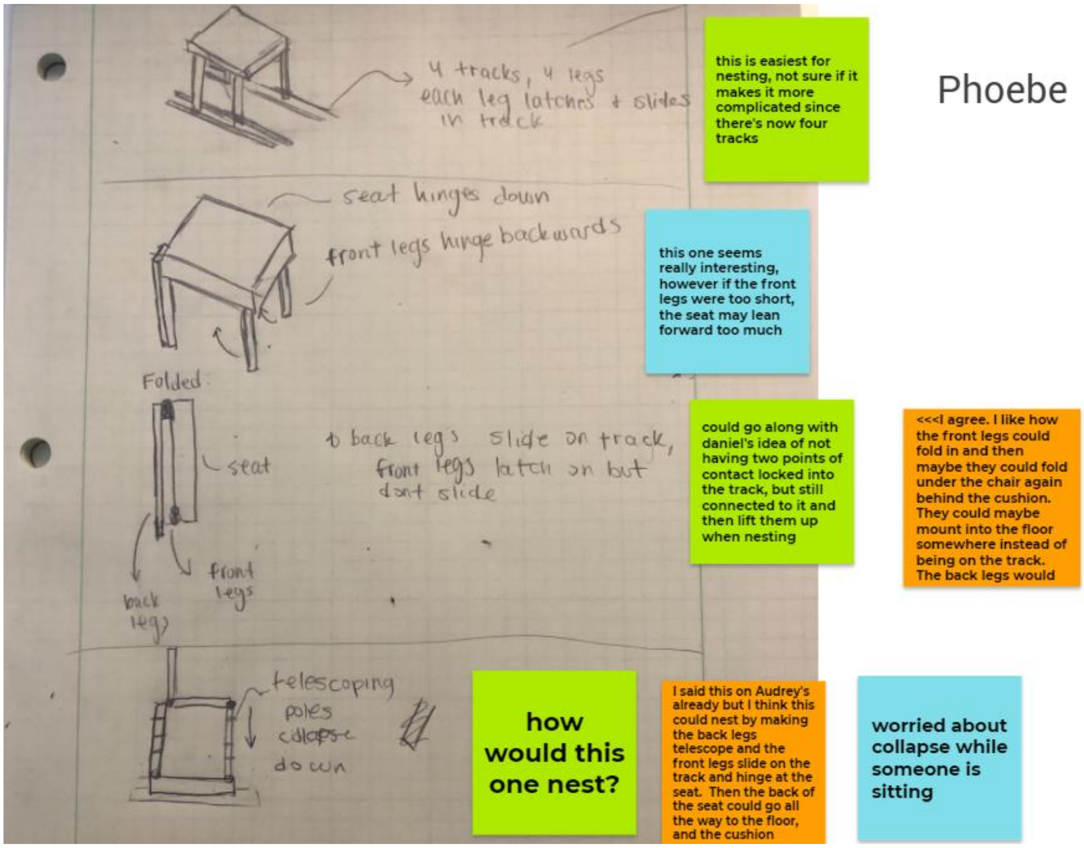
Contour and shape will be a key feature- for nesting and comfort

Folding armrests - comfort of user and save space when folded

Create a flat surface on top for storage- may be difficult

Height adjustability- mount on the back sliding up and down.

Undercarriage Brainwriting Results:



Phoebe

this is easiest for nesting, not sure if it makes it more complicated since there's now four tracks

this one seems really interesting, however if the front legs were too short, the seat may lean forward too much

could go along with daniel's idea of not having two points of contact locked into the track, but still connected to it and then lift them up when nesting

<<<I agree. I like how the front legs could fold in and then maybe they could fold under the chair again behind the cushion. They could maybe mount into the floor somewhere instead of being on the track. The back legs would

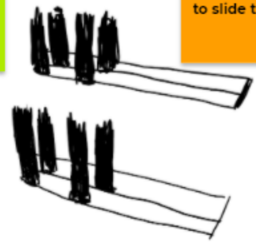
how would this one nest?

I said this on Audrey's already but I think this could nest by making the back legs telescope and the front legs slide on the track and hinge at the seat. Then the back of the seat could go all the way to the floor, and the cushion

worried about collapse while someone is sitting

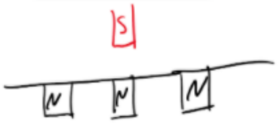
Steven

think the four track would make it more secure/easier for nesting, they would have to be angled in order to nest easily



with the four track it could make adjusting quite easy since you just have to slide the seat.

This would be pretty cool



I like this idea a lot even though it might be too high-tech for our purposes. This would simplify the mechanism for latching.

i agree, i think this design looks the most sturdy compared to most of ours that have two separate poles

The truss-like structure of this undercarriage idea would keep the seat sturdy.

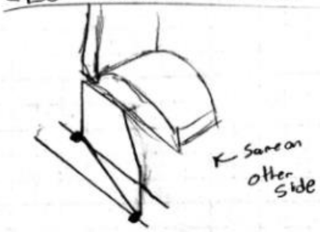
we should look into making supports go across, perpendicular to the track. i agree this will add some rigidity and support to the legs, it also would make it look more sturdy

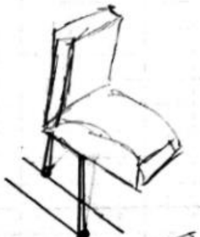
This could be a good way for the latch team to secure the seats

Daniel

LEG Mount - Nesting

great idea for nesting of legs, but would have to consider the seat itself also

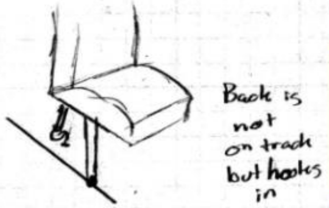




this seems to be the most space efficient idea

the four track idea is most space efficient, i'm wondering where the legs would be attached though so that they don't interfere with the seat articulation

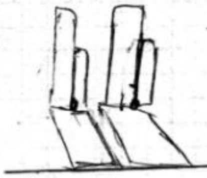
This would simplify the track design by having 2 instead of 4. Also would save floor space

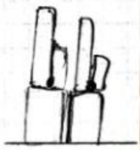


they could also somehow latch into the same track so it'd be on the same plane as track, but fold up retract when nesting in order to save space

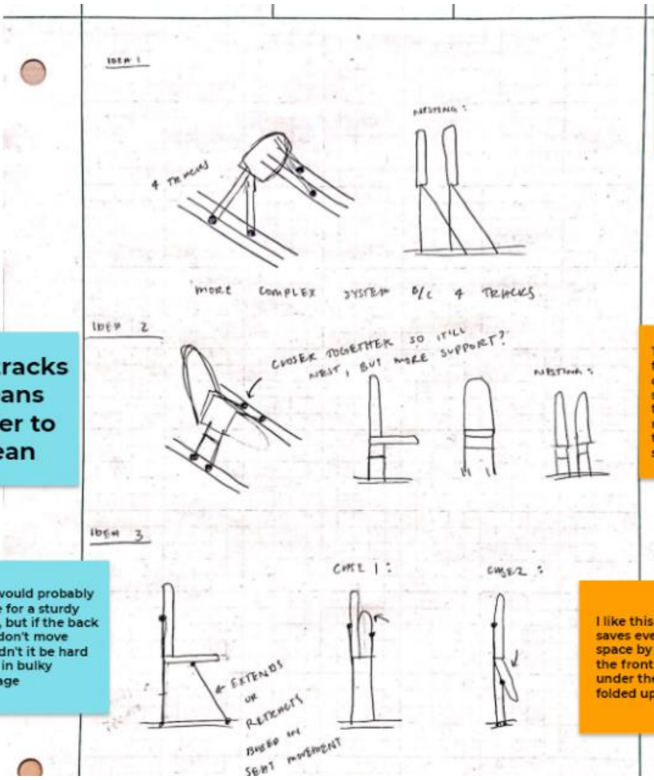
i like this idea, might make for a more stable arrangement than the 4 track idea

allows for flexibility of seat/back shape while maximizing space





Audrey



we should double check to see what the patent limits us to and if we might have to go with this idea bc the patent says so

potentially could include support pole for front of seat that collapses into other poles when nesting. This would address the support concern

less tracks means easier to clean

This idea could be feasible depending on how tight the seats fold up bc you technically can make it as wide as the space under the seats

I like the idea of minimizing the amount of tracks, the less the better

the extending poles would give us flexibility in how the seat itself collapses/nests

this would probably make for a sturdy chair, but if the back legs don't move wouldn't it be hard to fit in bulky luggage

I like this idea bc it saves even more space by making the front legs now under the seat folded up.

Maybe on this you could make the back telescope instead and keep the front rigid. Then the seat would be lower to the ground and take up less volume.

Wrap Up Thoughts

liked steven's idea of the criss crossed legs, maybe legs could be horizontal when folded, but would provide stability

telescoping/collapsing legs has some stability concerns, but could work well if the front stayed the same and back collapsed

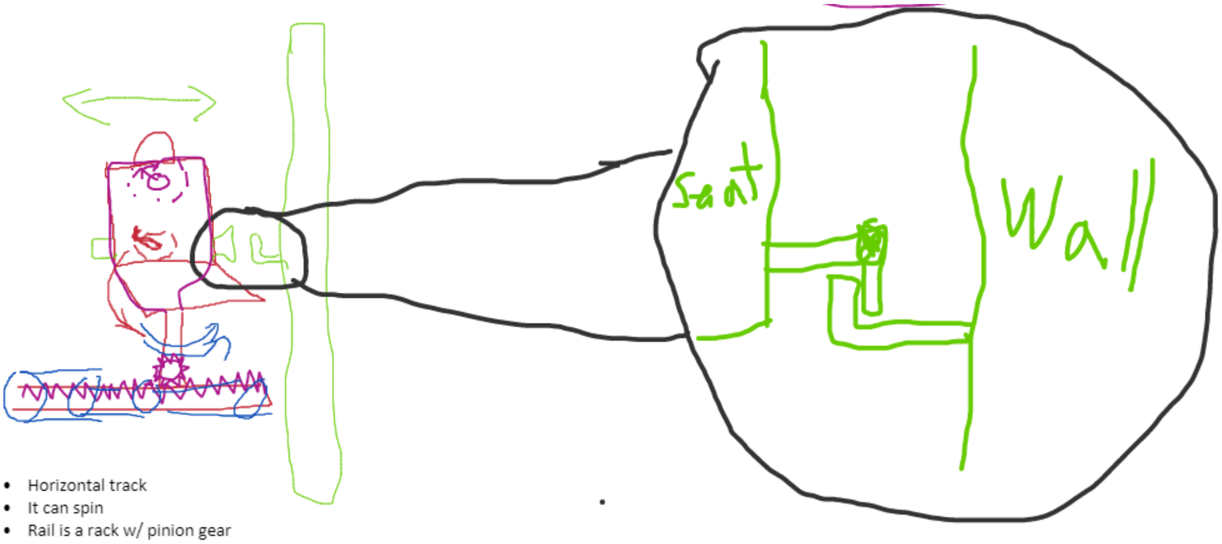
could have just one sturdy leg instead of multiple

lot of existing buses have one support under them

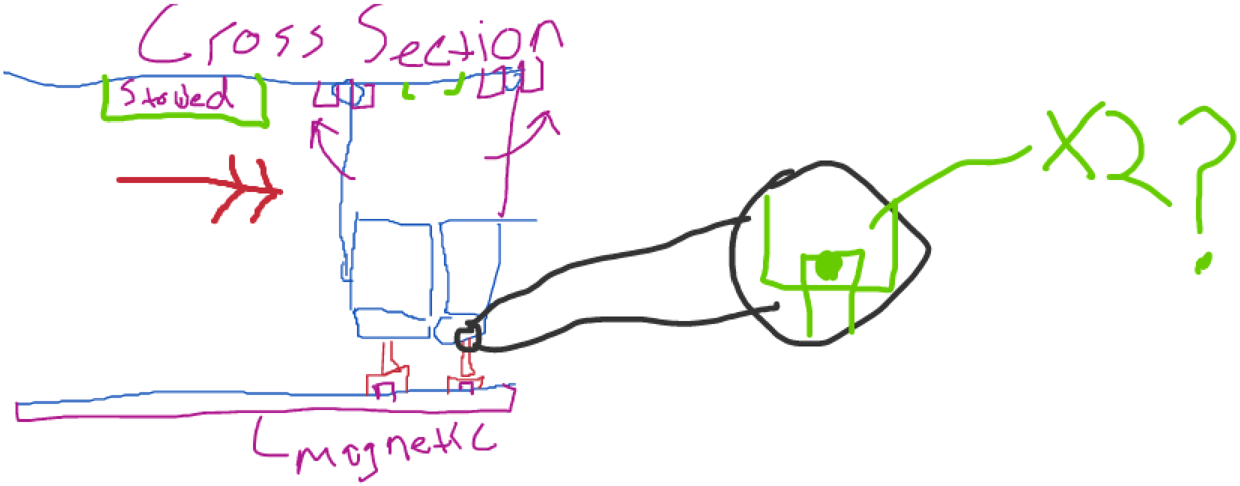
one pair of legs could be still locked into track, but could be taken off and folded up when nesting

Appendix H: Track and Latch Team Ideation Session Results

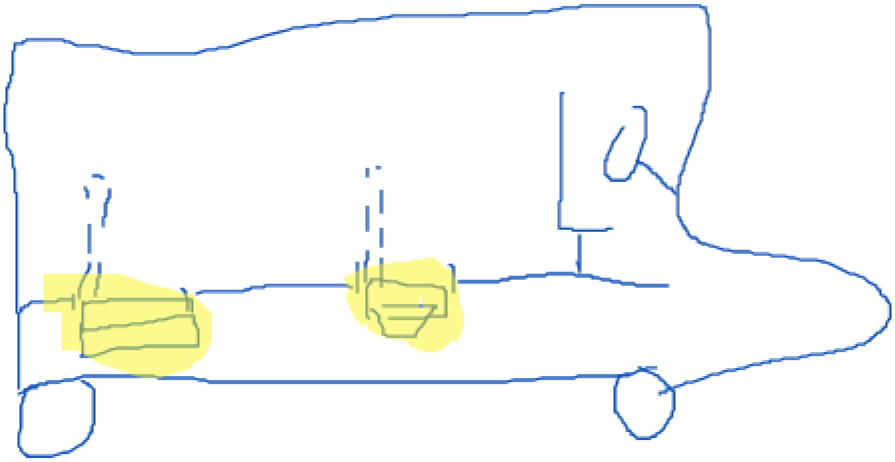
- Handle
- legs/rails
- Pulley
- Latch
- Wheels
- Lock indicator on handle
- Dimples on top side of track
- Spring loaded in tension OR tension; pin-lock
  - Spring only loaded when not-locked



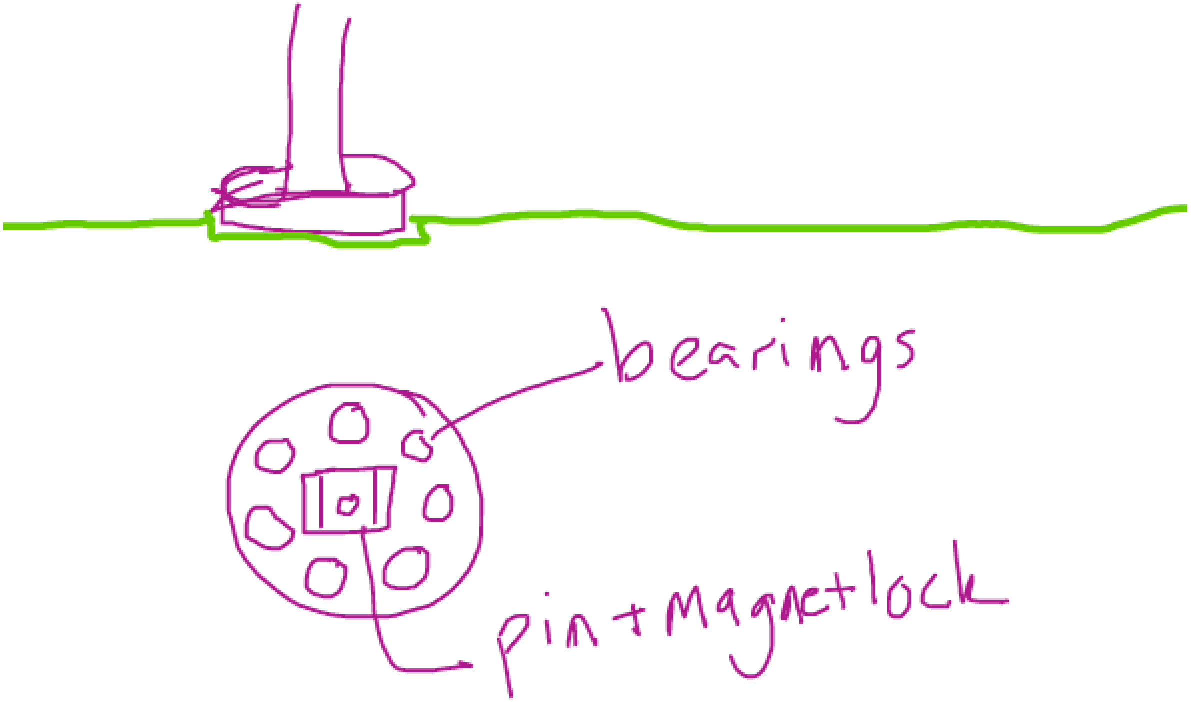
- Horizontal track
- It can spin
- Rail is a rack w/ pinion gear
- Mating latches on seat and wall
- Rack cover
- Crank handle on back of seat to translate
- Crank handle lower to rotate



- Ceiling attachment
- Longitudinal rails (slots) in ceiling
- Locking load support on bottom
- Pins secure seats to support structure
- Rotate to stow on ceiling
- Hooks to secure seats on ceiling



- Nico's crazy idea 2.0
- Seats fold into floor



Kai's latch idea

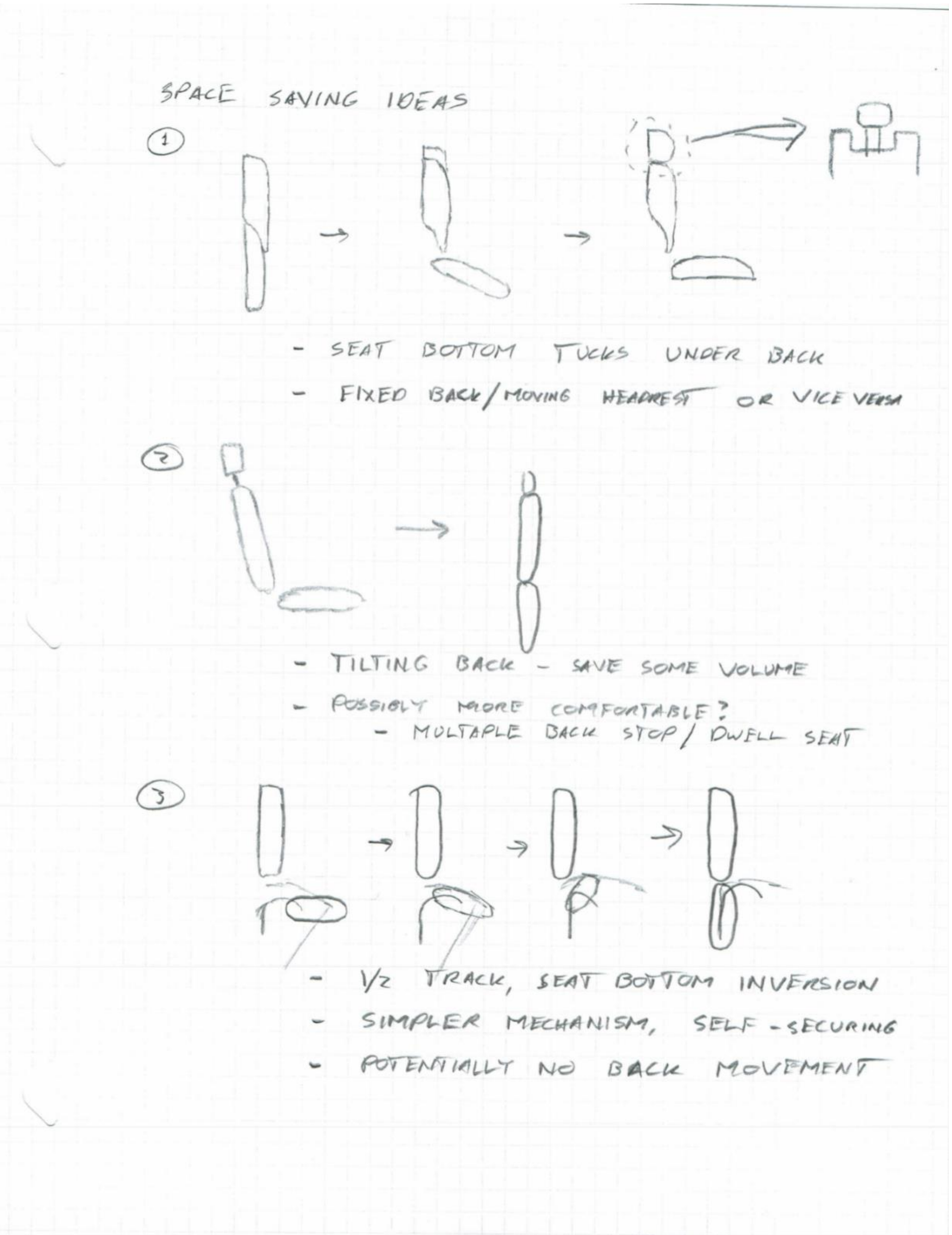
- Wheel rotates about vertical axis
- Pin pushes wheel up to unload bearing
- Indents in floor for wheel to fall in to
- Magnet locks wheel into place on floor
- Multiple legs or 1 really big wheel would probably help prevent tipping moment

Appendix I: Seat Articulation Team Ideation Session Results

Worst Possible Idea:

- Inflateable
  - ↳ Inflate all the seats like an air mattress!
  - ↳ Emily
  - · Blow it up Somehow
    - ↳ Take too long
    - ↳ Not Safe
  - · Maximizes Space
  - · Lightweight
  - · Can handle large loads
- All the Chairs fold into a pocket dimension
  - ↳ Rick
  - · High Cost
  - · Requires negative energy
    - ↳ Unobtainable resources
  - · Infinite Storage Space
- Deploy the Seats from the Ceiling
  - ↳ Pulley System
  - ↳ Emily
  - · Not Safe
  - · Falling Hazard
  - · Reduces Vertical Cargo Space
  - · Maximize Floor Space
- Maximize Deflection
  - ↳ CHEESE SEAT
  - ↳ Anil
  - · Cheese Seat Could melt
  - · Passenger Comfort minimized
  - · Lactose Intolerance
  - · Delicious
  - · Handles large acceleration
- Spring · Loaded Seat
  - ↳ Body weight extends seat
  - ↳ Emily
  - · Doesn't lock into position
  - · Low operation loading
  - · No Manual Setup / Deploy
  - · Simple Operation
- Stow them in the ground
  - ↳ Emily
  - ↳ Stow passengers in ground
  - · Have enough ground clearance
  - · High labor
  - · Not enough Storage Space
  - · Maximize Storage
- They just Stand
  - ↳ Anil
  - · Not Safe
  - · Not maximizing pass. Comfort
  - · Bad Senior Project
  - · Not DRC Accessible
  - · Maximize Storage
  - · Minimize Cost
  - · Simple Implementation
- Collapses in Transverse Direction Sideways
  - ↳ Rick
  - · Not enough
  - · Nested Storage Space
  - · Maximize linear storage (front to back)
- Seats are all animals
  - ↳ Sit on the animals
  - · Maintenance Cost
  - · Waste Disposal
  - · Marketable
  - · Aesthetic

Braimdump:



SPACE SAVING IDEAS

①

- SEAT BOTTOM TUCKS UNDER BACK
- FIXED BACK/MOVING HEADREST OR VICE VERSA

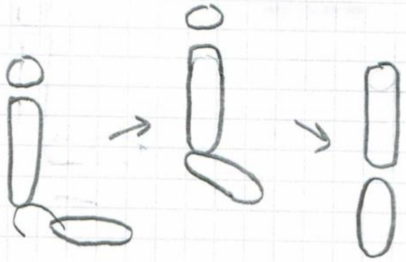
②

- TILTING BACK – SAVE SOME VOLUME
- POSSIBLY MORE COMFORTABLE?
  - MULTAPLE BACK STOP/ DWELL SEAT

③

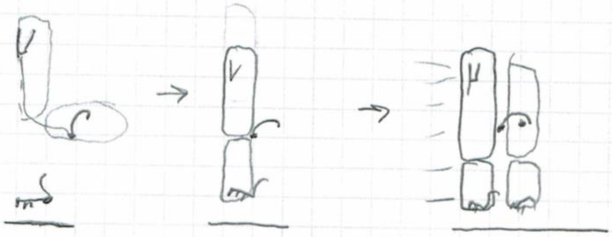
- 1/2 TRACK, SEAT BOTTOM INVERSION
- SIMPLER MECHANISM, SELF-SECURING
- POTENTIALLY NO BACK MOVEMENT

④



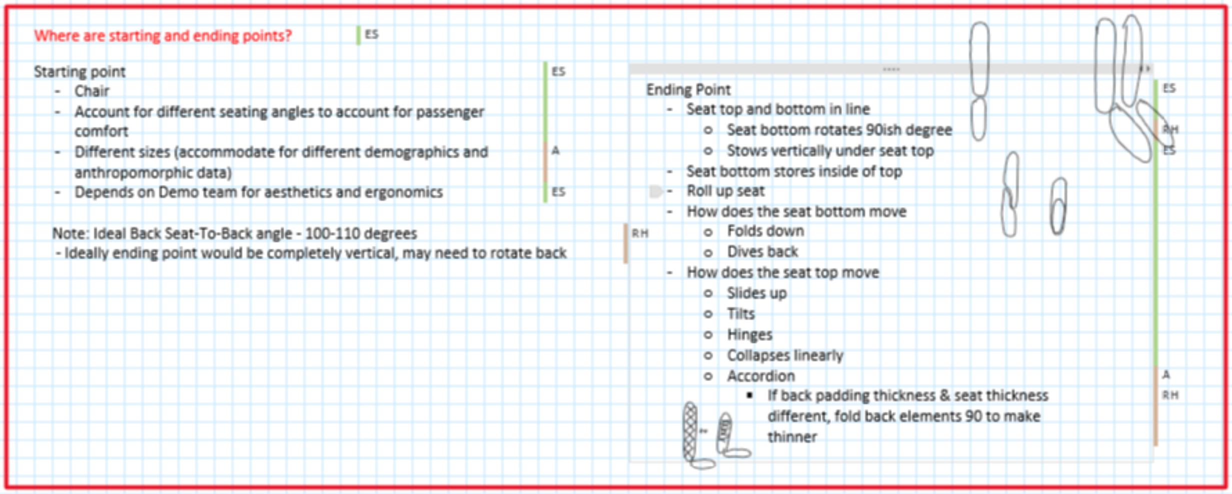
- J POSITION INCLUDES HALF-SEATED
- LIFT & LOWER - BOTH POSITIONS IN EXTREME LOCATION ON DOWNWARD MVT

⑤



- RELEASE FOR ARTICULATION ALSO OPERATES NESTING LATCH
- ARTICULATION ACTUATES SLIDING LATCH
  - \+ ELEGANT
  - \- NO IN-PLACE ADJUSTMENT

Brainstorm:

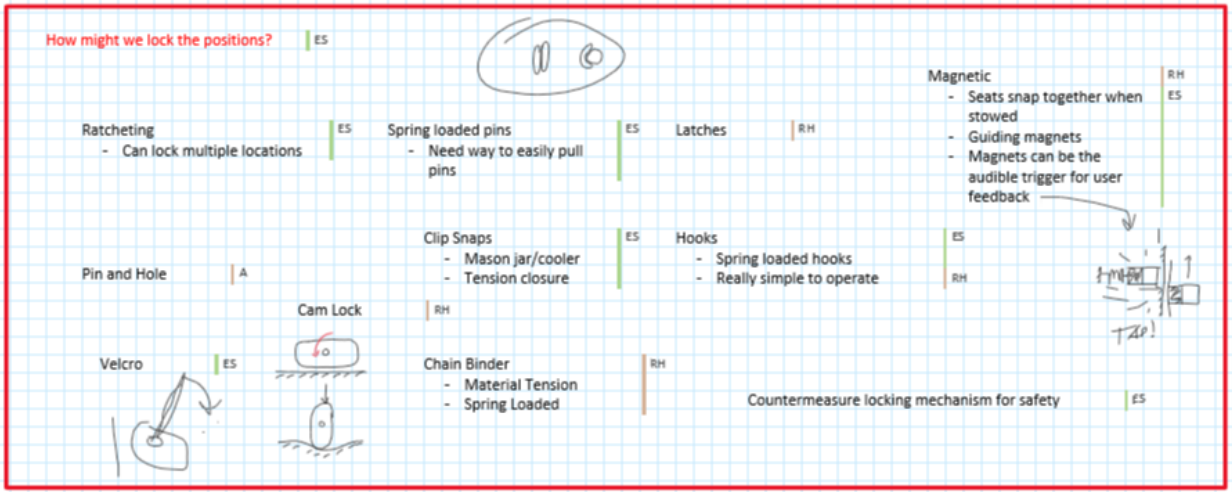


Where are starting and ending points? ES

Starting point ES
- Chair
- Account for different seating angles to account for passenger comfort
- Different sizes (accommodate for different demographics and anthropomorphic data) A
- Depends on Demo team for aesthetics and ergonomics ES

Note: Ideal Back Seat-To-Back angle - 100-110 degrees RH
- Ideally ending point would be completely vertical, may need to rotate back

Ending Point ES
- Seat top and bottom in line
  - Seat bottom rotates 90ish degree RH
  - Stows vertically under seat top ES
- Seat bottom stores inside of top
- Roll up seat
- How does the seat bottom move
  - Folds down
  - Dives back
- How does the seat top move
  - Slides up
  - Tilts
  - Hinges
  - Collapses linearly
  - Accordion A
    - If back padding thickness & seat thickness different, fold back elements 90 to make thinner RH



How might we lock the positions? ES

Ratcheting ES
- Can lock multiple locations

Spring loaded pins ES
- Need way to easily pull pins

Latches RH

Magnetic RH ES
- Seats snap together when stowed
- Guiding magnets
- Magnets can be the audible trigger for user feedback

Clip Snaps ES
- Mason jar/cooler
- Tension closure

Hooks ES RH
- Spring loaded hooks
- Really simple to operate

Pin and Hole A

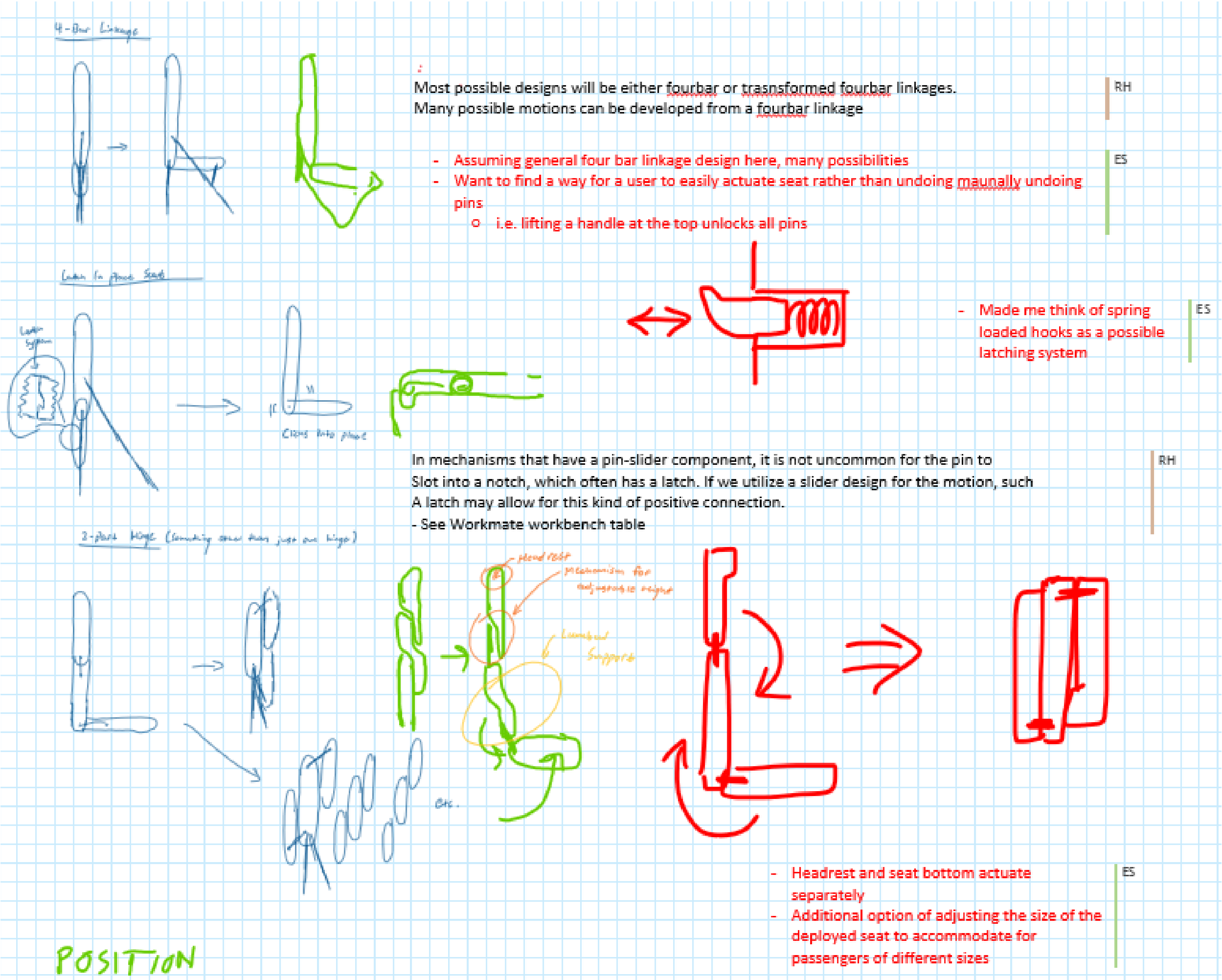
Cam Lock RH

Velcro ES

Chain Binder RH
- Material Tension
- Spring Loaded

Countermeasure locking mechanism for safety ES

Brainwrite:



Most possible designs will be either fourbar or trasnsformed fourbar linkages.
Many possible motions can be developed from a fourbar linkage

RH

- Assuming general four bar linkage design here, many possibilities
- Want to find a way for a user to easily actuate seat rather than undoing maunally undoing pins
  - i.e. lifting a handle at the top unlocks all pins

ES

- Made me think of spring loaded hooks as a possible latching system

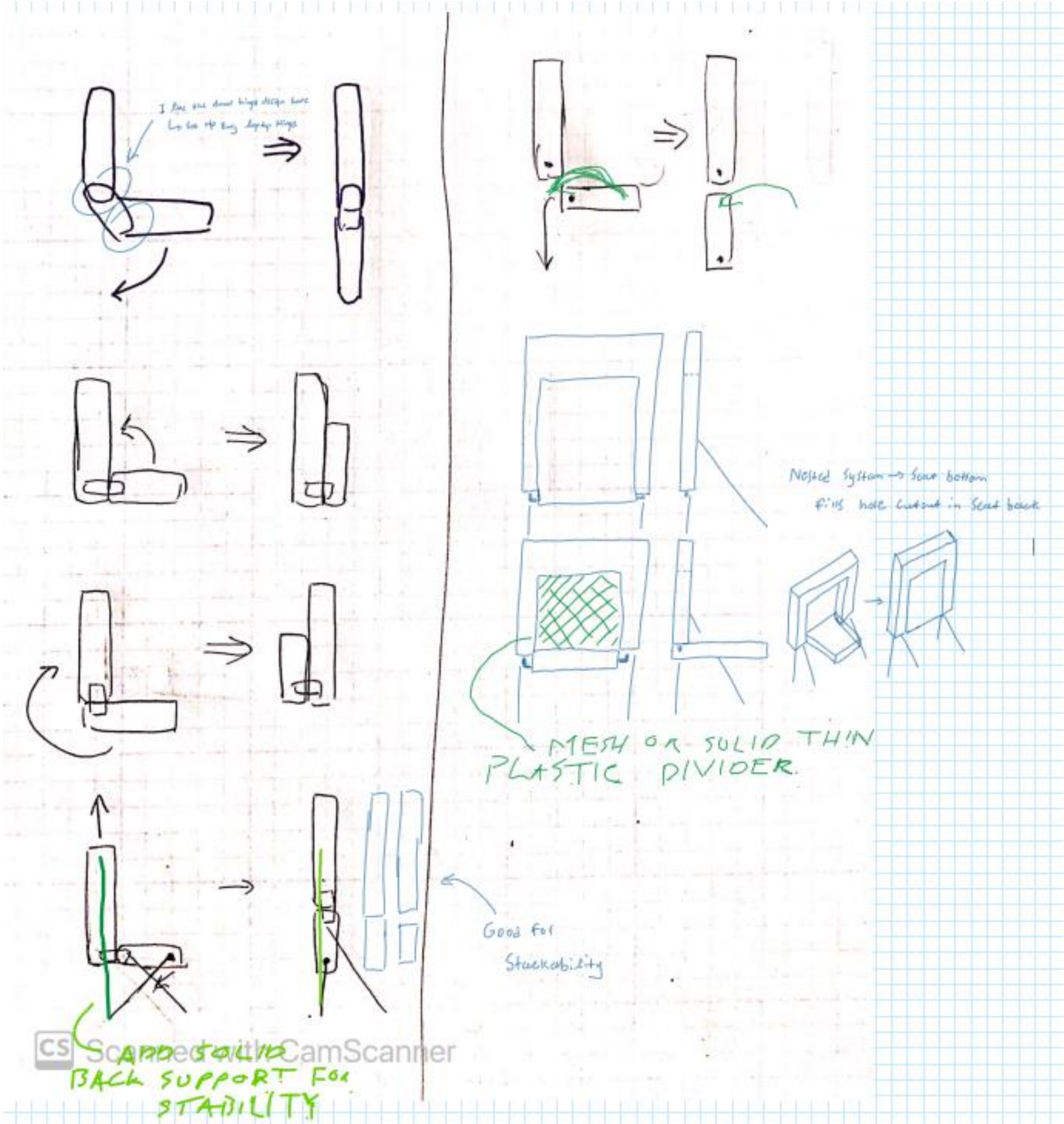
ES

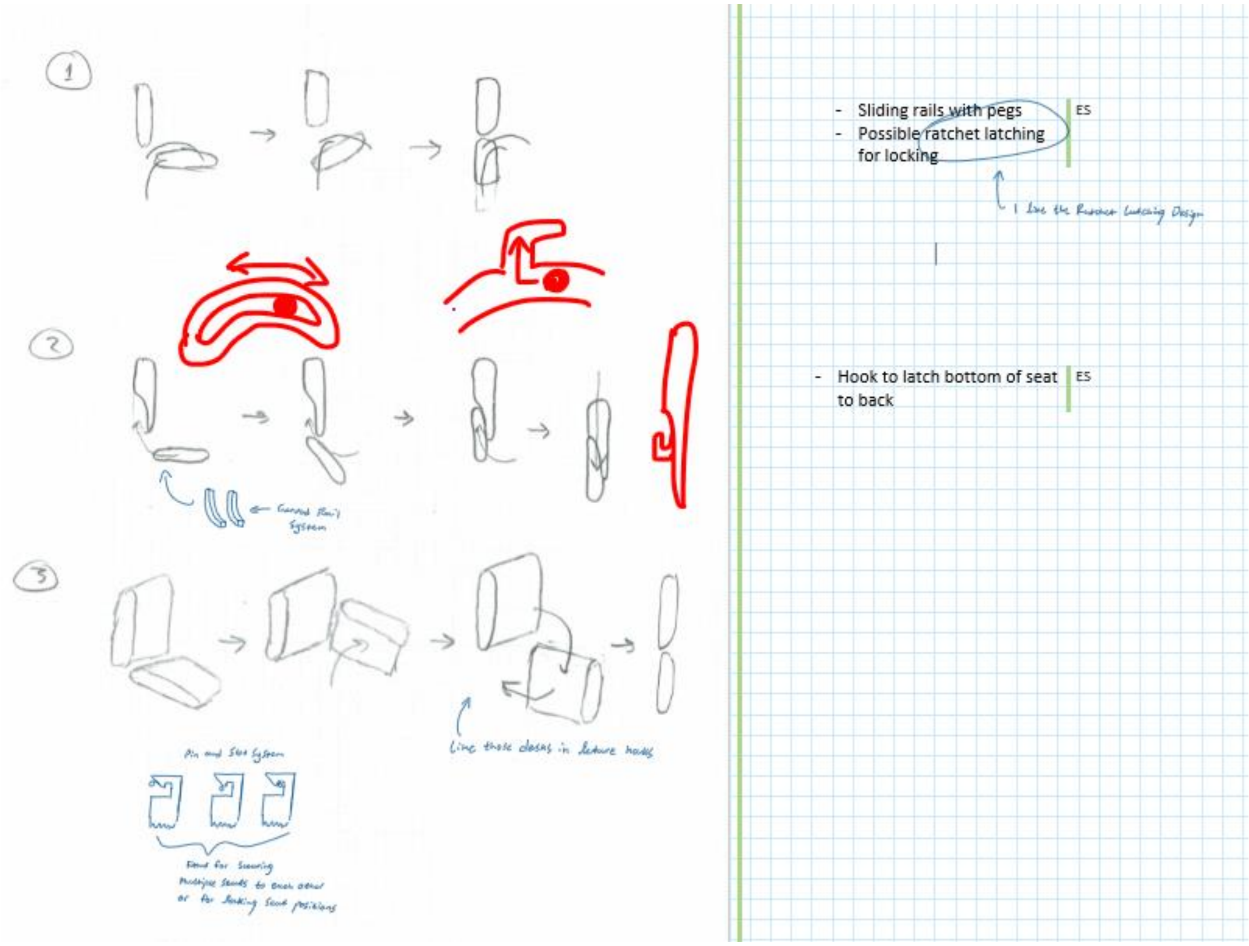
In mechanisms that have a pin-slider component, it is not uncommon for the pin to
Slot into a notch, which often has a latch. If we utilize a slider design for the motion, such
A latch may allow for this kind of positive connection.
- See Workmate workbench table

RH

- Headrest and seat bottom actuate separately
- Additional option of adjusting the size of the deployed seat to accommodate for passengers of different sizes

ES


I like the dowel hinge design here
Like the HP Envy laptop hinge
Nested System → Seat bottom
fills hole cutout in Seat back
MESH OR SOLID THIN PLASTIC DIVIDER.
Good for
Stackability
ADD SOLID BACK SUPPORT FOR STABILITY



Curved Rail System

Pin and Slot System

Good for securing multiple seats to each other or for locking seat positions

Like those desks in lecture halls

- Sliding rails with pegs
- Possible ratchet latching for locking

ES

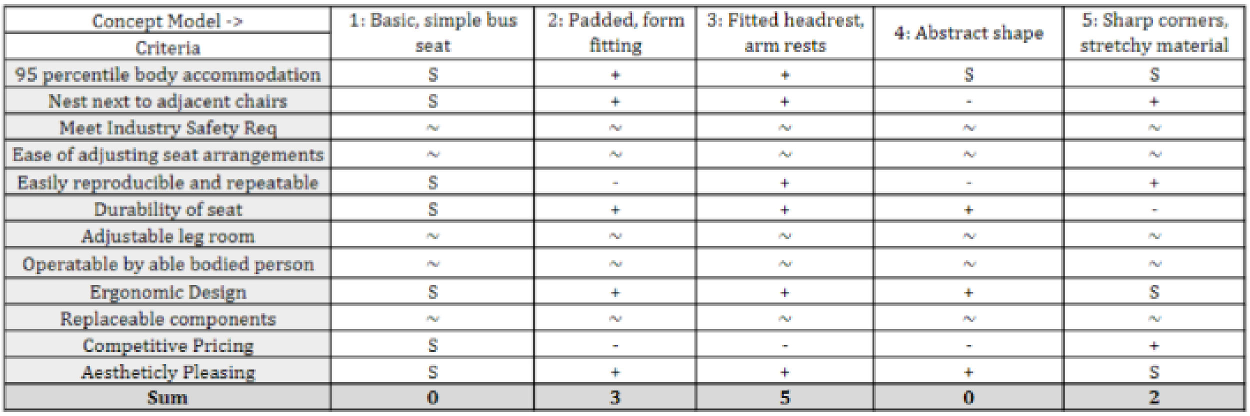
I like the Ratchet Latching Design

- Hook to latch bottom of seat to back

ES

Appendix J: System and Demo Team Pugh Matrices

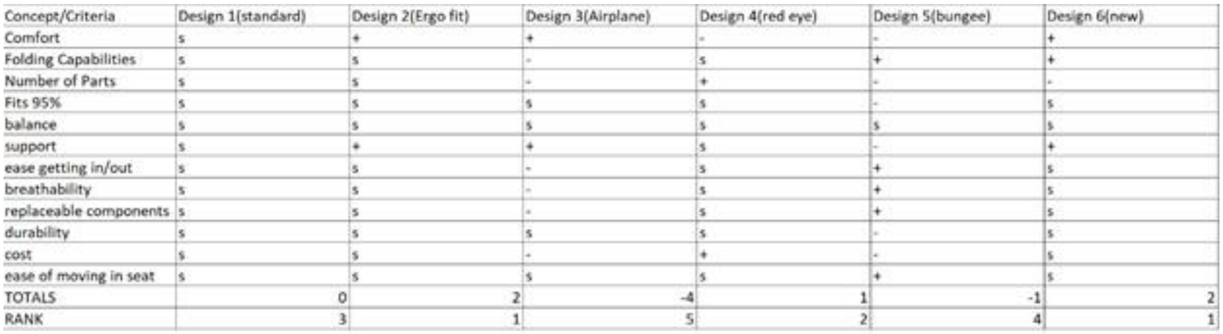
Aesthetics Pugh Matrix



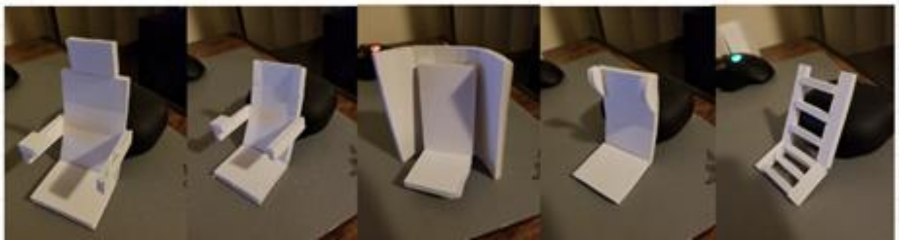
Concept Model -> Criteria	1: Basic, simple bus seat	2: Padded, form fitting	3: Fitted headrest, arm rests	4: Abstract shape	5: Sharp corners, stretchy material
95 percentile body accommodation	S	+	+	S	S
Nest next to adjacent chairs	S	+	+	-	+
Meet Industry Safety Req	~	~	~	~	~
Ease of adjusting seat arrangements	~	~	~	~	~
Easily reproducible and repeatable	S	-	+	-	+
Durability of seat	S	+	+	+	-
Adjustable leg room	~	~	~	~	~
Operatable by able bodied person	~	~	~	~	~
Ergonomic Design	S	+	+	+	S
Replaceable components	~	~	~	~	~
Competitive Pricing	S	-	-	-	+
Aestheticly Pleasing	S	+	+	+	S
Sum	**0**	**3**	**5**	**0**	**2**

#1	#2	#3	#4	#5
				

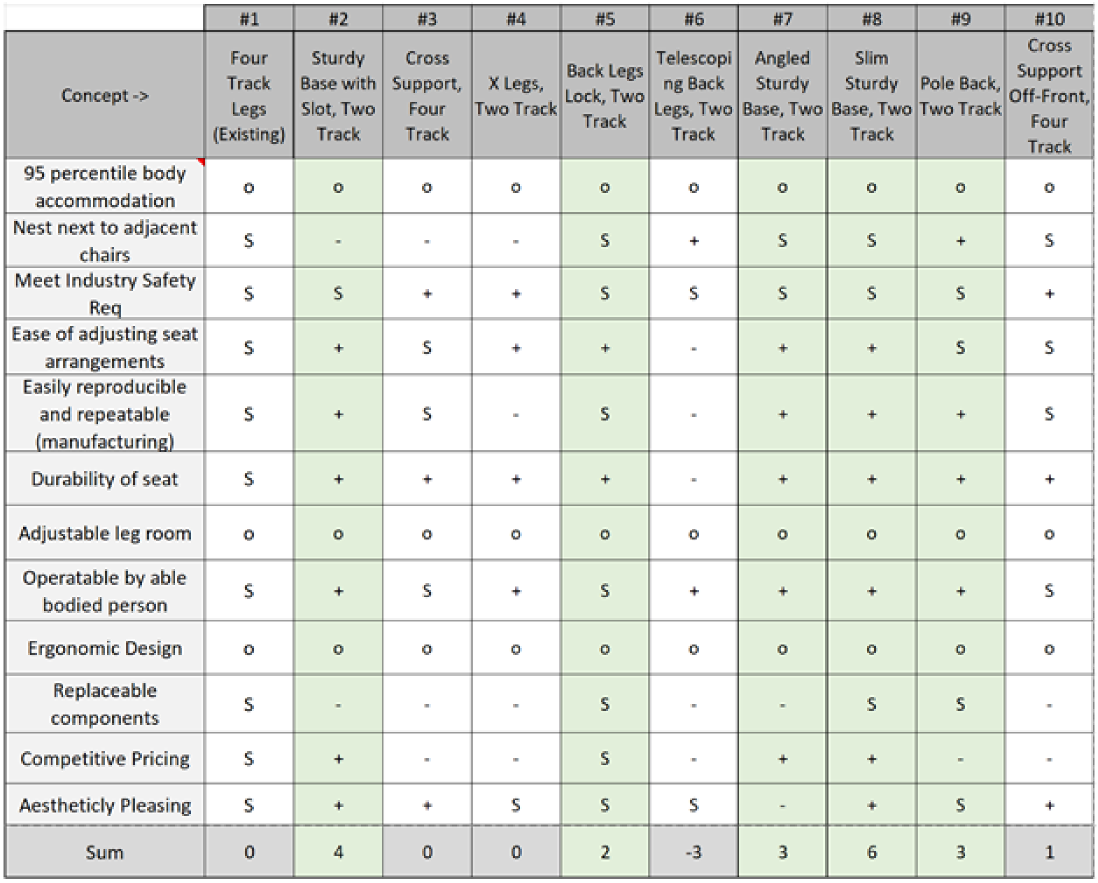
Ergonomics Pugh Matrix



Concept/Criteria	Design 1(standard)	Design 2(Ergo fit)	Design 3(Airplane)	Design 4(red eye)	Design 5(bungee)	Design 6(new)
Comfort	s	+	+	-	-	+
Folding Capabilities	s	s	-	s	+	+
Number of Parts	s	s	-	+	-	-
Fits 95%	s	s	s	s	-	s
balance	s	s	s	s	s	s
support	s	+	+	s	-	+
ease getting in/out	s	s	-	s	+	s
breathability	s	s	-	s	+	s
replaceable components	s	s	-	s	+	s
durability	s	s	s	s	-	s
cost	s	s	-	+	-	s
ease of moving in seat	s	s	s	s	+	s
TOTALS	0	2	-4	1	-1	2
RANK	3	1	5	2	4	1

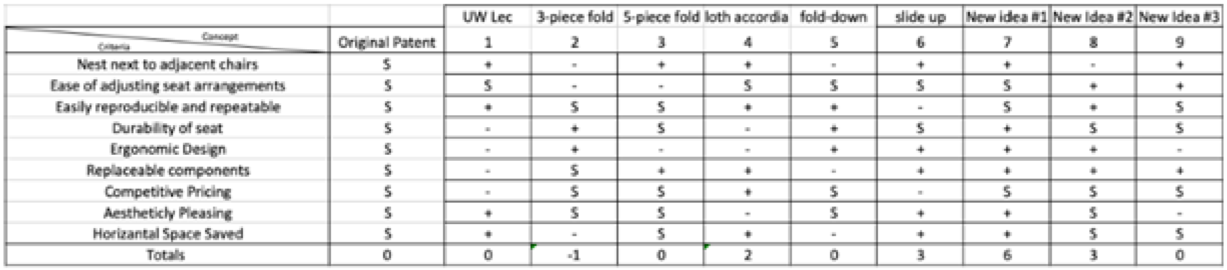


Undercarriage Pugh Matrix



	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Concept ->	Four Track Legs (Existing)	Sturdy Base with Slot, Two Track	Cross Support, Four Track	X Legs, Two Track	Back Legs Lock, Two Track	Telescoping Back Legs, Two Track	Angled Sturdy Base, Two Track	Slim Sturdy Base, Two Track	Pole Back, Two Track	Cross Support Off-Front, Four Track
95 percentile body accommodation	o	o	o	o	o	o	o	o	o	o
Nest next to adjacent chairs	S	-	-	-	S	+	S	S	+	S
Meet Industry Safety Req	S	S	+	+	S	S	S	S	S	+
Ease of adjusting seat arrangements	S	+	S	+	+	-	+	+	S	S
Easily reproducible and repeatable (manufacturing)	S	+	S	-	S	-	+	+	+	S
Durability of seat	S	+	+	+	+	-	+	+	+	+
Adjustable leg room	o	o	o	o	o	o	o	o	o	o
Operatable by able bodied person	S	+	S	+	S	+	+	+	+	S
Ergonomic Design	o	o	o	o	o	o	o	o	o	o
Replaceable components	S	-	-	-	S	-	-	S	S	-
Competitive Pricing	S	+	-	-	S	-	+	+	-	-
Aestheticly Pleasing	S	+	+	S	S	S	-	+	S	+
Sum	0	4	0	0	2	-3	3	6	3	1

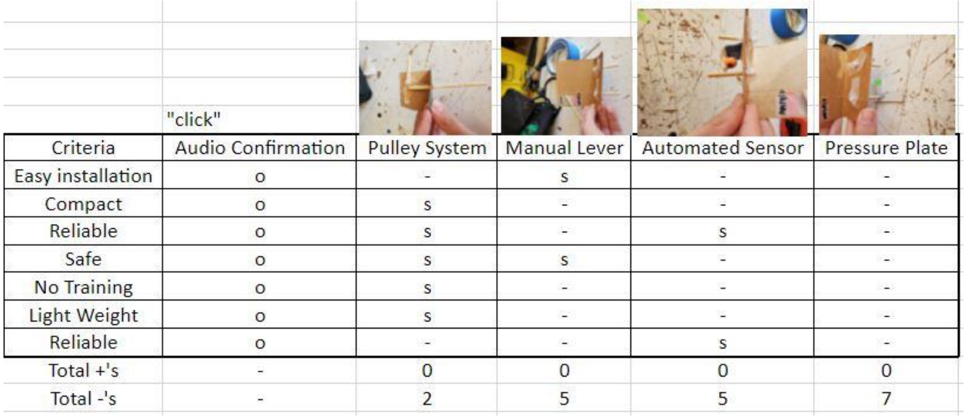
Nesting Pugh Matrix



		UW Lec	3-piece fold	5-piece fold	loth accordia	fold-down	slide up	New idea #1	New Idea #2	New Idea #3
Concept Criteria	Original Patent	1	2	3	4	5	6	7	8	9
Nest next to adjacent chairs	S	+	-	+	+	-	+	+	-	+
Ease of adjusting seat arrangements	S	S	-	-	S	S	S	S	+	+
Easily reproducible and repeatable	S	+	S	S	+	+	-	S	+	S
Durability of seat	S	-	+	S	-	+	S	+	S	S
Ergonomic Design	S	-	+	-	-	+	+	+	+	-
Replaceable components	S	-	S	+	+	-	+	+	+	+
Competitive Pricing	S	-	S	S	+	S	-	S	S	S
Aestheticly Pleasing	S	+	S	S	-	S	+	+	S	-
Horizantal Space Saved	S	+	-	S	+	-	+	+	S	S
Totals	0	0	-1	0	2	0	3	6	3	0

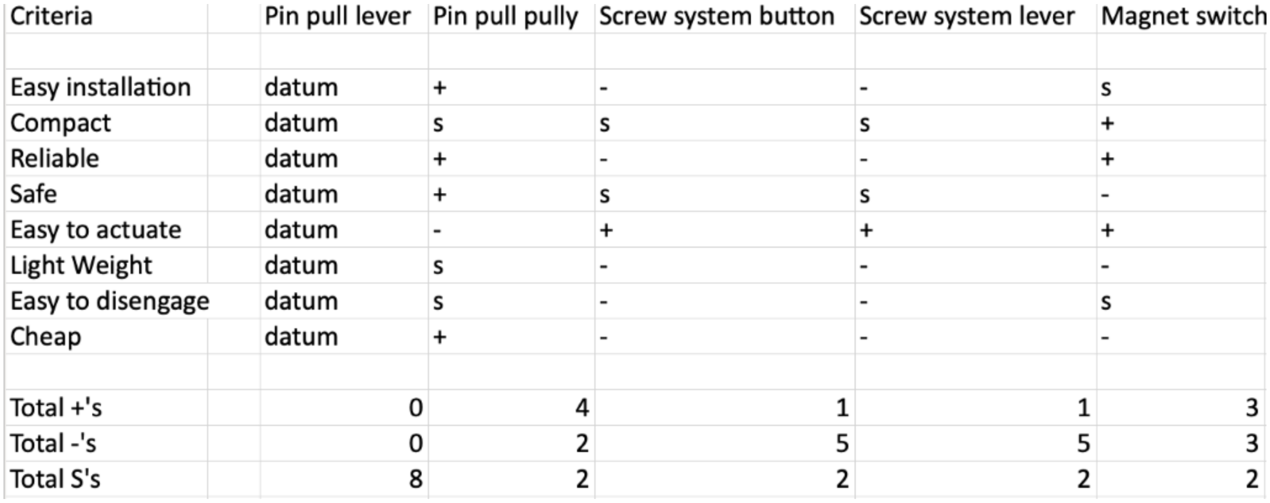
Appendix K: Track and Latch Team Pugh Matrices

Lock Confirmation Pugh Matrix



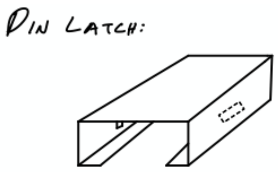
	"click"				
Criteria	Audio Confirmation	Pulley System	Manual Lever	Automated Sensor	Pressure Plate
Easy installation	o	-	s	-	-
Compact	o	s	-	-	-
Reliable	o	s	-	s	-
Safe	o	s	s	-	-
No Training	o	s	-	-	-
Light Weight	o	s	-	-	-
Reliable	o	-	-	s	-
Total +'s	-	0	0	0	0
Total -'s	-	2	5	5	7

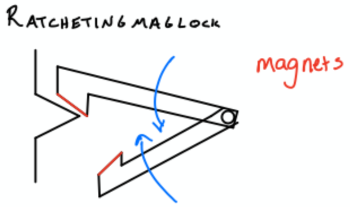
Lock Actuation Pugh Matrix

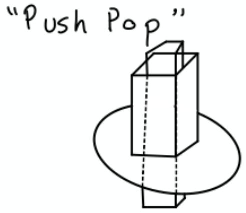


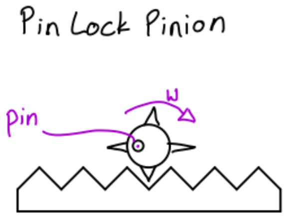
Criteria	Pin pull lever	Pin pull pully	Screw system button	Screw system lever	Magnet switch
Easy installation	datum	+	-	-	s
Compact	datum	s	s	s	+
Reliable	datum	+	-	-	+
Safe	datum	+	s	s	-
Easy to actuate	datum	-	+	+	+
Light Weight	datum	s	-	-	-
Easy to disengage	datum	s	-	-	s
Cheap	datum	+	-	-	-
Total +'s	0	4	1	1	3
Total -'s	0	2	5	5	3
Total S's	8	2	2	2	2

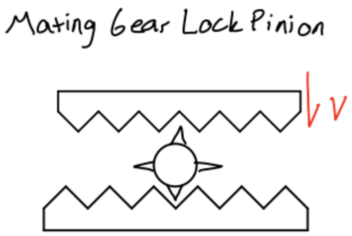
Locking Mechanism Pugh Matrix







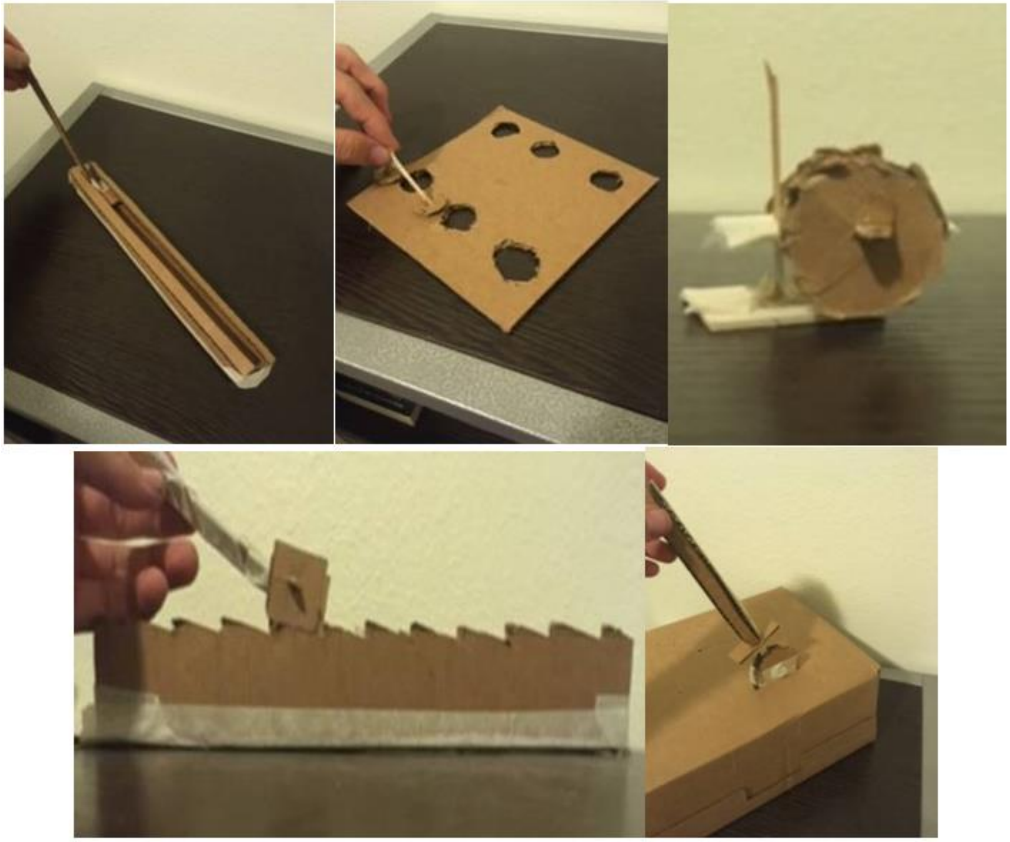




Criteria	Din Latch	Ratcheting MagLock	"Push Pop"	Pin-Lock Pinion	Mating Gear Lock Pinion
Stability	D	s	+	+	+
Compact	A	-	+	-	-
Reliable	T	s	s	+	+
Safe	U	s	s	+	+
Locking Force	M	+	+	+	+
Rapid Disengagement		s	+	-	s
Simplicity		-	+	-	+
Total +'s	-	1	5	4	5
Total -'s	-	2	0	3	1

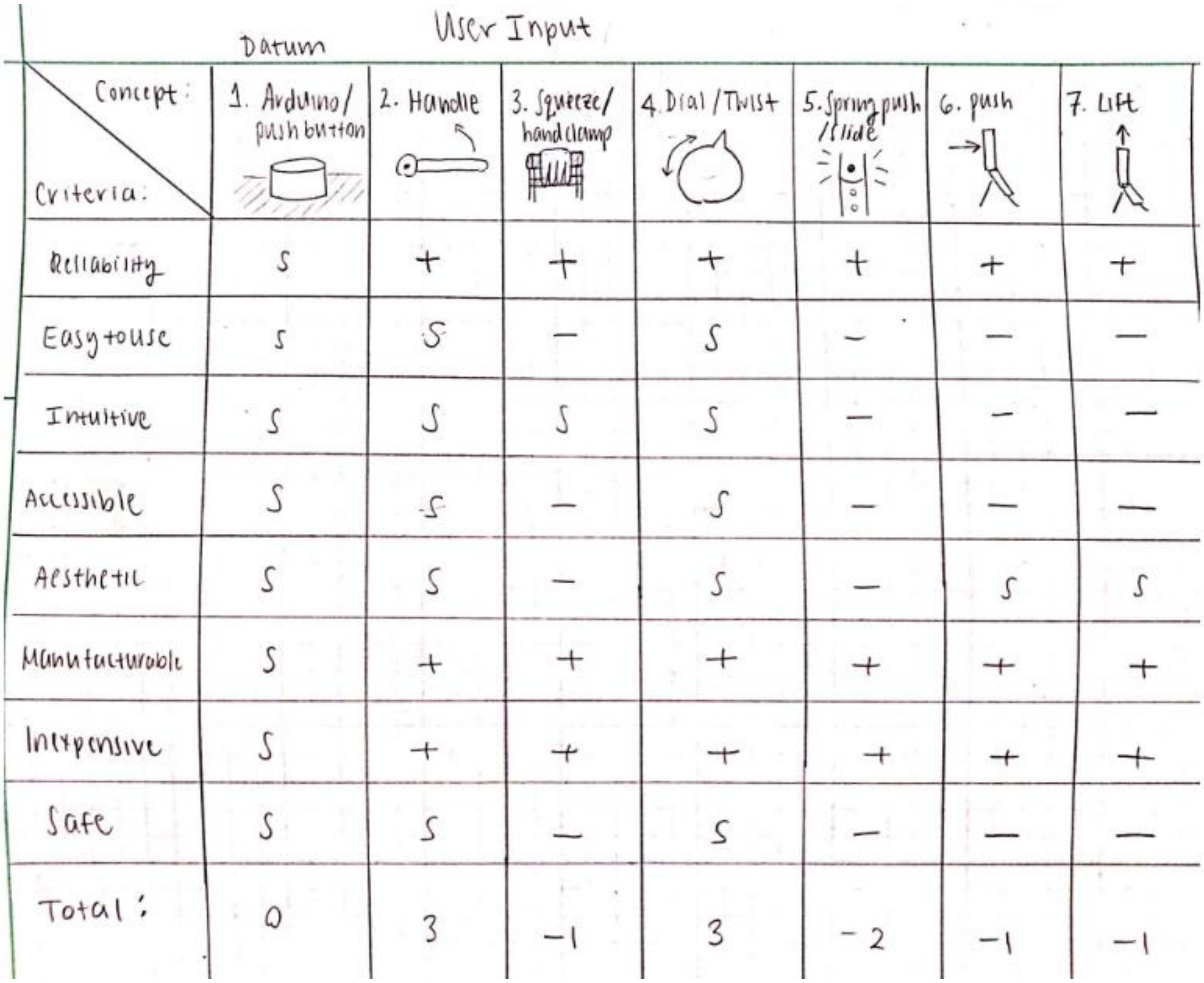
Seat Movement Pugh Matrix

Criteria	Sliding Seat Track	Seat Track with wheels, grooves	Wheels w/ Spring Push-up Mount	Rack and Pinion	Swivel wheel
Easy installation	o	s	-	-	+
Compact	o	s	-	s	+
Reliable	o	s	-	s	-
Safe	o	s	s	s	-
Low Movement Force	o	s	+	s	+
Light Weight	o	+	+	s	+
Configurability (number of possible seat configs)	o	s	s	+	s
Easy to Lock/Unlock	o	s	-	-	-
Total +'s	0	1	2	1	4
Total -'s	0	0	4	2	3
Total s's	8	7	2	5	1



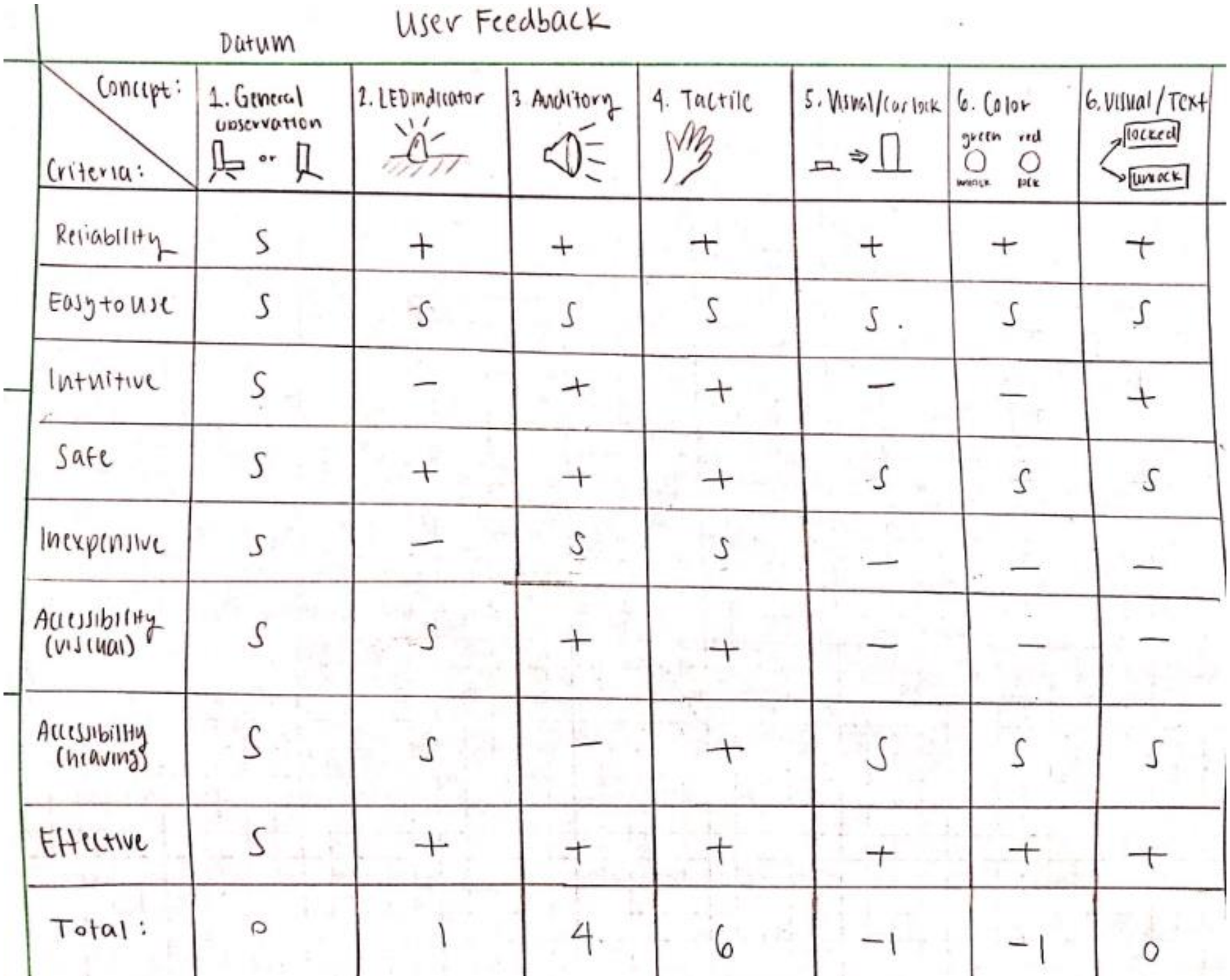
Appendix L: Seat Articulation Team Pugh Matrices

User Interface Pugh Matrix



	Datum	User Input					
Concept: / Criteria:	1. Arduino/ push button	2. Handle	3. Squeeze/ hand clamp	4. Dial/Twist	5. Spring push /slide	6. push	7. Lift
Reliability	S	+	+	+	+	+	+
Easy to use	S	S	−	S	−	−	−
Intuitive	S	S	S	S	−	−	−
Accessible	S	S	−	S	−	−	−
Aesthetic	S	S	−	S	−	S	S
Manufacturable	S	+	+	+	+	+	+
Inexpensive	S	+	+	+	+	+	+
Safe	S	S	−	S	−	−	−
Total:	0	3	−1	3	−2	−1	−1

User Feedback Pugh Matrix



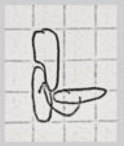
User Feedback

Concept: / Criteria:	1. General observation (Datum)	2. LED indicator	3. Auditory	4. Tactile	5. Visual/car lock	6. Color green red unlock lock	6. Visual / Text locked unlock
Reliability	S	+	+	+	+	+	+
Easy to use	S	S	S	S	S	S	S
Intuitive	S	−	+	+	−	−	+
Safe	S	+	+	+	S	S	S
Inexpensive	S	−	S	S	−	−	−
Accessibility (visual)	S	S	+	+	−	−	−
Accessibility (hearing)	S	S	−	+	S	S	S
Effective	S	+	+	+	+	+	+
Total:	0	1	4	6	−1	−1	0

Locking Mechanism Pugh Matrix

Concept	1	2	3	4	5	6
Criteria						
Strength	DATUM	+	-	-	-	+
Intuitive Nature		-	-	+	+	+
Simplicity		-	-	+	+	-
Safety		+	+	-	-	+
Security		S	S	-	-	-
Manufacturability		-	+	-	-	-
Locking Positions		+	+	S	+	+

Seat Movement Pugh Matrix

Seat Movement					
					
Criteria:	Standard Hinging	Fourbar Rocker-Slider Standard Hinging	Rocker Path-Slider Inverted	Seat Reversed Hinging	Seat Reversed Inverted
Projected Area	S	DATUM	S	-	-
Stowed Height	-		+	+	+
Strength	-		+	-	-
Complexity	+		-	+	+
Adaptability	-		+	S	+

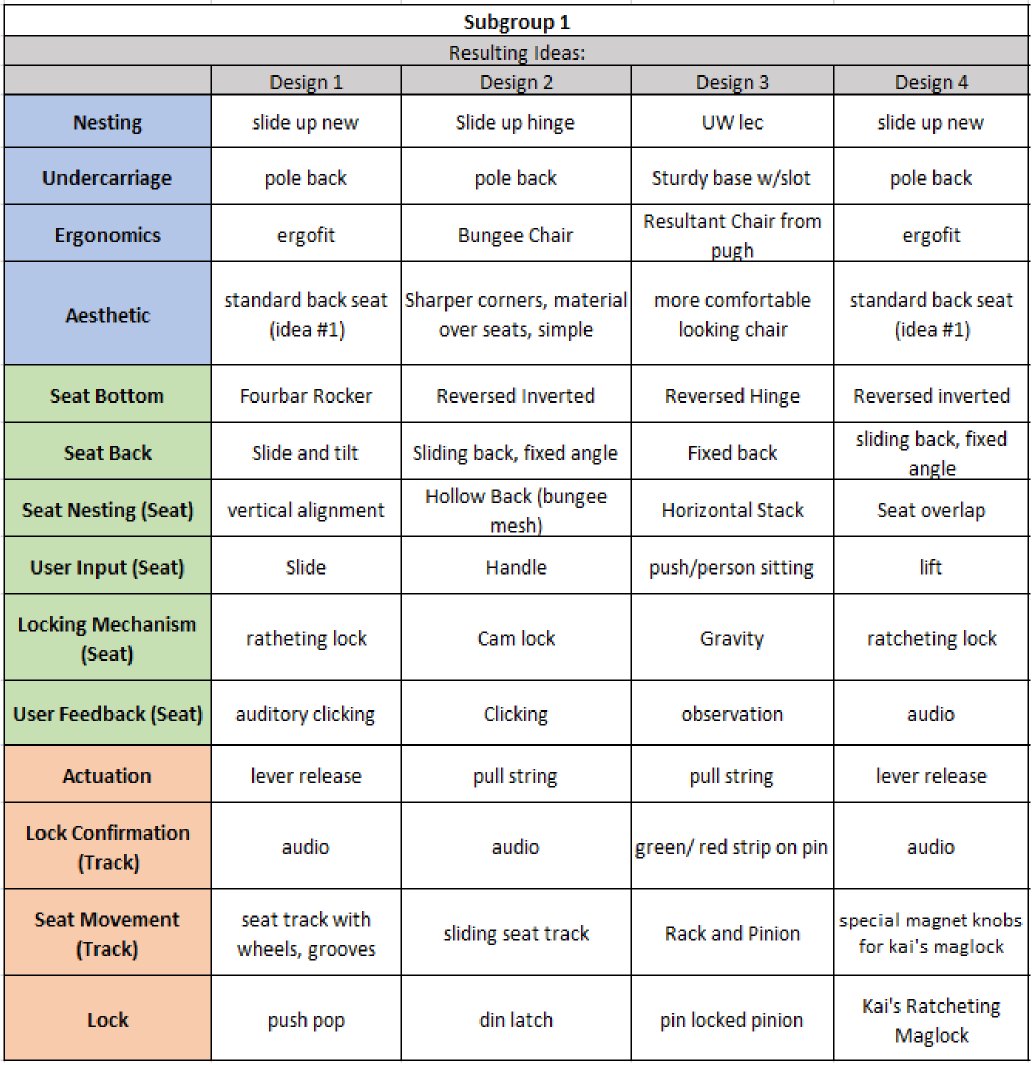
Back Movement Pugh Matrix

Back Movement					
					
Criteria	Fixed Back, Fixed Angle	Sliding Back, Fixed Angle	Fixed Back, Tilt	Sliding Back, Tilt	Bidirectional Sliding - Lift & Stow
Comfort	S	DATUM	S	S	S
Strength	+		-	--	-
Complexity	+		S	-	-
Stowed Height	+		+	S	+
Projected Area	S		+	+	S
Adaptability	-		S	+	+

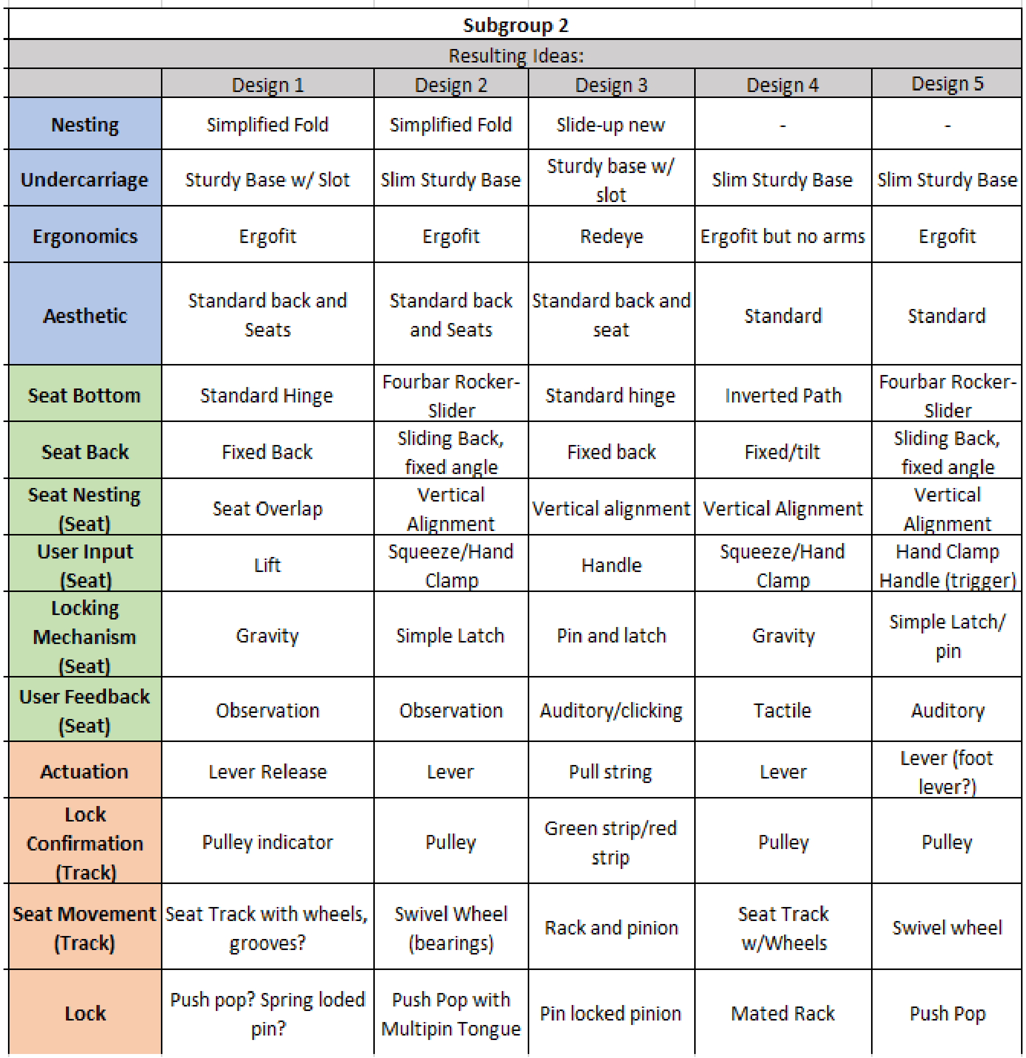
Seat Nesting Pugh Matrix

Seat Nesting					
					
Criteria	Vertical Alignment	Seat/Lumbar Overlap	Three-Piece Back	Horizontal Stacking	Hollow Back
Comfort	DATUM	S	-	S	-
Complexity		-	-	+	-
Volume		+	++	S	++
Projected Area		-	--	--	+
Stowed Height		S	-	+	+
Adaptability		S	-	-	-

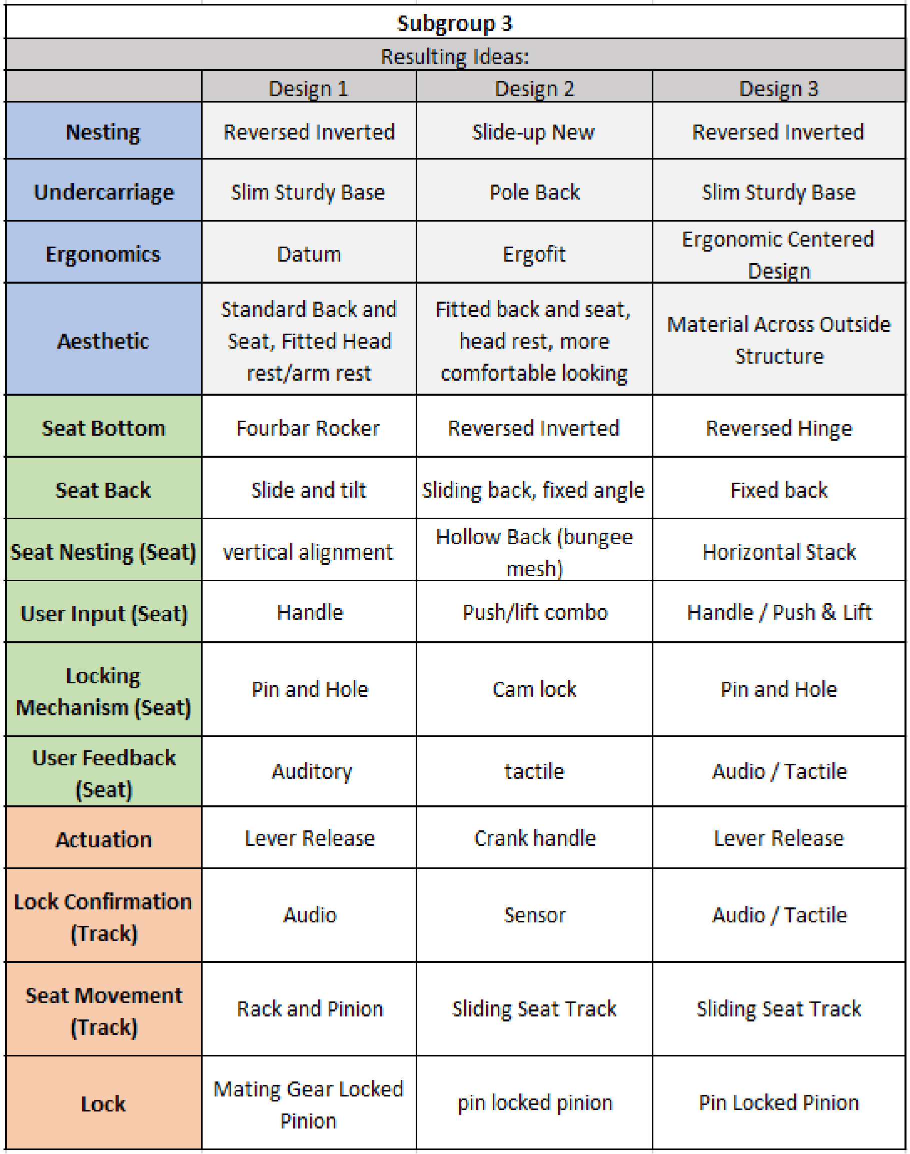
Appendix M: Subgroup Morphological Matrices



Subgroup 1				
Resulting Ideas:				
	Design 1	Design 2	Design 3	Design 4
Nesting	slide up new	Slide up hinge	UW lec	slide up new
Undercarriage	pole back	pole back	Sturdy base w/slot	pole back
Ergonomics	ergofit	Bungee Chair	Resultant Chair from pugh	ergofit
Aesthetic	standard back seat (idea #1)	Sharper corners, material over seats, simple	more comfortable looking chair	standard back seat (idea #1)
Seat Bottom	Fourbar Rocker	Reversed Inverted	Reversed Hinge	Reversed inverted
Seat Back	Slide and tilt	Sliding back, fixed angle	Fixed back	sliding back, fixed angle
Seat Nesting (Seat)	vertical alignment	Hollow Back (bungee mesh)	Horizontal Stack	Seat overlap
User Input (Seat)	Slide	Handle	push/person sitting	lift
Locking Mechanism (Seat)	ratheting lock	Cam lock	Gravity	ratcheting lock
User Feedback (Seat)	auditory clicking	Clicking	observation	audio
Actuation	lever release	pull string	pull string	lever release
Lock Confirmation (Track)	audio	audio	green/ red strip on pin	audio
Seat Movement (Track)	seat track with wheels, grooves	sliding seat track	Rack and Pinion	special magnet knobs for kai's maglock
Lock	push pop	din latch	pin locked pinion	Kai's Ratcheting Maglock



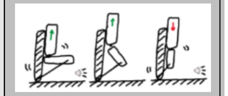
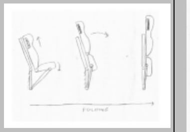
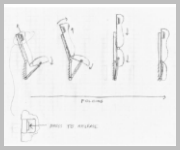
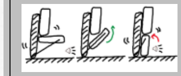
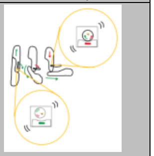
Subgroup 2					
Resulting Ideas:					
	Design 1	Design 2	Design 3	Design 4	Design 5
Nesting	Simplified Fold	Simplified Fold	Slide-up new	-	-
Undercarriage	Sturdy Base w/ Slot	Slim Sturdy Base	Sturdy base w/ slot	Slim Sturdy Base	Slim Sturdy Base
Ergonomics	Ergofit	Ergofit	Redeye	Ergofit but no arms	Ergofit
Aesthetic	Standard back and Seats	Standard back and Seats	Standard back and seat	Standard	Standard
Seat Bottom	Standard Hinge	Fourbar Rocker-Slider	Standard hinge	Inverted Path	Fourbar Rocker-Slider
Seat Back	Fixed Back	Sliding Back, fixed angle	Fixed back	Fixed/tilt	Sliding Back, fixed angle
Seat Nesting (Seat)	Seat Overlap	Vertical Alignment	Vertical alignment	Vertical Alignment	Vertical Alignment
User Input (Seat)	Lift	Squeeze/Hand Clamp	Handle	Squeeze/Hand Clamp	Hand Clamp Handle (trigger)
Locking Mechanism (Seat)	Gravity	Simple Latch	Pin and latch	Gravity	Simple Latch/ pin
User Feedback (Seat)	Observation	Observation	Auditory/clicking	Tactile	Auditory
Actuation	Lever Release	Lever	Pull string	Lever	Lever (foot lever?)
Lock Confirmation (Track)	Pulley indicator	Pulley	Green strip/red strip	Pulley	Pulley
Seat Movement (Track)	Seat Track with wheels, grooves?	Swivel Wheel (bearings)	Rack and pinion	Seat Track w/Wheels	Swivel wheel
Lock	Push pop? Spring loded pin?	Push Pop with Multipin Tongue	Pin locked pinion	Mated Rack	Push Pop



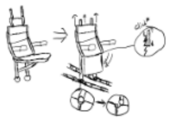
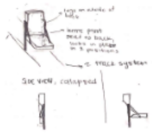
Subgroup 3			
Resulting Ideas:			
	Design 1	Design 2	Design 3
Nesting	Reversed Inverted	Slide-up New	Reversed Inverted
Undercarriage	Slim Sturdy Base	Pole Back	Slim Sturdy Base
Ergonomics	Datum	Ergofit	Ergonomic Centered Design
Aesthetic	Standard Back and Seat, Fitted Head rest/arm rest	Fitted back and seat, head rest, more comfortable looking	Material Across Outside Structure
Seat Bottom	Fourbar Rocker	Reversed Inverted	Reversed Hinge
Seat Back	Slide and tilt	Sliding back, fixed angle	Fixed back
Seat Nesting (Seat)	vertical alignment	Hollow Back (bungee mesh)	Horizontal Stack
User Input (Seat)	Handle	Push/lift combo	Handle / Push & Lift
Locking Mechanism (Seat)	Pin and Hole	Cam lock	Pin and Hole
User Feedback (Seat)	Auditory	tactile	Audio / Tactile
Actuation	Lever Release	Crank handle	Lever Release
Lock Confirmation (Track)	Audio	Sensor	Audio / Tactile
Seat Movement (Track)	Rack and Pinion	Sliding Seat Track	Sliding Seat Track
Lock	Mating Gear Locked Pinion	pin locked pinion	Pin Locked Pinion

Appendix N: Articulation and System Team's Individual Weighted Decision Matrices

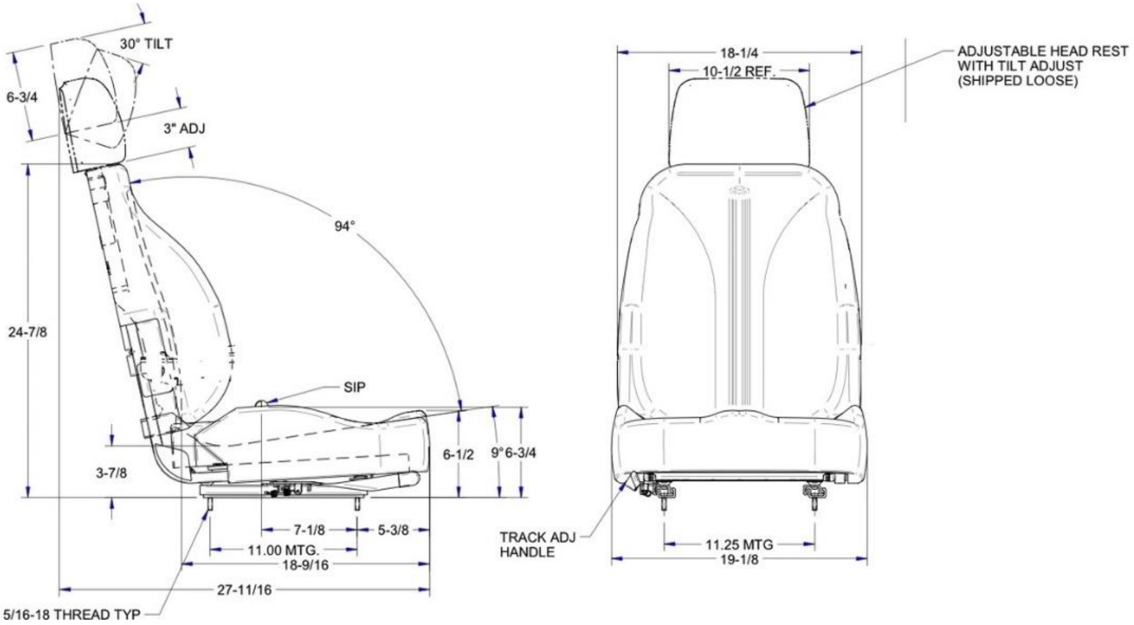
Seat Articulation Weighted Decision Matrix

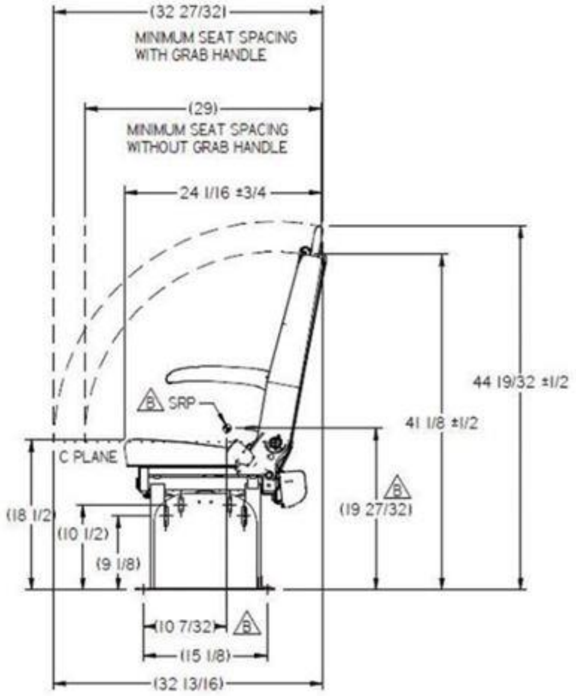
Weighted Decision Matrix		Design 1		Design 2		Design 3		Design 4		Design 5	
		Standard		Modified Standard		Complex Combined		Inverted		Overlap	
											
Criteria	Weight	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Seat Storage Space	0.3	3	0.9	4	1.2	5	1.5	3	0.9	2	0.6
Strength/Stiffness	0.15	4	0.6	3	0.45	3	0.45	5	0.75	4	0.6
Operation Effort/Time	0.15	5	0.75	4	0.6	3	0.45	4	0.6	3	0.45
Weight	0.1	4	0.4	3	0.3	3	0.3	5	0.5	4	0.4
Manufacturability	0.05	5	0.25	4	0.2	3	0.15	5	0.25	3	0.15
Operating environment	0.05	5	0.25	3	0.15	3	0.15	5	0.25	4	0.2
Operator Survey	0.2	3	0.6	4	0.8	5	1	3	0.6	2	0.4
SUM	1		3.75		3.7		4		3.85		2.8

System and Demo Weighted Decision Matrix

		Weighted Decision Matrix							
		Design 1		Design 2		Design 3		Design 4	
									
Criteria	Weight	Score	Total	Score	Total	Score	Total	Score	Total
Cad Packaging Verification	0.28	3	0.84	2	0.56	4	1.12	5	1.4
Customer Satisfaction Survey	0.08	3	0.24	3	0.24	4	0.32	4	0.32
Bill of Materials	0.04	4	0.16	5	0.2	3	0.12	3	0.12
Industry Safety Standards	0.2	3	0.6	4	0.8	3	0.6	3	0.6
Fatigue Life Calculations	0.08	4	0.32	5	0.4	4	0.32	3	0.24
Time to adjust seat	0.16	4	0.64	5	0.8	4	0.64	3	0.48
Industry Design Standards	0.04	5	0.2	5	0.2	5	0.2	5	0.2
Cost to Manufacture	0.12	4	0.48	5	0.6	4	0.48	3	0.36
SUM	1	3.48		3.8		3.8		3.72	

Appendix O: Referenced Ergonomic Van Seat Dimensions





Appendix P: System Team Failure Modes and Effects Analysis

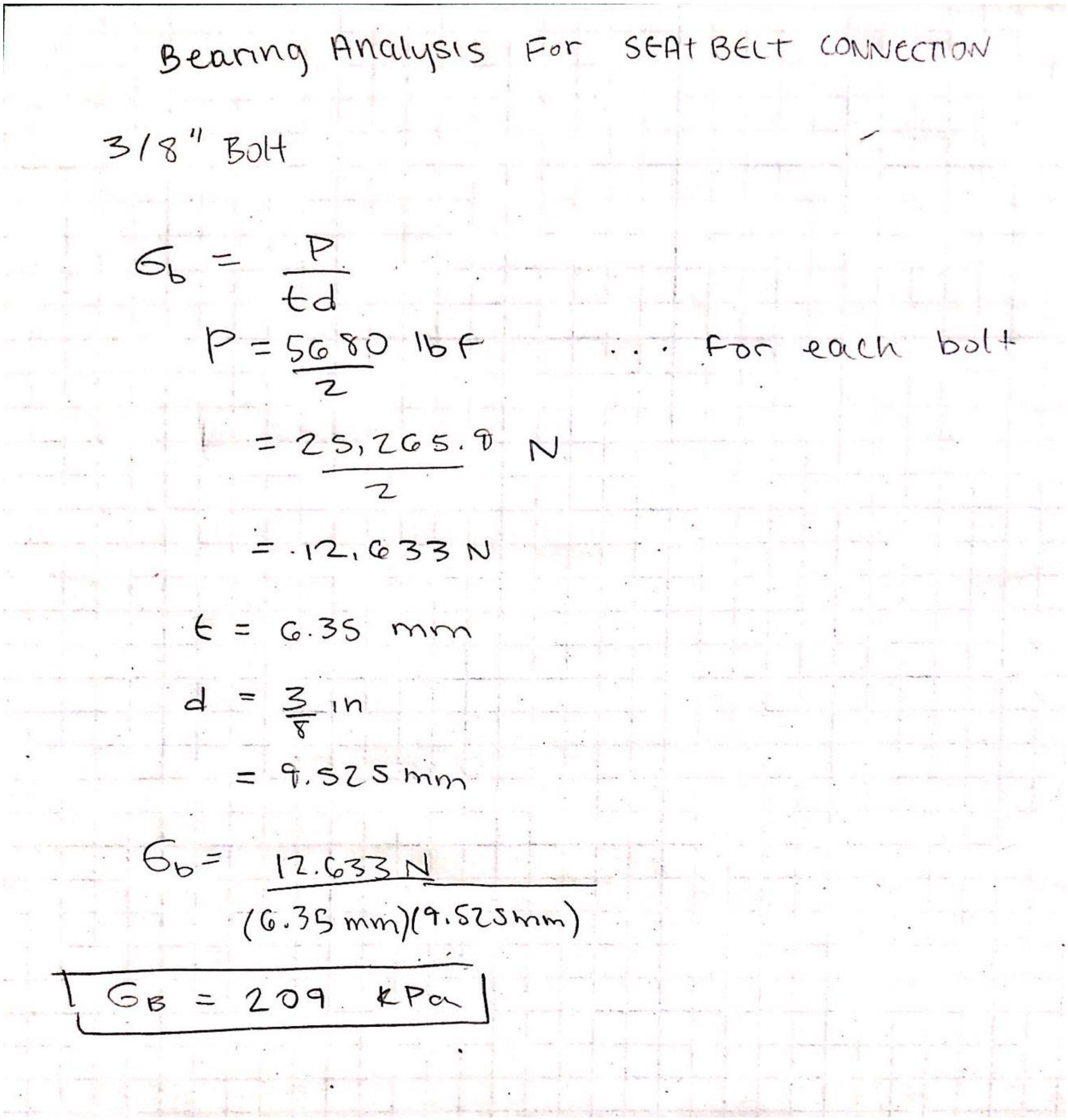
												Action Results				
System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	Priority	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Severity	Occurence	Detection	Criticality
Seat/Provide Seat Comfort	seat is uncomfortable	user is uncomfortable	4	1) seat doesn't fit user 2) seat is too hard/sharp 3) seat material is rough	1) measure users 2) round corners 3) soft material	7	customer survey	3	84							
Seat/ Seat Safety	seat injures user at pinch points	user is injured	9	exposed pinch points and moving components	cover pinch points with material	6	visual inspection	2	108							
Seat/ Support User	seat breaks	a) user is injured b) seat collapses	10	1) frame too weak 2) linkages too thin 3) linkage connection points shear 4) Seat hinge wears and breaks	1) fatigue analysis 2) linkage analysis 3) stress analysis	4	load test inspection	6	🟥 240	FEA and verifying hand calcs; Possible full scale model	Pheobe 2/14	Analyzed failure of polyeth. plastic seat under 300 lb tip load. FOS of 2.	10	1	6	60
	seat flexes too much	a) user discomfort b) seat instability	7	1) frame too weak 2) linkages too thin 3) linkage connection points become loose	1) fatigue analysis 2) linkage analysis 3) fastener analysis	4	load test inspection	6	🟧 168	FEA and verifying hand calcs; Possible full scale model	Pheobe 2/14	Analyzed displacement of polyeth. plastic seat under 300 lb tip load. FOS of 2.	5	1	6	30
Seat/Maintain appearance	seat rips open	interior is exposed	4	1) weak material 2) friction/rubbing points 3) sharp points	1) strong material selection 2) minimize friction	3	customer survey, visual inspection	3	36							
	seat loses shape	a) user discomfort b) appears worn out	5	1) frame too weak 2) cushion wears out	fatigue analysis	3	load test inspection, visual inspection	4	60	No longer relevant, plastic seat wont lose shape like a cushion						
	seat stains	appears dirty, unattractive	3	material not easily cleanable	material cleaning plan	6	visual inspection	2	36							
Back/Provide back comfort	back is uncomfortable	user is uncomfortable	5	1) back doesn't fit user 2) back is too hard/sharp 3) back material is rough	1) measure users 2) round corners 3) soft material	7	customer survey	3	105							
Back/ Back Safety	back injures user at pinch points	user is injured	9	exposed pinch points and moving components	cover pinch points with material	6	visual inspection	3	🟧 162	Complete integration of system and articulation in CAD, Possible verificaiton model	2/2 Daniel	Majority of moving components are housed in seat back	6	3	3	54
Back/ Support User	back breaks	a) user is injured b) seat collapses	10	1) frame too weak 2) linkages too thin 3) linkage connection points shear 4) Seat hinge wears and breaks	1) fatigue analysis 2) linkage analysis 3) stress analysis	4	load test inspection	6	🟥 240	FEA and verifying hand calcs; Possible full scale model	SEE Articulation	_				
	back flexes too much	a) user discomfort b) seat instability	7	1) frame too weak 2) linkages too thin 3) linkage connection points become loose	1) fatigue analysis 2) linkage analysis 3) fastener analysis	4	load test inspection	6	🟧 168	FEA and verifying hand calcs; Possible full scale model	SEE Articulation	_				
Back/Maintain appearance	back rips open	interior is exposed	4	1) weak material 2) friction/rubbing points 3) sharp points	1) strong material selection 2) minimize friction	4	load test inspection, customer survey	3	48							
	back stains	appears dirty, unattractive	3	1) material not easily cleanable	material cleaning plan	5	visual inspection	2	30							
	back loses shape	a) user discomfort b) appears worn out	5	1) frame too weak 2) cushion wears out	fatigue analysis	5	load test inspection, visual inspection	6	🟧 150	No longer relevant, plastic seat wont lose shape like a cushion	_	_				
Back/ User articulation	User cannot move/nest system	system unable to articulate	7	1) System is too heavy 2) User cannot grip seat/handle 3) handle is too weak and breaks 4) motion is not intuitive or out of reach	1) weigh system 2) intuitive design 3) stress analysis	3	load test inspection, customer survey	2	42							

												Action Results				
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**	**Actions Taken**	**Severity**	**Occurence**	**Detection**	**Criticality**
Seat Base/Conceal Linkages	Linkages/mounting points are exposed	a) appears unattractive b) exposes sharp edges	9	base does not cover linkages	measure linkage system	2	visual inspection	2	36							
Seat Base/ Safety	injures user at pinch points	user is injured	9	exposed pinch points and moving components	securely cover pinch points	2	visual inspection	2	36							
Seat Base/ Articulation Integration	Breaks at mounting holes	unable to articulate	7	1) base too thin 2) overloaded bearing stress 3) Friction wear 4) Fastener shear	1) stress analysis 2) fastener shear analysis 3) fatigue analysis	6	load test inspection	7	294	FEA and verifying hand calcs; Possible full scale model	SEE Articulation	–				
	base inteferes with motion path	system unable to articulate	7	Base contacts linkage in motion	define tolerances	2	visual inspection	2	28							
	base flexes too much	a) user discomfort b) seat instability	7	1) base too weak 2) linkages under out of plane loads 3) linkage connection points become loose 4) Track connections too weak	1) stress analysis 2) test fasteners	4	load test inspection, visual inspection	7	196	FEA and verifying hand calcs; Possible full scale model	SEE Articulation	–				
Seat Base/ Support system and user	base breaks	seat collapses and is no longer sturdy enough to carry a user	9	1) frame too thin 2) weak material 3) deterioration over time 4) Shear at linakge connections	1) stress analysis 2) strong material selection		load test inspection, visual inspection	8	0							
Armrest/Provide arm comfort	armrest is uncomfortable	user is uncomfortable	4	1) bad material 2) armrest incorrect height	strong material selection	2	customer survey	4	32							
Armrest/Support user	armrest breaks	user is uncomfortable	4	1) armrest is too thin 2) too weak of material used	strong material selection	2	customer survey	3	24							
	armrest does not lock	user is uncomfortable	4	1) not correctly toleranced 2) locking mechanism has foreign objects	strictly define tolerances	6	visual inspection	3	72							
Armrest/ Maintain Appearance	armrest surface deteriorates	appears unattractive	3	1) material is too thin 2) not correct choice of material 3) high friction areas	strong material selection	2	customer survey	5	30							
Headrest/ provide head comfort	headrest is uncomfortable	user is uncomfortable	4	1) bad material 2) headrest not at correct height or angles	ergonomic design considerations	2	customer survey	3	24							
Headrest/ Support User	headrest breaks	user is uncomfortable	4	1) headrest poles too thin 2) too weak of material is used	strong material selection	2	customer survey	6	48							

G3 Engineering

												Action Results				
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**	**Actions Taken**	**Severity**	**Occurence**	**Detection**	**Criticality**
Headrest/ Maintain Appearance	headrest surface deteriorates	appears unattractive	3	1) material is too thin 2) not correct choice of material	strong material selection	2	customer survey	5	30							
Headrest/ Adjustability	headrest does not move	user is uncomfortable	4	1) not correctly toleranced	strictly define tolerances	2	load test	7	56	No longer relevant bc headrest does not adjust	–	–				
	head rest does not lock	user is uncomfortable	4	1) not correctly toleranced 2) locking mechanism has foreign objects	strictly define tolerances	6	load test, visual inspection	3	72	No longer relevant bc headrest does not adjust	–	–				
Seatbelt/Secure user in seat	user is not properly secured	user is unsafe in moving vehicle	9	1) seatbelt attachment to seat is not secured 2) seatbelt itself is defective	fastener shear analysis. Mounting plate strength analysis	2	load inspection	7	126	analysis on seatbelt attachment methods	Phoebe 2/4/21	Hand Calcs on localized bearing failure. Loads given to Articulation/Latch for base calcs. All components are easily inspected	9	1	3	27

Appendix Q: Hand Calculations for the Seatbelt Design



Bearing Analysis For SEAT BELT CONNECTION

3/8" Bolt

$$\sigma_b = \frac{P}{td}$$

$$P = \frac{5680}{2} \text{ lbf} \quad \ldots \text{ for each bolt}$$

$$= \frac{25,265.9}{2} \text{ N}$$

$$= 12,633 \text{ N}$$

$$t = 6.35 \text{ mm}$$

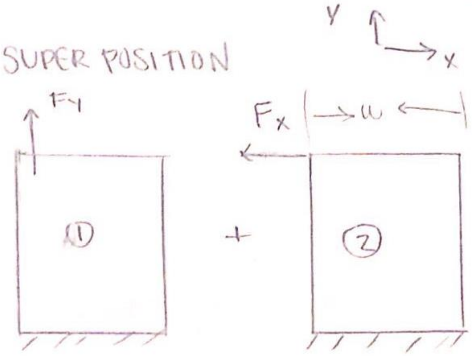
$$d = \frac{3}{8} \text{ in}$$

$$= 9.525 \text{ mm}$$

$$\sigma_b = \frac{12.633 \text{ N}}{(6.35 \text{ mm})(9.525 \text{ mm})}$$

$$\boxed{\sigma_B = 209 \text{ kPa}}$$

SUPER POSITION



$w = .2032 m$

$F_x = F_y = F\cos 45°$

Modulus of Elasticity for steel

$E = 200 \times 10^9 \frac{N}{m^2}$

① Normal stress on base

$A = (.00635 m)(.2032 m)$

$= .00129 m^2$

$\sigma = \frac{F_y}{A} = \frac{25265.9 N \cos 45}{.00129 m^2} = 13.9 MPa$

$\boxed{\sigma = 13.9 MPa}$

② shear stress

$Q = A\bar{y} = A\, w/2$

$= .00129 m^2 (.2032 m)/2$

$= 1.31 \times 10^{-4} m^3$

$V = F_x = 25265.9 N \cos 45 = 17866 N$

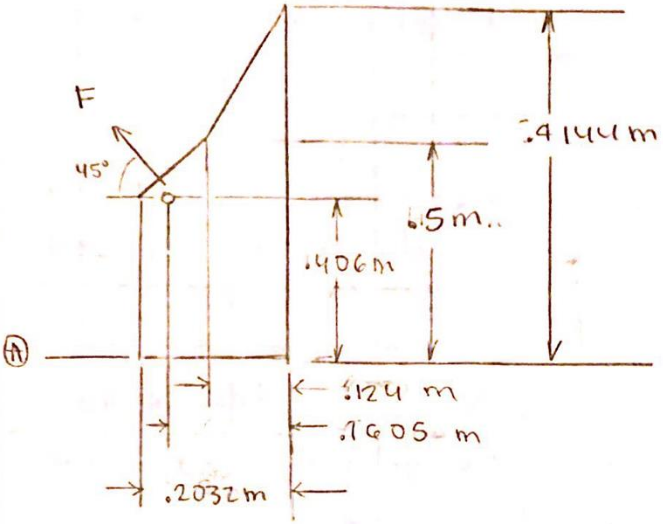
$I = \frac{w^3 t}{12} = \frac{(.2032m)^3(.00635m)}{12} = 4.44 \times 10^6 m^4$

$b = t = .00635 m$

SEAT BELT ANALYSIS

$\frac{1}{4}$" thick steel frame

↳ 6.35 mm = t



ESTIMATED FORCE OF CRASH

95th percentile weight for men in U.S. is 284 lbs

∴ m = 284 lbs

Using approximation

$F = 20 \cdot m$

$= 5,680$ lbf > 3000 lbf for regulations

$= 25,265.9$ N

Assumptions and simplifications

- the frame can be simplified to just the bottom triangular portion
- Datum A is fixed
- vertical component is applied evenly along surface

$$\tau = \frac{VQ}{Ib} = \frac{(17866\ N)(1.31 \times 10^{-4}\ m^3)}{4.44 \times 10^{6}\ m^4\ (.00635\ m)}$$

$$\boxed{\tau = 8.3 \times 10^{-5}\ Pa}$$

MAXIMUM DEFLECTIONS

Along y-axis:

$$\delta = \frac{PL}{EA}$$

$P = F_y = 17866\ N$

$L = .406\ m$

$$\delta = \frac{17866\ N\ (.406\ m)}{200 \times 10^{9}\ \frac{N}{m^2}\ (.00129\ m^2)}$$

$$\boxed{\delta = .028\ mm}$$

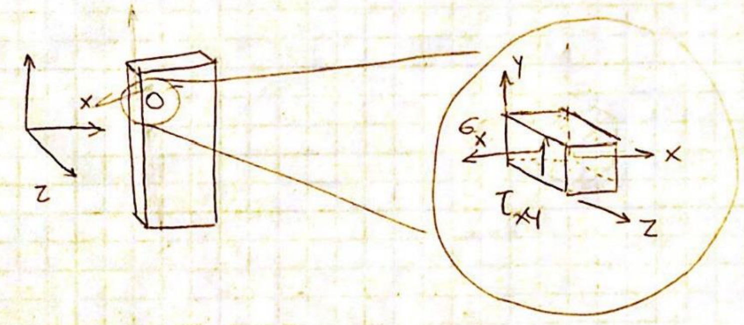
Along x-axis: (maximum)

$$\delta = \frac{PL^3}{3EI}$$

$$= \frac{17866\ N\ (.406\ m)^3}{200 \times 10^{9}\ \frac{N}{m^2}\ (4.44 \times 10^{6}\ m^4)}$$

$$\boxed{\delta = 1.35 \times 10^{-12}\ mm}$$

SEAT BELT FAILURE ANALYSIS



Von mises

$$\sigma_v = \sqrt{.5\left[(\sigma_x - \cancel{\sigma_y})^2 + (\cancel{\sigma_y} - \sigma_z)^2 + (\cancel{\sigma_z} - \sigma_x)^2 + 3(\tau_{xy}^2 + \cancel{\tau_{yz}}^2 + \cancel{\tau_{zx}}^2)\right.}$$

$\sigma_x = 13.4$ MPa

$\tau_{xy} = 8.3 \times 10^{-5}$ Psi

$\sigma_v = \sqrt{(13.9 \times 10^6) + 3(8.3 \times 10^{-5})}$

$\sigma_v = 3728.3$ Pa

Failure stress of steel (minimum)

$\sigma_f = 300$ MPa

$\sigma_v < \sigma_f$ ✓

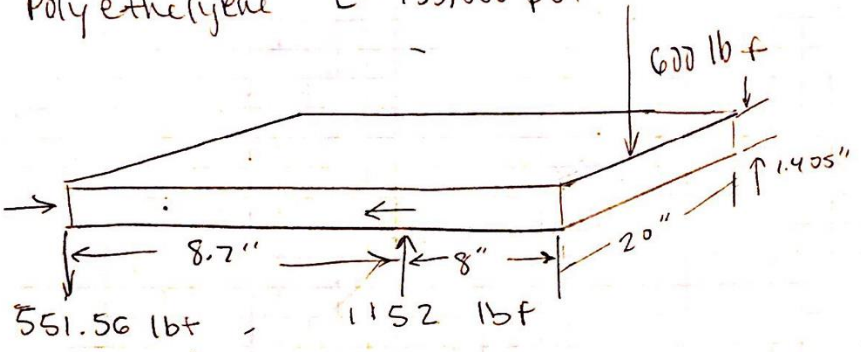
failure of seatbelt wont happen happen in event of crash

Appendix R: Hand Calculations for the Seat Tip Load

Seat Displacement @ tip

* modelled as canteliver beam

Polyethelyene $E = 155{,}000$ psi

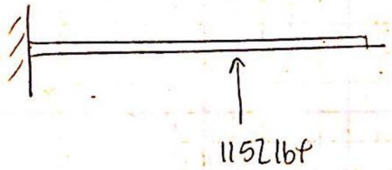


Super position:

$$\delta_{end1} = \frac{Pl^3}{3EI} = \frac{600lbf(16.7")^3}{3(155\times10^3 psi)(4.62 in^4)}$$

$$\delta_{end1} = 1.3"$$

+



$$y(16.7)_{end2} = \frac{Pa^2}{6EI}(3x-a)$$

$$= \frac{1152lbf\,(8.7")^2}{6(155\times10^3 psi)(4.62 in^4)}(3\cdot16.7"-8.7")$$

$$\delta_{end2} = -.84"$$

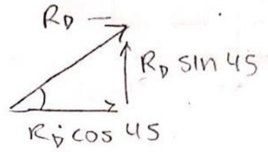
$$\delta_{end} = \delta_{end2} + \delta_{end1}$$

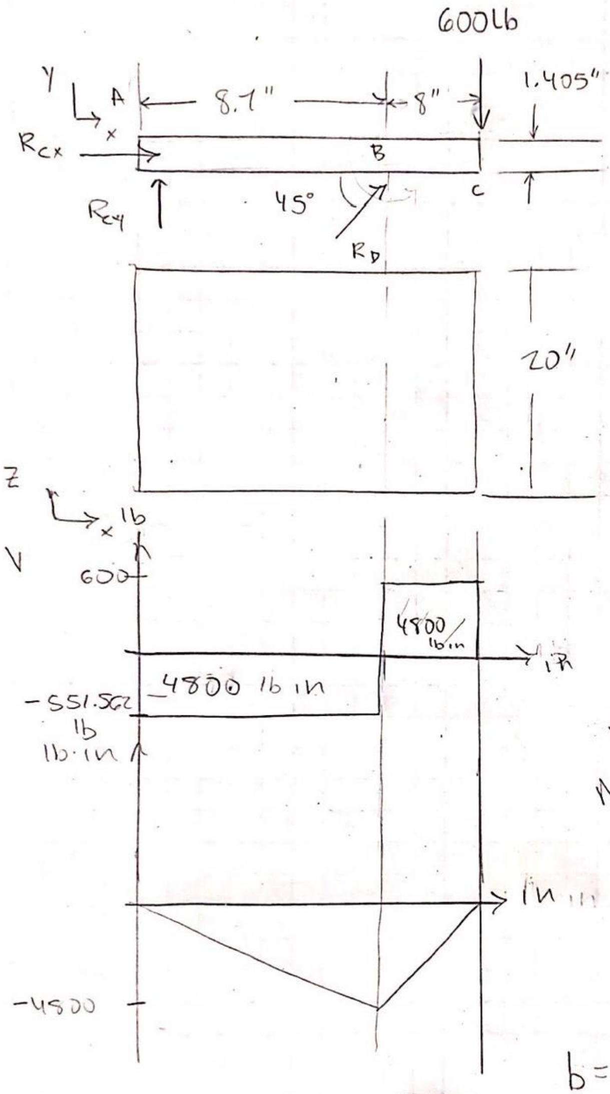
$$= 1.3" - .84"$$

$$\boxed{\delta_{end} = .4598"}$$

displacement at end of seat (downwards) for 600lb load (@ end)

SEAT ANALYSIS





$\Sigma F_x = 0$

$R_{cx} = -R_D \cos 45$

$\Sigma F_y = 0$

$600lb - R_D \sin 45 - R_{cy} = 0$

$\circlearrowleft^{+} \Sigma M_A = 0$

$8.7'' R_D \sin 45 = 600lb(16.7'')$

$R_D = 1628.8 lb$

$R_{cy} = 600 - R_D \sin 45$

$= -551.562 lb$

$V_{max} = 600lb$

$M_{max} = -4800 lb\,in$

@ $x = 8.7 in$

$b = 20''$

$h = 1.405''$

$Q_{max} = \frac{bh^2}{8}$

$I = \frac{bh^3}{12} = 4.6225 in^4$

$$\tau_{max} = \frac{V_{max}\, Q_{max}}{I\, b}$$

$$= \frac{600lb\, \frac{\cancel{b}h^2}{8}}{\frac{bh^3}{12}\ \cancel{b}}$$

$$= \frac{600lb\, \frac{1}{8}(12)}{bh}$$

$$= \frac{600\ lb\ (12/8)}{20'' \cdot 1.405''}$$

$$\boxed{\tau_{max} = 32.03 \text{ psi}} = \tau_{xy}$$

$$\sigma_{max} = \frac{M_{max}\, c'}{I}$$

$$= \frac{-4800 \text{ lb}\cdot\text{in}\,(1.405/2)\text{in}}{4.6225 \text{ in}^4}$$

$$\boxed{\sigma_{max} = 729.5 \text{ psi}} = \sigma_x$$

von Mises

$$\sigma_v = \sqrt{.5\left[(\sigma_x - \cancelto{0}{\sigma_y})^2 + (\cancelto{0}{\sigma_y} - \cancelto{0}{\sigma_z})^2 + (\cancelto{0}{\sigma_z} - \sigma_x)^2\right]}$$

$$+ \sqrt{3(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)}$$

rest of stresses assumed to be zero

$$= \sqrt{.5[2\sigma_y^2]} + \sqrt{3\tau_{xy}^2}$$

$$= 729.5 \text{ psi} + \sqrt{3}(32.03 \text{ psi})$$

$$\sigma_v = 784.978 \text{ psi}$$

yeild strength for polyethylene

$$\sigma_y = 26 \text{ MPa} = 3770.98 \text{ psi}$$

$$784.978 < 3770.98 \text{ psi} \checkmark$$

$$\sigma_v < \sigma_y$$

Does not fail!

Appendix S: System Team Design Hazard Checklist

PDR Design Hazard Checklist **F72 Configurable Seat System Team**

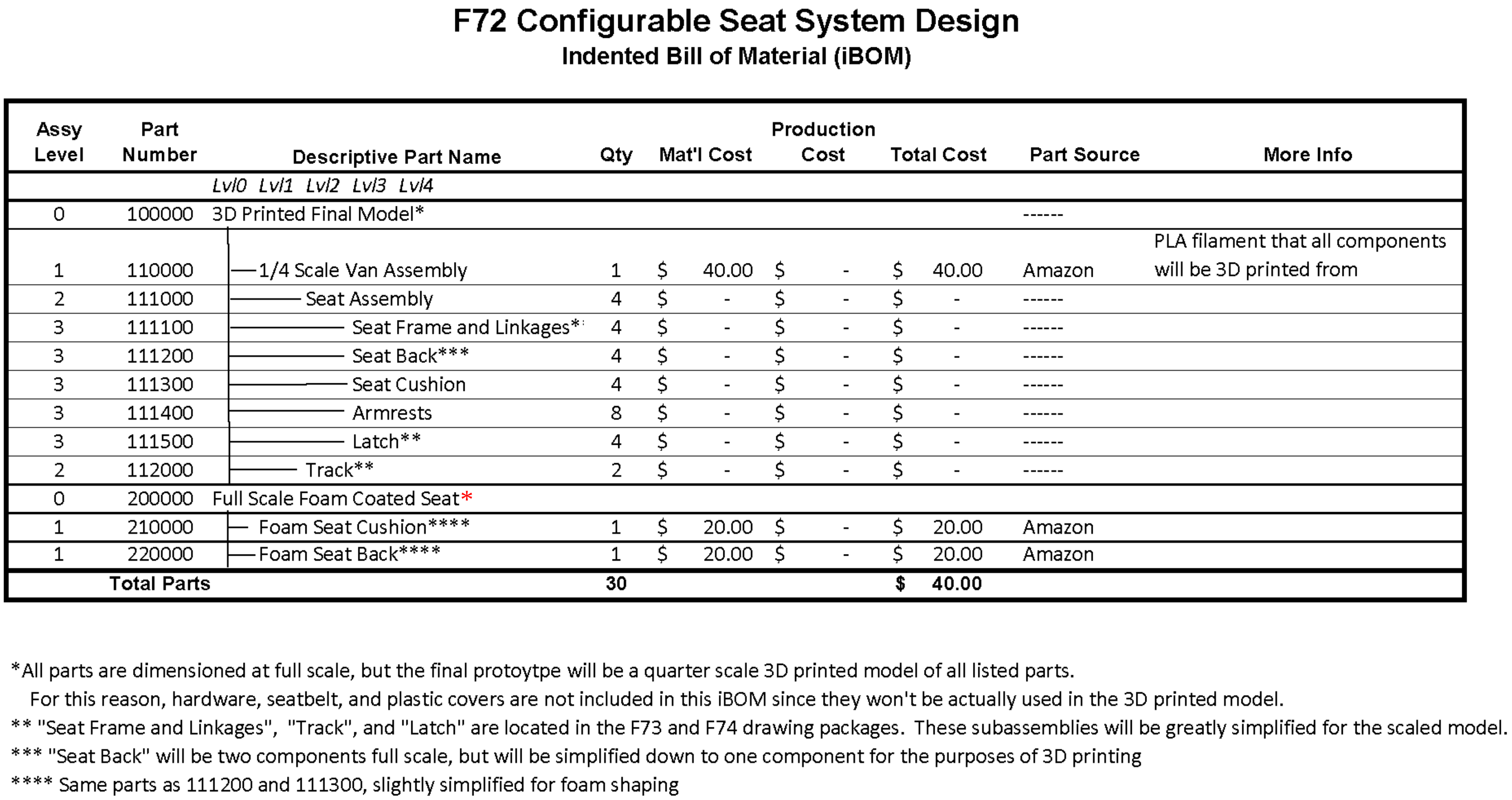
Y	N	
✓		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
	✓	2. Can any part of the design undergo high accelerations/decelerations?
✓		3. Will the system have any large moving masses or large forces?
	✓	4. Will the system produce a projectile?
✓		5. Would it be possible for the system to fall under gravity creating injury?
	✓	6. Will a user be exposed to overhanging weights as part of the design?
✓		7. Will the system have any sharp edges?
	✓	8. Will any part of the electrical systems not be grounded?
	✓	9. Will there be any large batteries or electrical voltage in the system above 40 V?
	✓	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	✓	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
✓		12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	✓	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	✓	14. Can the system generate high levels of noise?
	✓	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
✓		16. Is it possible for the system to be used in an unsafe manner?
	✓	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, on the reverse side add:
(1) a complete description of the hazard,
(2) the corrective action(s) you plan to take to protect the user, and
(3) a date by which the planned actions will be completed.

PDR Design Hazard Checklist **F72 Configurable Seat System Team**

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Pinch Points	Protective plastic covers or encasing most of the moving components within the seat back itself - Completed	1/28	2/4
Large moving Masses	Put a gas spring inside seat to help minimize the force of the seat and dampen any sudden motion - Completed	1/28	1/28
Fall under gravity, or crash scenarios	Analysis on the frame and track system to ensure it will stay in place under a crash scenario. Analyzed for a specific weight, which articulation will aim for. - Completed	1/28	2/9
Sharp Edges	Fillet edges where possible and cover as many exposed metal components as possible. Propose powder coating. - Completed	1/28	2/16
User exerting abnormal effort or physical posture	Again, the addition of the gas spring will help minimize the required input force from the user. Also handles are added for the user to grab onto - Completed	1/28	1/28
Possible for the system to be used in an unsafe manner. If it is not properly locked in place in either position it could be dangerous	Create lock confirmation and safety mechanisms. Current locking mechanisms subject to change for ergonomic concerns.	1/28	2/16

Appendix T: System Team iBOM and Drawing Package



F72 Configurable Seat System Design

Indented Bill of Material (iBOM)

Assy Level	Part Number	Descriptive Part Name	Qty	Mat'l Cost	Production Cost	Total Cost	Part Source	More Info
		Lvl0 Lvl1 Lvl2 Lvl3 Lvl4						
0	100000	3D Printed Final Model*					------	
1	110000	1/4 Scale Van Assembly	1	$ 40.00	$ -	$ 40.00	Amazon	PLA filament that all components will be 3D printed from
2	111000	Seat Assembly	4	$ -	$ -	$ -	------	
3	111100	Seat Frame and Linkages*	4	$ -	$ -	$ -	------	
3	111200	Seat Back***	4	$ -	$ -	$ -	------	
3	111300	Seat Cushion	4	$ -	$ -	$ -	------	
3	111400	Armrests	8	$ -	$ -	$ -	------	
3	111500	Latch**	4	$ -	$ -	$ -	------	
2	112000	Track**	2	$ -	$ -	$ -	------	
0	200000	Full Scale Foam Coated Seat*						
1	210000	Foam Seat Cushion****	1	$ 20.00	$ -	$ 20.00	Amazon	
1	220000	Foam Seat Back****	1	$ 20.00	$ -	$ 20.00	Amazon	
	Total Parts		**30**			**$ 40.00**		

*All parts are dimensioned at full scale, but the final protoytpe will be a quarter scale 3D printed model of all listed parts.
For this reason, hardware, seatbelt, and plastic covers are not included in this iBOM since they won't be actually used in the 3D printed model.

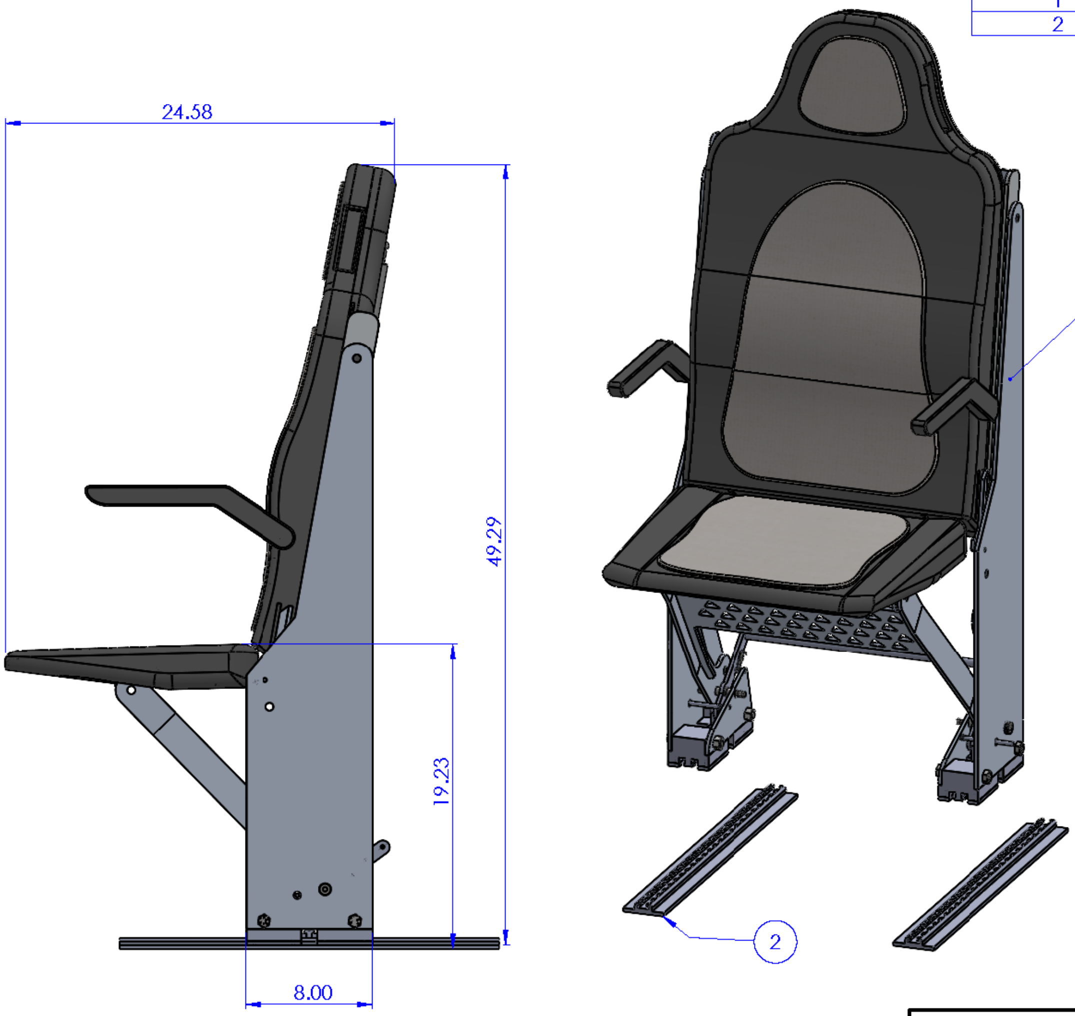
** "Seat Frame and Linkages", "Track", and "Latch" are located in the F73 and F74 drawing packages. These subassemblies will be greatly simplified for the scaled model.

*** "Seat Back" will be two components full scale, but will be simplified down to one component for the purposes of 3D printing

**** Same parts as 111200 and 111300, slightly simplified for foam shaping

*Manufacturing was not completed on the full scale foam seat in lieu of grant proposal, hence Full scale foam components were omitted from the IBOM.

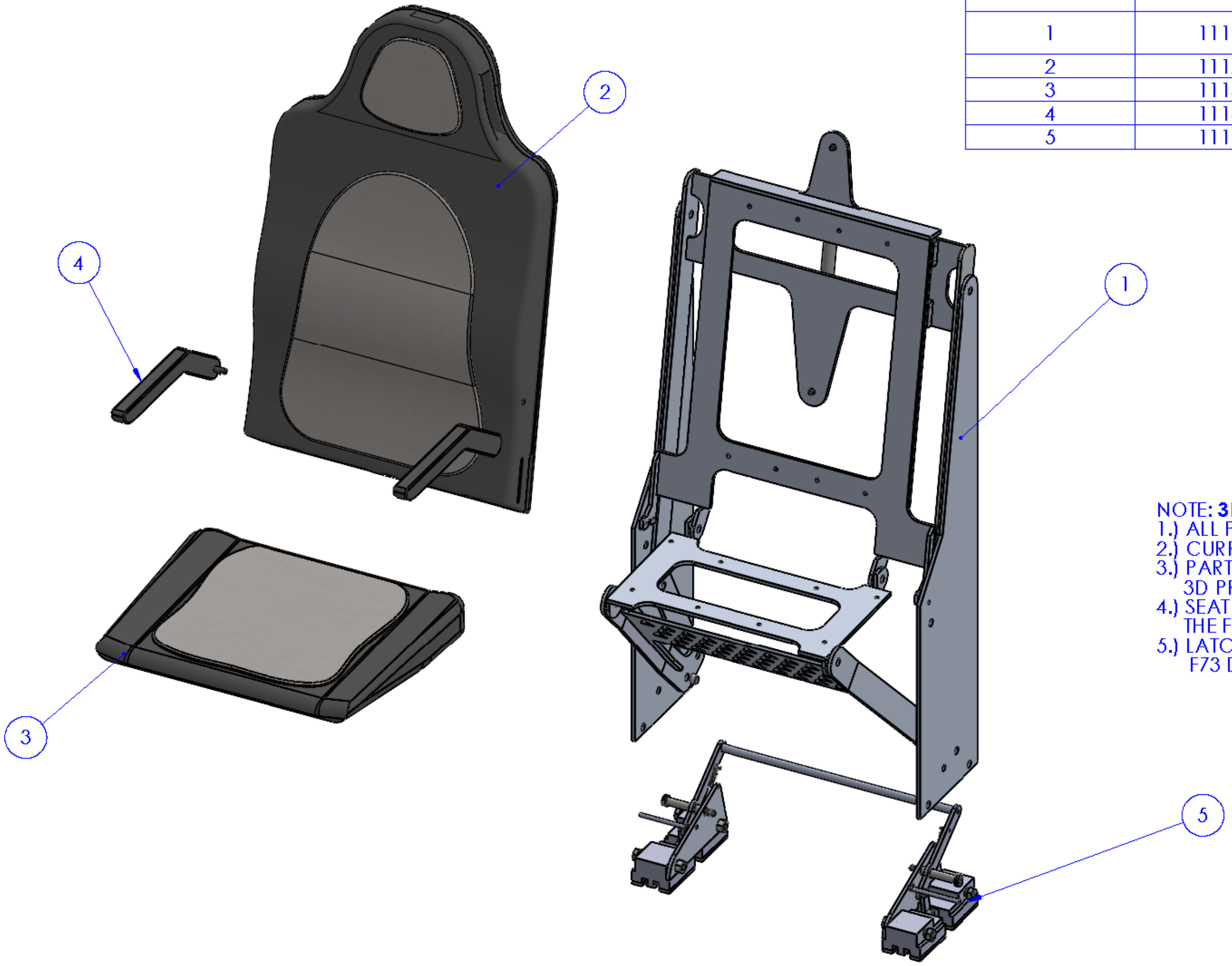
ITEM NUMBER	PART NUMBER	DESCRIPTION	QUANTITY
1	111000	SEAT ASSEMBLY	4
2	112000	TRACK	2



NOTE: **3D PRINTED PART**
1.) ALL PARTS WILL BE SIMPLIFIED FOR 3D PRINTING
2.) CURRENT DIMENSIONS ARE FOR A FULL SCALE MODEL
3.) PART WILL BE 3D PRINT AT 1/4 SCALE.
3D PRINTER TOLERANCES WILL BE ACCEPTABLE
4.) THE VAN ASSEMBLY WILL HAVE 4 OF THESE SEAT ASSEMBLIES ALL ON TWO SHARED TRACKS
5.) TRACK DRAWINGS ARE IN THE F73 DRAWING PACKAGE

Cal Poly Mechanical Engineering
ME 429 - WINTER 2021
Title: VAN ASSEMBLY
PART #: 110000
Material: PLA
Date: 02/18/21
Scale: 1:7
Drwn. By: DANIEL TURN

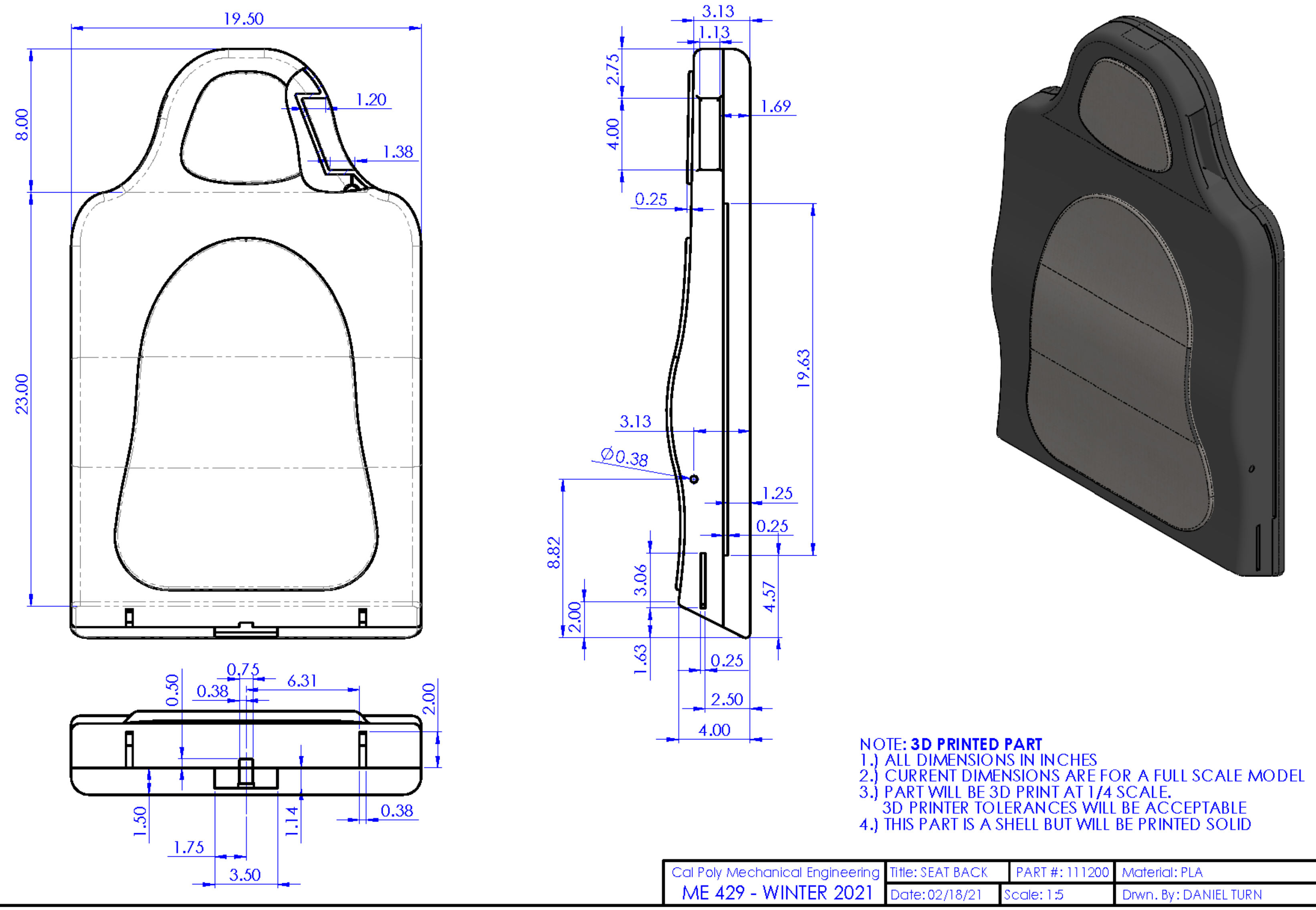
ITEM NUMBER	PART NUMBER	DESCRIPTION	QUANTITY PER SEAT ASSEMBLY
1	111100	SEAT FRAME/LINKAGES	1
2	111200	SEAT BACK	1
3	111300	SEAT CUSHION	1
4	111400	ARMRESTS	2
5	111500	LATCH	1



NOTE: **3D PRINTED PART**

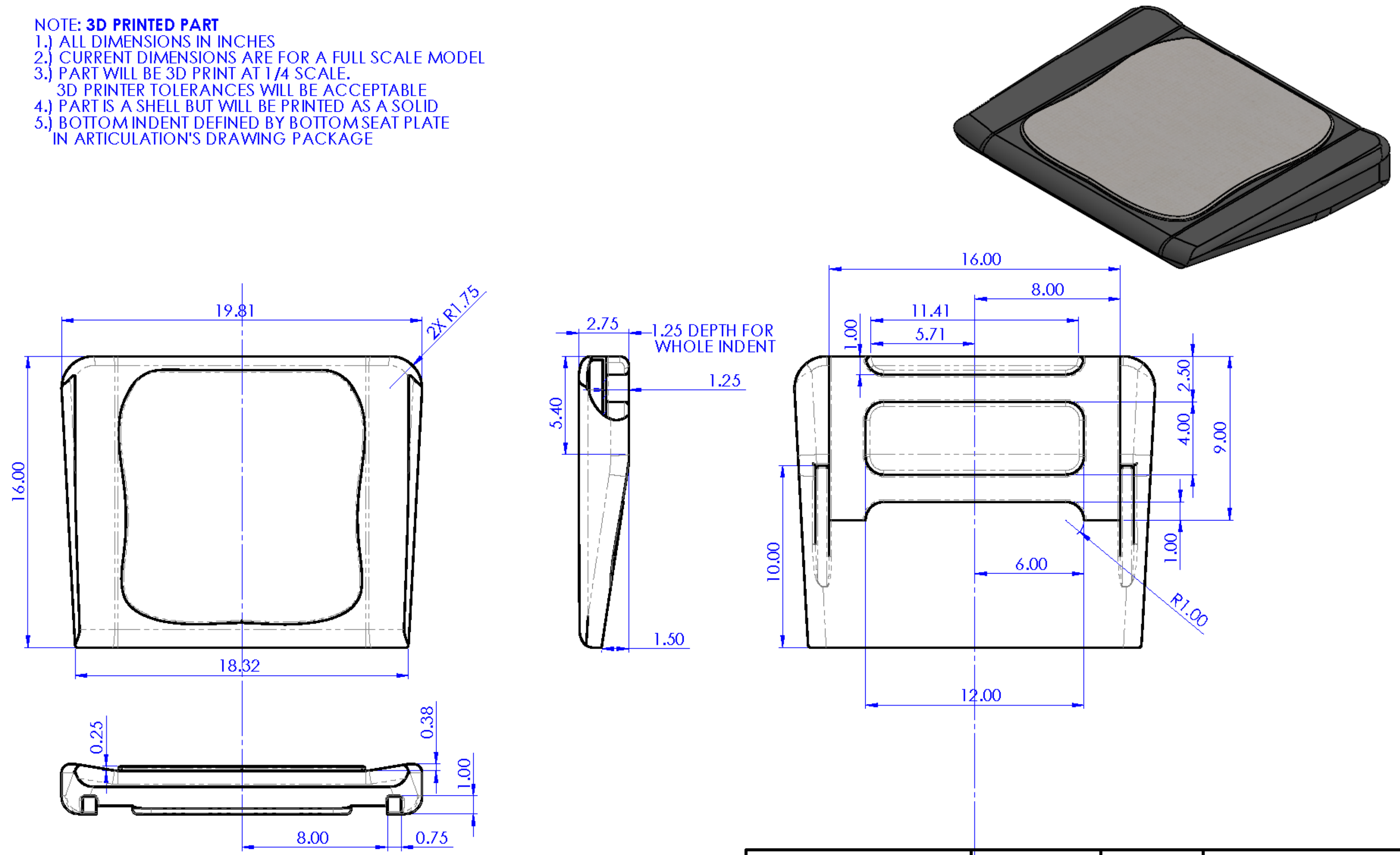
1.) ALL PARTS WILL BE SIMPLIFIED FOR 3D PRINTING
2.) CURRENT DIMENSIONS ARE FOR A FULL SCALE MODEL
3.) PART WILL BE 3D PRINT AT 1/4 SCALE.
3D PRINTER TOLERANCES WILL BE ACCEPTABLE
4.) SEAT FRAME/LINKAGE DRAWINGS ARE LOCATED IN THE F74 DRAWING PACKAGE
5.) LATCH DRAWINGS ARE LOCATED IN THE F73 DRAWING PACKAG

Cal Poly Mechanical Engineering	Title: SEAT ASSEMBLY	PART #: 111000	Material: PLA
ME 429 - WINTER 2021	Date: 02/18/21	Scale: 1:7	Drwn. By: DANIEL TURN



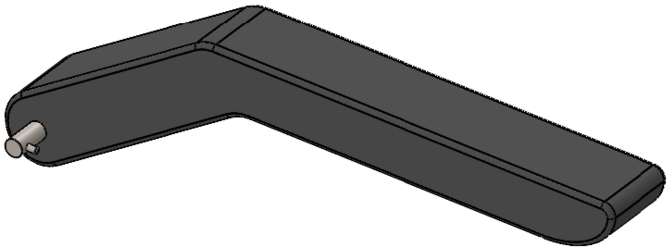
NOTE: **3D PRINTED PART**
1.) ALL DIMENSIONS IN INCHES
2.) CURRENT DIMENSIONS ARE FOR A FULL SCALE MODEL
3.) PART WILL BE 3D PRINT AT 1/4 SCALE.
3D PRINTER TOLERANCES WILL BE ACCEPTABLE
4.) THIS PART IS A SHELL BUT WILL BE PRINTED SOLID

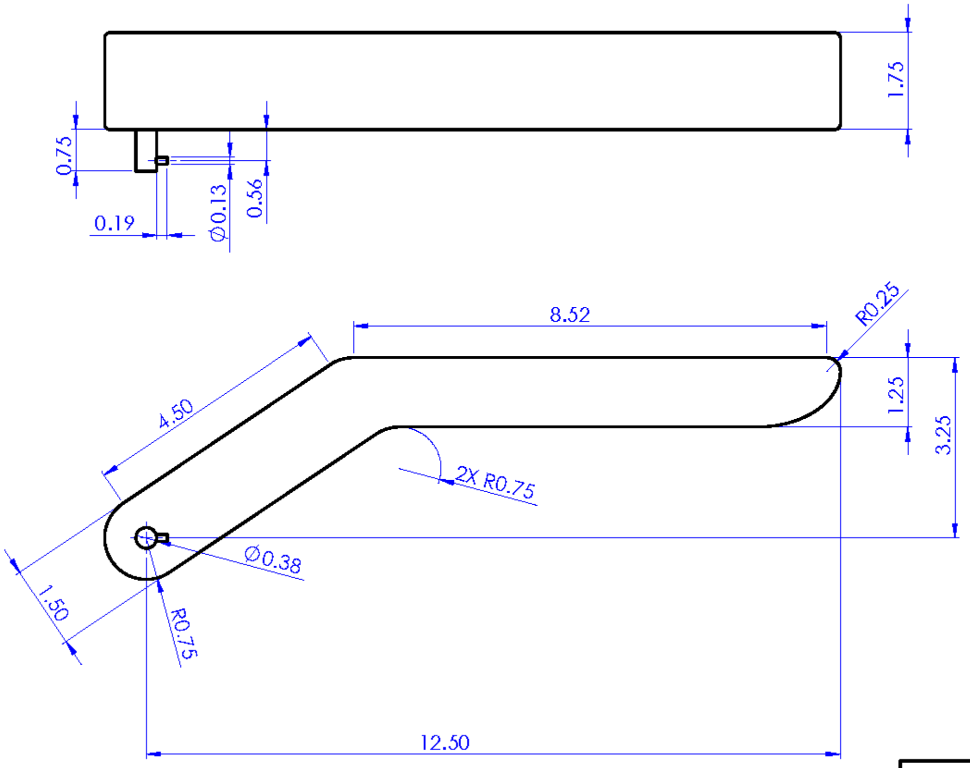
Cal Poly Mechanical Engineering
ME 429 - WINTER 2021
Title: SEAT BACK
Date: 02/18/21
PART #: 111200
Scale: 1:5
Material: PLA
Drwn. By: DANIEL TURN



NOTE: **3D PRINTED PART**
1.) ALL DIMENSIONS IN INCHES
2.) CURRENT DIMENSIONS ARE FOR A FULL SCALE MODEL
3.) PART WILL BE 3D PRINT AT 1/4 SCALE.
3D PRINTER TOLERANCES WILL BE ACCEPTABLE
4.) PART IS A SHELL BUT WILL BE PRINTED AS A SOLID
5.) BOTTOM INDENT DEFINED BY BOTTOM SEAT PLATE
IN ARTICULATION'S DRAWING PACKAGE

Cal Poly Mechanical Engineering	Title: SEAT CUSHION	PART #: 111300	Material: PLA
ME 429 - WINTER 2021	Date: 02/18/21	Scale: 1:5	Drwn. By: DANIEL TURN





NOTE: **3D PRINTED PART**

1.) ALL DIMENSIONS IN INCHES
2.) CURRENT DIMENSIONS ARE FOR A FULL SCALE MODEL
3.) PART WILL BE 3D PRINT AT 1/4 SCALE.
3D PRINTER TOLERANCES WILL BE ACCEPTABLE
4.) THIS PART HAS A LEFT AND RIGHT. THE RIGHT IS CURRENTLY SHOWN.
THE LEFT HAS THE KNOB ON THE OTHER SIDE

Cal Poly Mechanical Engineering	Title: ARMRESTS	PART #: 111400	Material: PLA
ME 429 - WINTER 2021	Date:02/10/21	Scale: 1:2	Drwn. By: DANIEL TURN

Appendix U: System Team Project Budget

Materials Budget for Senior Project

Title of Senior Project: F72, Configurable Seating System

Team members: Audrey Trejo, Phoebe Zeiss, Daniel Turn, Steven Kam

Designated Team Treasurer: Phoebe Zeiss

Faculty Advisor: Sarah Harding

Sponsor: Ritch Hollingsworth, Joe Mello

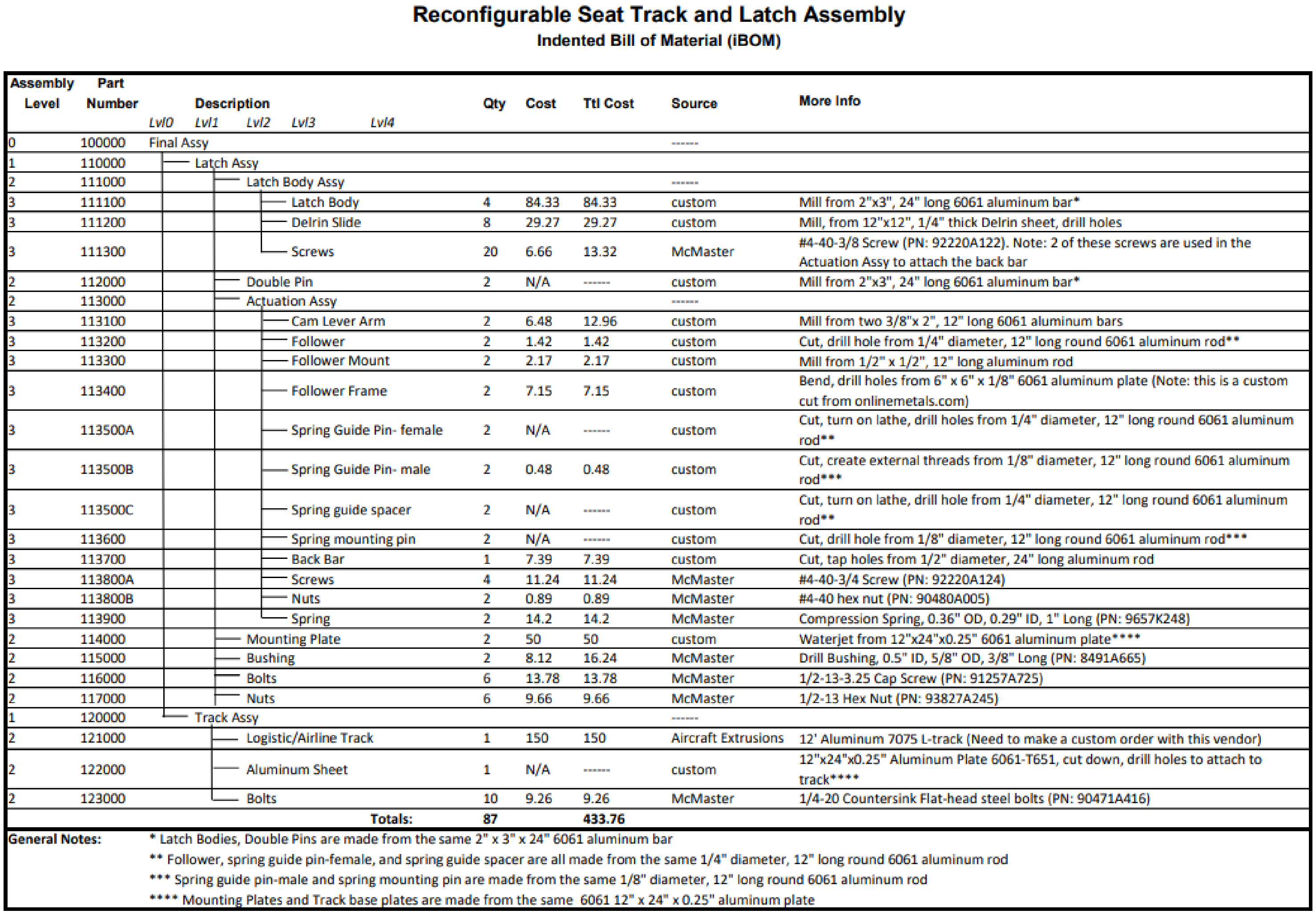
Quarter and year project began: Fall 2020

Materials budget given for this project: **$1,000.00**

Date purchased	Vendor	Description of items purchased	Transaction amount
01/26/21	Summit Racing	Plastic Racing Seat	$72.91
TBD	Amazon	PLA Filament, silver 1.75 mm, 1 kg spool, AmazonBasics brand (x2)	$ 45.98
TBD	Amazon	Sandpaper, 18 pack, assorted grit	$ 5.85
TBD	Amazon	Epoxy Coating: ProMarine Supplies Art Resin, 16 Oz.	$ 24.97
TBD	Amazon	Glue: Gorilla 102433 XL Super Glue Gel, 1-Pack, Clear	$ 6.84
TBD	Amazon	EPS Foam: Silverlake Large Craft Foam Block - 11x17x7 EPS (x2)	$ 39.90
TBD	Amazon	Electric Foam Cutting Tools: Hot Knife Foam Cutter Hot Wire, 3 Pack	$ 27.99
TBD	Hot Wire Foam Factory	Plastic Coating: Styroplast #024	$ 29.95
TBD	Amazon	Glue: 3M Hi-Strength 90 Spray Adhesive	$ 18.95
		Total expenses:	$ 273.34

budget:	$	1,000.00
actual expenses:	$	273.34
remaining balance:	$	726.66

Appendix V: Track and Latch Team Indented Bill of Materials (IBOM)



Reconfigurable Seat Track and Latch Assembly

Indented Bill of Material (iBOM)

Assembly Level	Part Number	Description					Qty	Cost	Ttl Cost	Source	More Info
		Lvl0	*Lvl1*	*Lvl2*	*Lvl3*	*Lvl4*					
0	100000	Final Assy								------	
1	110000		Latch Assy								
2	111000			Latch Body Assy						------	
3	111100				Latch Body		4	84.33	84.33	custom	Mill from 2"x3", 24" long 6061 aluminum bar*
3	111200				Delrin Slide		8	29.27	29.27	custom	Mill, from 12"x12", 1/4" thick Delrin sheet, drill holes
3	111300				Screws		20	6.66	13.32	McMaster	#4-40-3/8 Screw (PN: 92220A122). Note: 2 of these screws are used in the Actuation Assy to attach the back bar
2	112000			Double Pin			2	N/A	------	custom	Mill from 2"x3", 24" long 6061 aluminum bar*
2	113000			Actuation Assy						------	
3	113100				Cam Lever Arm		2	6.48	12.96	custom	Mill from two 3/8"x 2", 12" long 6061 aluminum bars
3	113200				Follower		2	1.42	1.42	custom	Cut, drill hole from 1/4" diameter, 12" long round 6061 aluminum rod**
3	113300				Follower Mount		2	2.17	2.17	custom	Mill from 1/2" x 1/2", 12" long aluminum rod
3	113400				Follower Frame		2	7.15	7.15	custom	Bend, drill holes from 6" x 6" x 1/8" 6061 aluminum plate (Note: this is a custom cut from onlinemetals.com)
3	113500A				Spring Guide Pin- female		2	N/A	------	custom	Cut, turn on lathe, drill holes from 1/4" diameter, 12" long round 6061 aluminum rod**
3	113500B				Spring Guide Pin- male		2	0.48	0.48	custom	Cut, create external threads from 1/8" diameter, 12" long round 6061 aluminum rod***
3	113500C				Spring guide spacer		2	N/A	------	custom	Cut, turn on lathe, drill hole from 1/4" diameter, 12" long round 6061 aluminum rod**
3	113600				Spring mounting pin		2	N/A	------	custom	Cut, drill hole from 1/8" diameter, 12" long round 6061 aluminum rod***
3	113700				Back Bar		1	7.39	7.39	custom	Cut, tap holes from 1/2" diameter, 24" long aluminum rod
3	113800A				Screws		4	11.24	11.24	McMaster	#4-40-3/4 Screw (PN: 92220A124)
3	113800B				Nuts		2	0.89	0.89	McMaster	#4-40 hex nut (PN: 90480A005)
3	113900				Spring		2	14.2	14.2	McMaster	Compression Spring, 0.36" OD, 0.29" ID, 1" Long (PN: 9657K248)
2	114000			Mounting Plate			2	50	50	custom	Waterjet from 12"x24"x0.25" 6061 aluminum plate****
2	115000			Bushing			2	8.12	16.24	McMaster	Drill Bushing, 0.5" ID, 5/8" OD, 3/8" Long (PN: 8491A665)
2	116000			Bolts			6	13.78	13.78	McMaster	1/2-13-3.25 Cap Screw (PN: 91257A725)
2	117000			Nuts			6	9.66	9.66	McMaster	1/2-13 Hex Nut (PN: 93827A245)
1	120000		Track Assy							------	
2	121000			Logistic/Airline Track			1	150	150	Aircraft Extrusions	12' Aluminum 7075 L-track (Need to make a custom order with this vendor)
2	122000			Aluminum Sheet			1	N/A	------	custom	12"x24"x0.25" Aluminum Plate 6061-T651, cut down, drill holes to attach to track****
2	123000			Bolts			10	9.26	9.26	McMaster	1/4-20 Countersink Flat-head steel bolts (PN: 90471A416)
						Totals:	**87**		**433.76**		

General Notes:

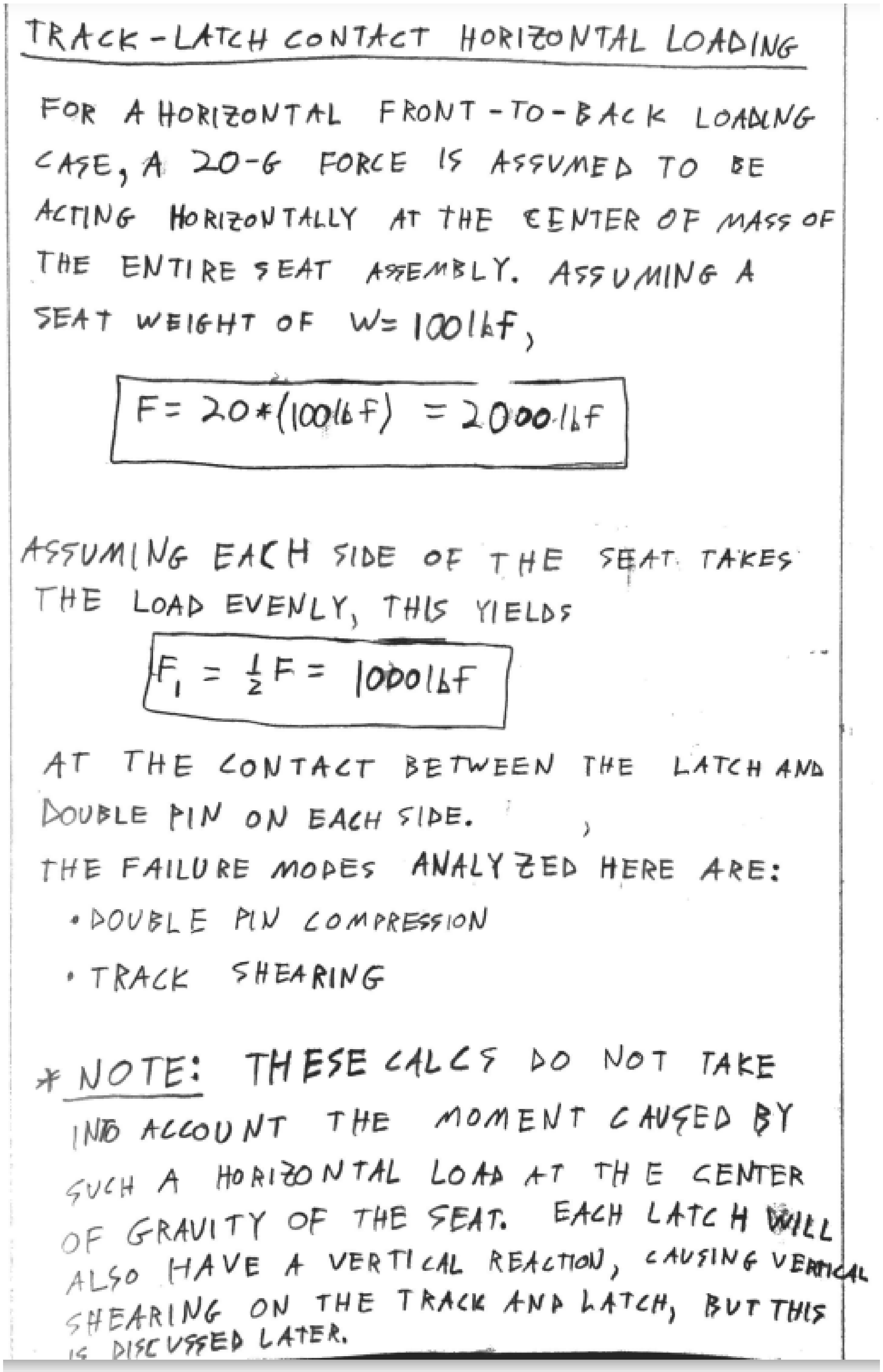
* Latch Bodies, Double Pins are made from the same 2" x 3" x 24" 6061 aluminum bar

** Follower, spring guide pin-female, and spring guide spacer are all made from the same 1/4" diameter, 12" long round 6061 aluminum rod

*** Spring guide pin-male and spring mounting pin are made from the same 1/8" diameter, 12" long round 6061 aluminum rod

**** Mounting Plates and Track base plates are made from the same 6061 12" x 24" x 0.25" aluminum plate

Appendix W: Track and Latch Team Hand Calculations



TRACK-LATCH CONTACT HORIZONTAL LOADING

FOR A HORIZONTAL FRONT-TO-BACK LOADING CASE, A 20-G FORCE IS ASSUMED TO BE ACTING HORIZONTALLY AT THE CENTER OF MASS OF THE ENTIRE SEAT ASSEMBLY. ASSUMING A SEAT WEIGHT OF W= 100lbF,

$$\boxed{F = 20 * (100 \text{lbF}) = 2000 \text{lbF}}$$

ASSUMING EACH SIDE OF THE SEAT TAKES THE LOAD EVENLY, THIS YIELDS

$$\boxed{F_1 = \frac{1}{2} F = 1000 \text{lbF}}$$

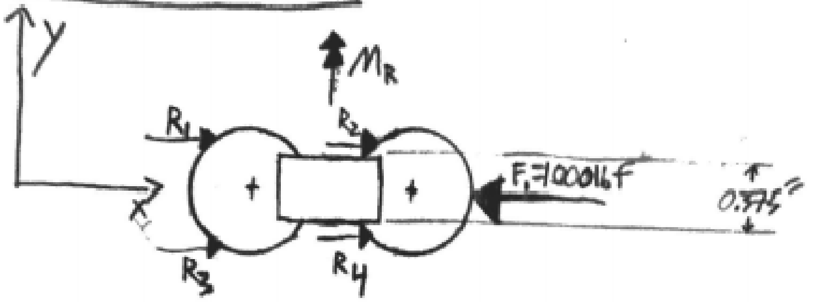
AT THE CONTACT BETWEEN THE LATCH AND DOUBLE PIN ON EACH SIDE.

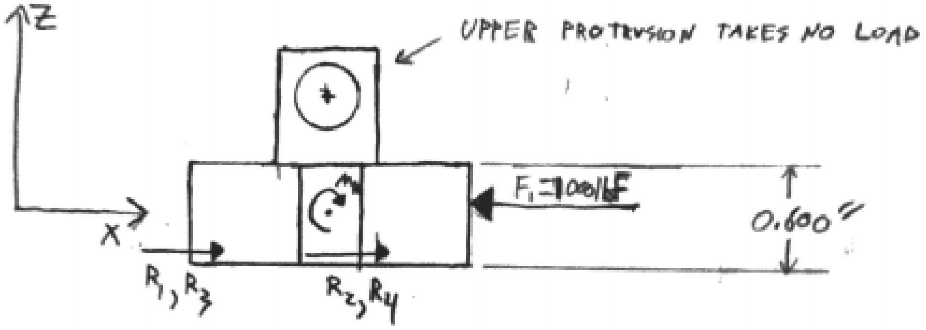
THE FAILURE MODES ANALYZED HERE ARE:

- DOUBLE PIN COMPRESSION
- TRACK SHEARING

* NOTE: THESE CALCS DO NOT TAKE INTO ACCOUNT THE MOMENT CAUSED BY SUCH A HORIZONTAL LOAD AT THE CENTER OF GRAVITY OF THE SEAT. EACH LATCH WILL ALSO HAVE A VERTICAL REACTION, CAUSING VERTICAL SHEARING ON THE TRACK AND LATCH, BUT THIS IS DISCUSSED LATER.

DOUBLE PIN FBD:





*$R_1 - R_4$ ARE THE REACTIONS FROM THE TRACK.

ASSUMING $R_1 = R_2 = R_3 = R_4 = R$:

$$\Sigma F_x = 0$$

$$R_1 + R_2 + R_3 + R_4 - F_1 = 0$$

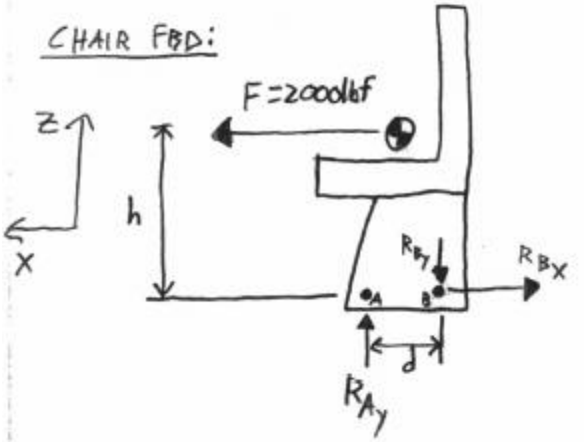
$$4R = F_1$$

$$\boxed{R = 250 \text{lbF}}$$

* THIS ANALYSIS ASSUMES THE PIN CAN TRANSLATE ALONG THE Z-AXIS, BUT IS CONSTRAINED FROM ROTATING ABOUT THE Y-AXIS. M_R IS THE REACTION MOMENT IMPOSED ON THE DOUBLE PIN FROM THE LATCH GEOMETRY.

NOW THAT THE HORIZONTAL LOAD HAS BEEN ANALYZED, THE ANALYSIS BELOW CONSIDERS THE VERTICAL REACTIONS IN EACH LATCH UNDER A 20G HORIZONTAL FORCE (F=2400lbf)

CHAIR FBD:



$\Sigma F_x = 0$

$R_{B_x} = F = 2000$ lbf

(SEE ANALYSIS ABOVE)

$h = 14.5$ in

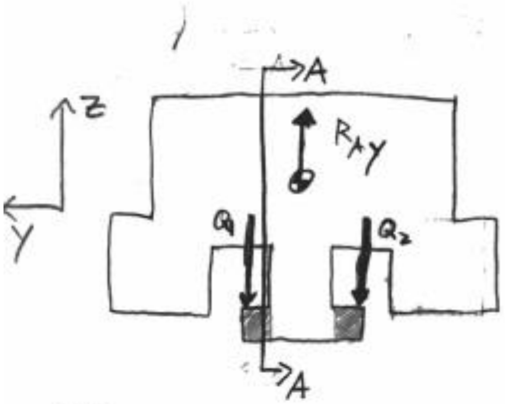
$d = 5.75$ in

$$\Sigma M_A = 0 \Rightarrow Fh - R_{B_y} d = 0$$

$$R_{B_y} = \frac{Fh}{d} = \frac{(2000\,\text{lbF})(14.5\,\text{in})}{(5.75\,\text{in})} = \underline{5{,}043.5\,\text{lbF}}$$

$$\Sigma F_y = 0 \Rightarrow R_{A_y} = R_{B_y} \Rightarrow \boxed{R_{A_y} = 5{,}043.5\,\text{lbF}}$$

DUE TO LATCH GEOMETRY, THE LATCH AT POINT "A" DISTRIBUTES THE VERTICAL REACTION EVENLY ACROSS BOTH OF THE SHADED FLANGES BELOW:

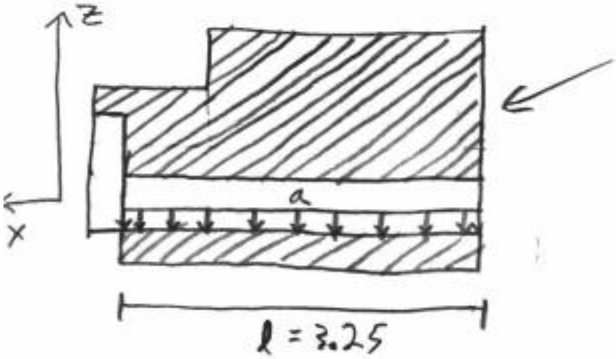


$\Sigma F_y = 0 \quad ; \; Q_1 = Q_2 = Q$

$R_{Ay} = 2Q$

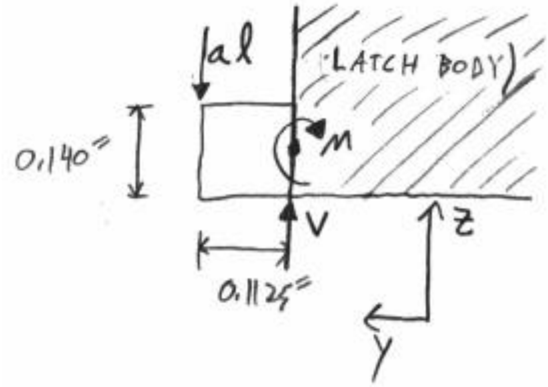
$Q = \frac{R_{Ay}}{2}$

$\boxed{Q = 2{,}521 \text{ lbF}}$



$a = \frac{Q}{l} = 775.92 \text{ lbf/in}$

MODELING THE LATCH PROFILE ON WHICH "a" ACTS AS A CANTILEVER. WITH A RIGID LATCH BODY:



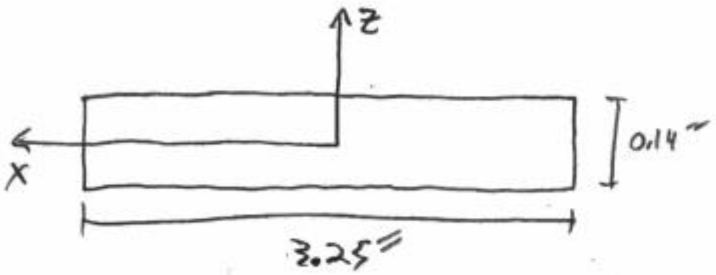
$M = al(0.1125)$

$M = Q(0.1125")$

$\underline{M = 283.7 \text{ lbf-in}}$

$\underline{V = Q = 2{,}521 \text{ lbf}}$

FOR THE MODELED CANTILEVER, THE CROSS-SECTION IS:



$A = (0.14")(3.25") = 0.455\ in^2$

$I = \frac{1}{12}(3.25")(0.14")^3 = 7.432 \times 10^{-4}\ in^4$

$c = 0.14"/2 = 0.07\ in$

$$\sigma_{BENDING} = \frac{Mc}{I} = \frac{(283.7)(0.07)}{(7.4 \times 10^{-4})} = \boxed{26,720\ ksi}$$

$$\sigma_{SHEAR} = \frac{3V}{2A} = \frac{3(2,521)}{2(0.455)} = \boxed{8.313\ ksi}$$

COMBINED STRESS; LATCH:

$$\sigma' = \sqrt{\sigma_{BENDING}^2 + 3\sigma_{SHEAR}^2} = \boxed{30,353.35\ psi}$$

$$\sigma' = \boxed{30.35\ ksi}$$

FOR 1018 CD STEEL LATCH, $S_y = 54\ ksi$,

SO $\eta_d = \frac{54}{30.35} = \boxed{1.78}$

NEXT, VERTICAL TRACK STRIPPING WOULD BE ANALYZED, BUT THE SELECTED TRACK FROM AIRCRAFT EXTRUSIONS CO. HAS A VERTICAL LOAD RATING OF 6000 lbF, WHICH IS GREATER THAN THE MAX LOAD $R_B = 5043\ lbF$

Configurable Seat Loading Cases

Descended from Master Thesis FEA work by Zach Witchtaker

Performed By: Kai Quizon
Checked By: Jacob Winkler

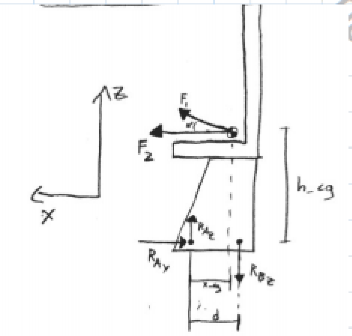
All cases follow previous calculations that determine the critical section to be individual track teeth in vertical shear out. Track teeth are modeled as short cantilever beams in bending.

In this case, a load equal to 20 times the weight of the seat will be applied at the seats center of gravity in the horizontal direction. A load of 5000 pounds will be applied at the location of the seatbelt interface.

Note: This analysis assumes the seat belt force's line of action passes through the system center of gravity

System Geometry:

$x_{cg} := 4.75\ \boldsymbol{in}$	X coordinate of center of gravity from front of seat base.
$h_{cg} := 20\ \boldsymbol{in}$	Height of center of gravity off track
$d := 8.25\ \boldsymbol{in}$	Distance between bolts attaching vertical containment latches to structure.
$l := 3.75\ \boldsymbol{in}$	Latch length



Applied Loads:

$F_1 := 5000\ \boldsymbol{lbf}$	Seatbelt load
$F_2 := 20 \cdot 63\ \boldsymbol{lbf}$	20 times system weight
$\theta := 10\ \boldsymbol{deg}$	Angle of application of seatbelt load

Now assume the centroid is located evenly between the latches such that each latch pair takes half the applied load:

$$F_1 := 0.5 \cdot F_1$$

$$F_2 := 0.5 \cdot F_2$$

Static Analysis:

Sum of moments about point A:

$$R_{By} := \frac{F_1 \cdot h_{cg} + F_2 \cdot \cos(\theta) \cdot h_{cg} + F_2 \cdot \sin(\theta) \cdot x_{cg}}{d}$$

$$R_{By} = \left(7.628 \cdot 10^3\right)\ \mathbf{lbf}$$

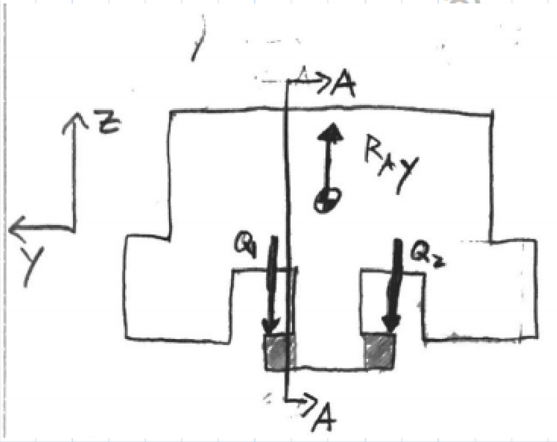
Sum of forces in the y direction:

$$R_{Ay} := F_2 \cdot \sin(\theta) - R_{By}$$

$$R_{Ay} = -7.518 \cdot 10^3\ \mathbf{lbf}$$

We identify the trailing latch as critical (as both latches are symmetric). Analysis proceeds on the trailing latch

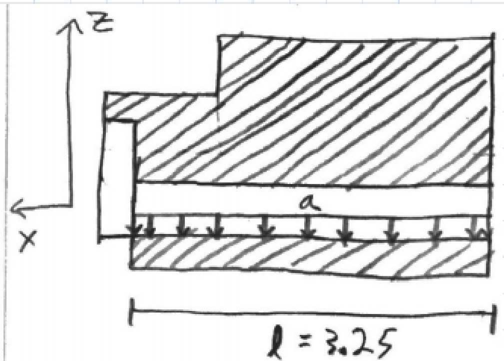
Transferring the load to the mating profile. This assumes that the only contacting surface (only load path) is the mating profile.



Assuming the load is applied along the bolt such that it may be reduced to a single point load above the latch's center of gravity, Q1=Q2=Q

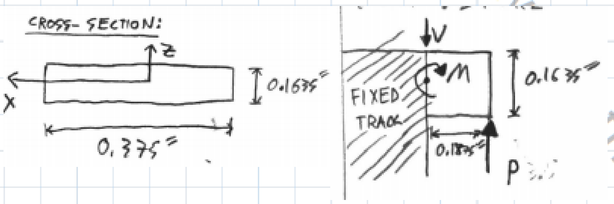
$Q := 0.5 \cdot R_{By}$ $\qquad$ $Q = (3.814 \cdot 10^{3})\ \mathbf{lbf}$

By analyzing the latch as a rigid body, Q may be decomposed into a uniform pressure along the mating profile as shown below in section A-A:



$a := \dfrac{Q}{l}$ $\qquad$ $a = (1.017 \cdot 10^{3})\ \dfrac{\mathbf{lbf}}{\mathbf{in}}$

Now resolve into a single tip load on a single tooth:



Tooth width:
$w_t := 0.375\ \mathbf{in}$

Tooth length:
$l_t := 0.1875\ \mathbf{in}$

Tooth height:
$h_t := 0.1635\ \mathbf{in}$

$F_t := a \cdot w_t$ $\qquad$ $F_t = 381.383\ \mathbf{lbf}$

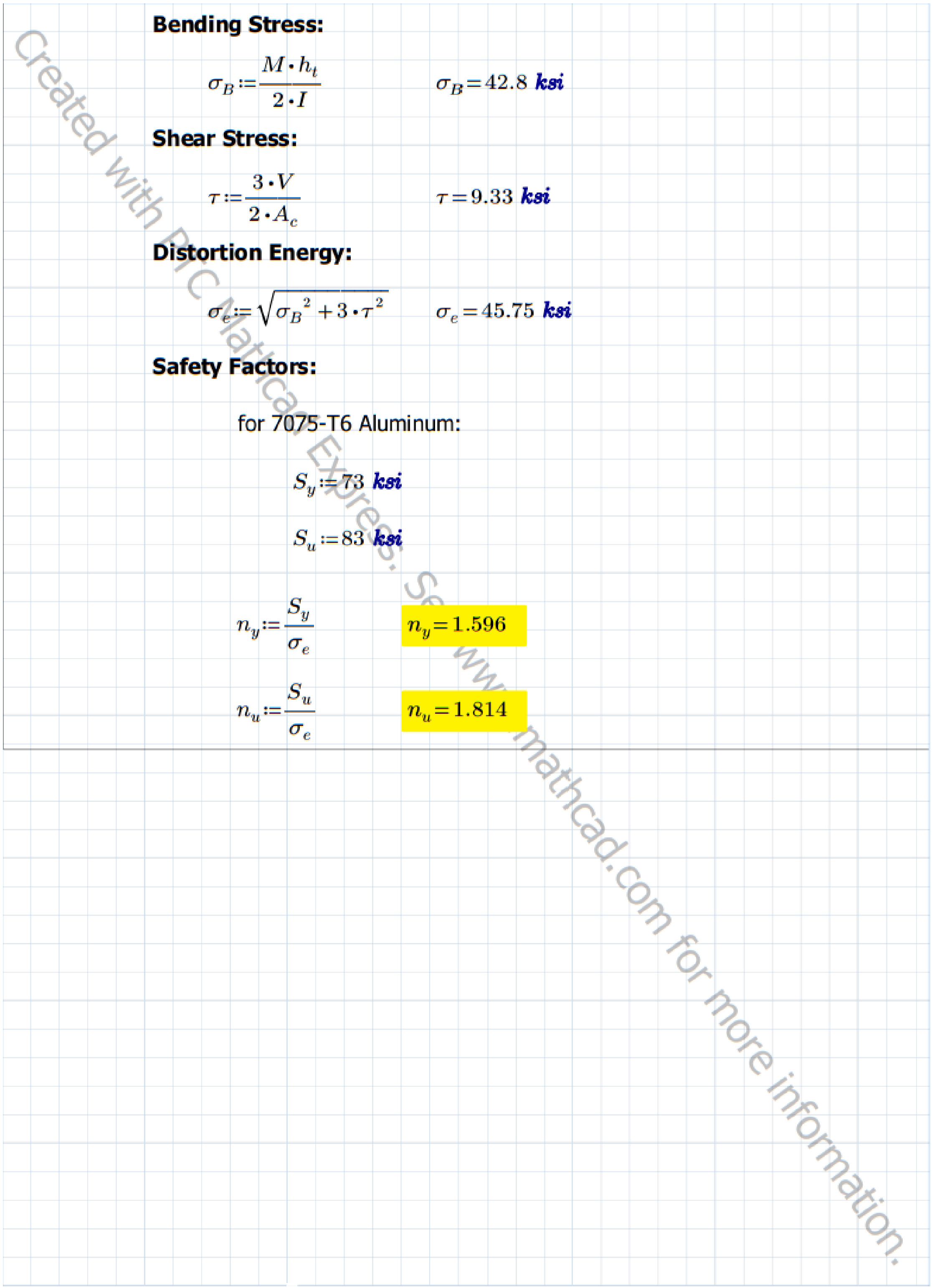
$V := F_t$ $\qquad$ $M := F_t \cdot l_t$

Stress Analysis:

Section Properties:

$A_c := w_t \cdot h_t$ $\qquad$ $A_c = 0.061\ \mathbf{in}^2$ $\qquad$ Cross sectional area of tooth

$I := \dfrac{1}{12}\, w_t \cdot h_t^{\,3}$ $\qquad$ $I = (1.366 \cdot 10^{-4})\ \mathbf{in}^4$ $\qquad$ Second moment of area



Bending Stress:

$$\sigma_B := \frac{M \cdot h_t}{2 \cdot I} \qquad \sigma_B = 42.8\ \mathbf{ksi}$$

Shear Stress:

$$\tau := \frac{3 \cdot V}{2 \cdot A_c} \qquad \tau = 9.33\ \mathbf{ksi}$$

Distortion Energy:

$$\sigma_e := \sqrt{{\sigma_B}^2 + 3 \cdot \tau^2} \qquad \sigma_e = 45.75\ \mathbf{ksi}$$

Safety Factors:

for 7075-T6 Aluminum:

$$S_y := 73\ \mathbf{ksi}$$

$$S_u := 83\ \mathbf{ksi}$$

$$n_y := \frac{S_y}{\sigma_e} \qquad n_y = 1.596$$

$$n_u := \frac{S_u}{\sigma_e} \qquad n_u = 1.814$$

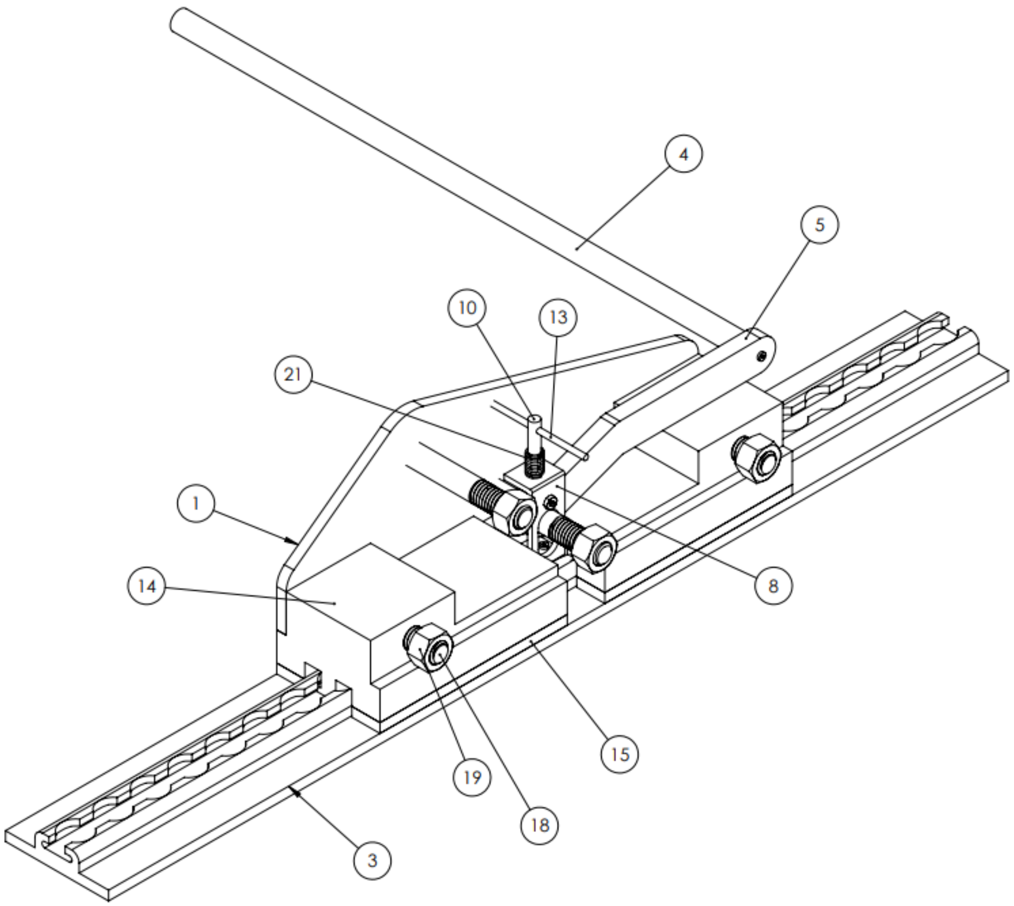
Appendix X. Track and Latch Team Drawing Package

Manufactured Components

- **100000 –** Full Track and Latch Assembly
    - **110000** – Latch Assembly [Drawing Not Shown]
        - **111000** – Latch Body Assembly
            - **111100** – Latch
            - **111200** – Delrin Slide
        - **112000** – Double Pin
        - **113000** – Actuation Assembly
            - **113100** – Cam Lever
            - **113200** – Follower
            - **113300** – Follower Mount
            - **113400 –** Follower Frame
            - **113500 –** Spring Guide Pins
            - **113600 –** Spring Mounting Pin
            - **113700** – Back Bar
        - **114000** – Mounting Plate
    - **120000** – Track Assembly [Drawing Not Shown]

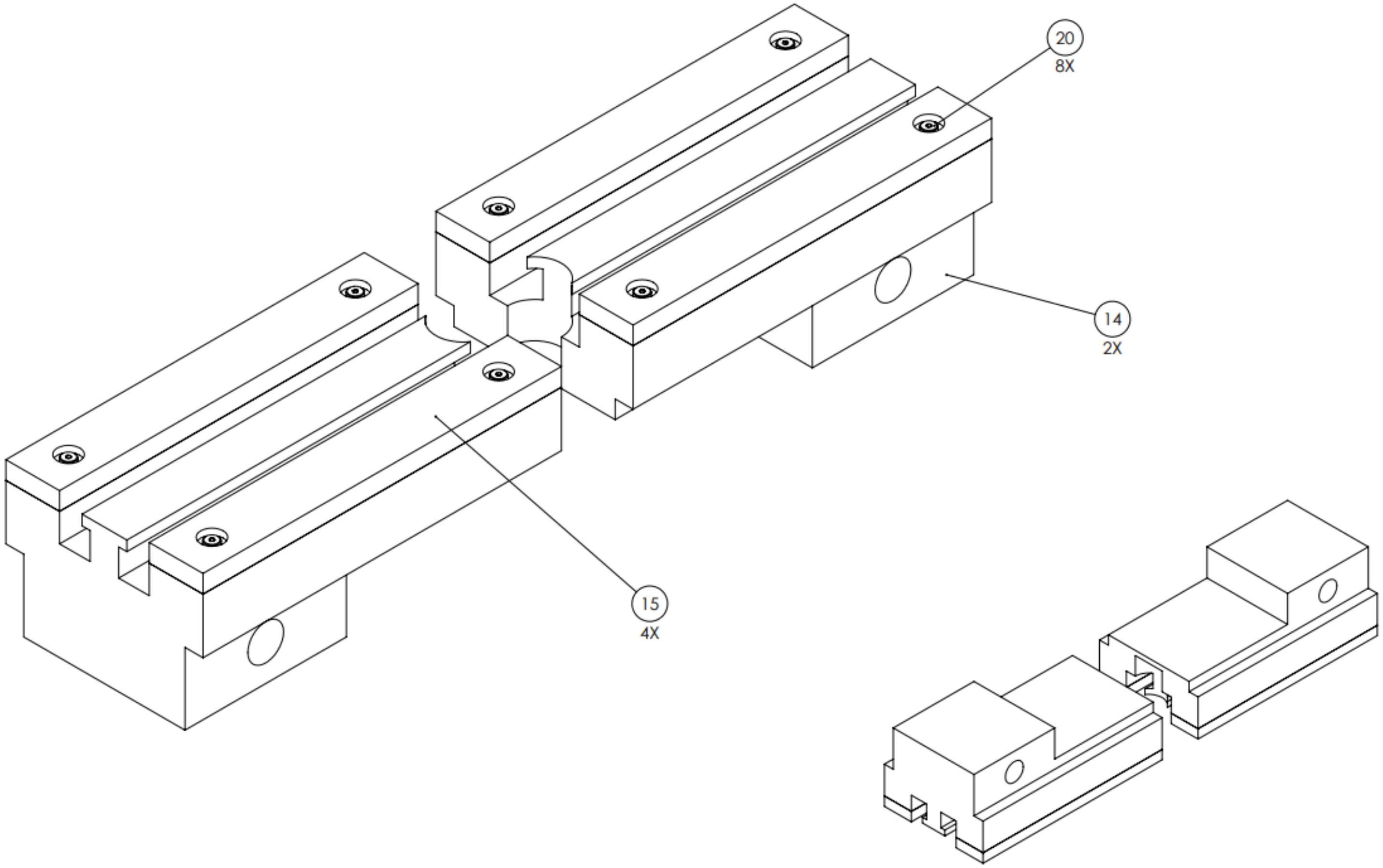
Other Components

- **Airline Track**
- **Purchased Hardware -** Bolts, Nuts, Bushings, Springs

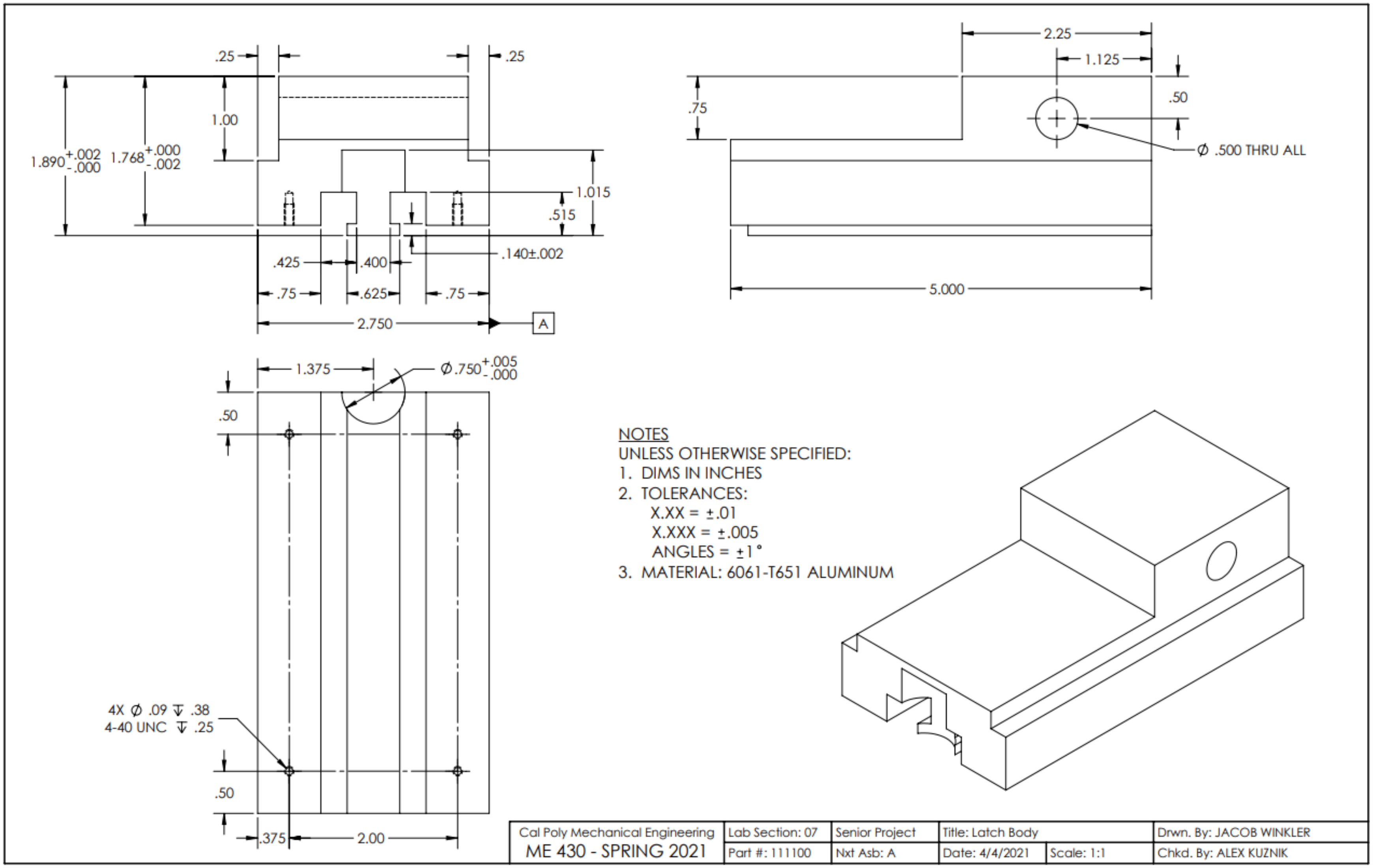


ITEM NO.	PART NAME	PART NUMBER	QTY.
1	Mounting Plate	114000	1
2	Seat Side Plate [from Articulation Team's Assy]	[This part is actually part of the Articulation assembly, hence, no part number. IT IS NOT SHOWN IN THESE VIEWS]	1
3	Track Assembly	120000	1
4	Back Bar [foot pedal]	113700	1
5	Cam Lever Arm	113100	1
6	Follower	113200	1
7	Follower Mount	113300	1
8	Follower Frame	113400	1
9	Spring Guide Pin- male	113500B	1
10	Spring Guide Pin- female	113500A	1
11	Spring Guide Spacer	113500C	1
12	Double Pin	112000	1
13	Spring Mounting Pin	113600	1
14	Latch Body	111100	2
15	Delrin Slide	111200	4
16	92220A124 [4-40-3/4 screw]	113800A	2
17	90480A005 [4-40 hex nut]	113800B	1
18	91257A725 [1/2-13-3.25 Bolts]	116000	4
19	93827A245 [1/2-13 hex nut]	117000	4
20	92220A122 [4-40-3/8 screw]	111300	10
21	9657K248 [Spring]	113900	1
22	8491A665 [Drill Bushing]	115000	1

Cal Poly Mechanical Engineering	Lab Section: 07	Senior Project	Title: Full Track & Latch Assembly		Drwn. By: JACOB WINKLER
ME 430 - SPRING 2021	Part #: 100000	Nxt Asb: A	Date: 6/3/2021	Scale: 1:2	Chkd. By: ALEX KUZNIK

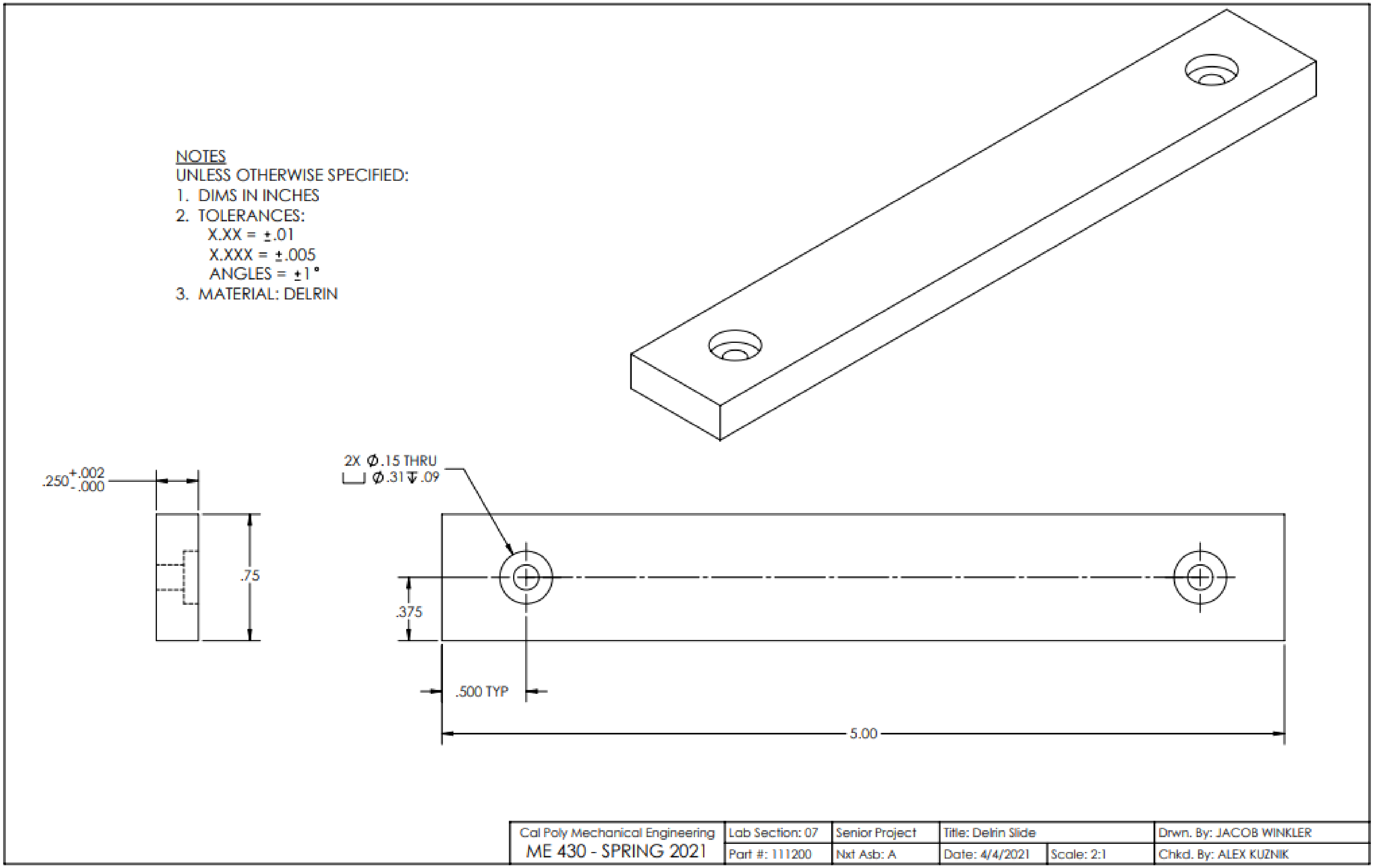


Cal Poly Mechanical Engineering	Lab Section: 07	Senior Project	Title: Latch Body Assembly		Drwn. By: JACOB WINKLER
ME 430 - SPRING 2021	Part #: 111000	Nxt Asb: A	Date: 6/3/2021	Scale: 1:1	Chkd. By: ALEX KUZNIK



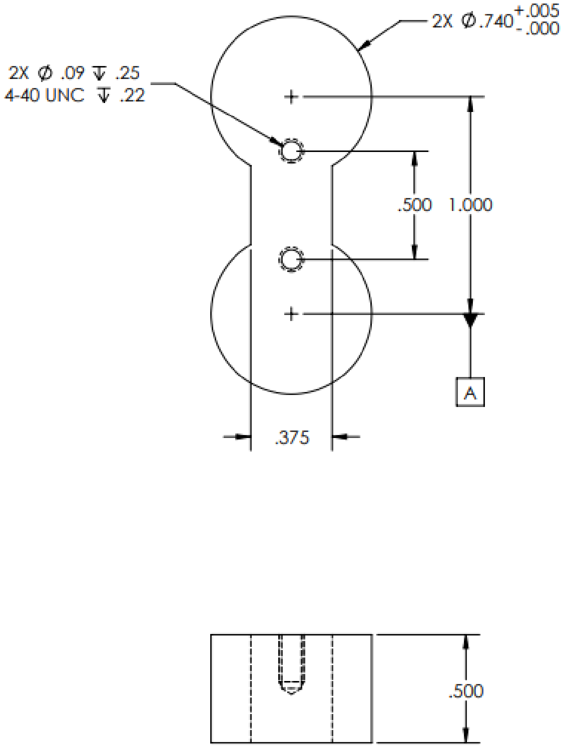
NOTES
UNLESS OTHERWISE SPECIFIED:
1. DIMS IN INCHES
2. TOLERANCES:
X.XX = ±.01
X.XXX = ±.005
ANGLES = ±1°
3. MATERIAL: 6061-T651 ALUMINUM

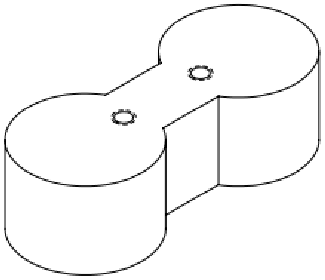
Cal Poly Mechanical Engineering	Lab Section: 07	Senior Project	Title: Latch Body		Drwn. By: JACOB WINKLER
ME 430 - SPRING 2021	Part #: 111100	Nxt Asb: A	Date: 4/4/2021	Scale: 1:1	Chkd. By: ALEX KUZNIK



NOTES
UNLESS OTHERWISE SPECIFIED:
1. DIMS IN INCHES
2. TOLERANCES:
   X.XX = ±.01
   X.XXX = ±.005
   ANGLES = ±1°
3. MATERIAL: DELRIN

Cal Poly Mechanical Engineering	Lab Section: 07	Senior Project	Title: Delrin Slide		Drwn. By: JACOB WINKLER
ME 430 - SPRING 2021	Part #: 111200	Nxt Asb: A	Date: 4/4/2021	Scale: 2:1	Chkd. By: ALEX KUZNIK





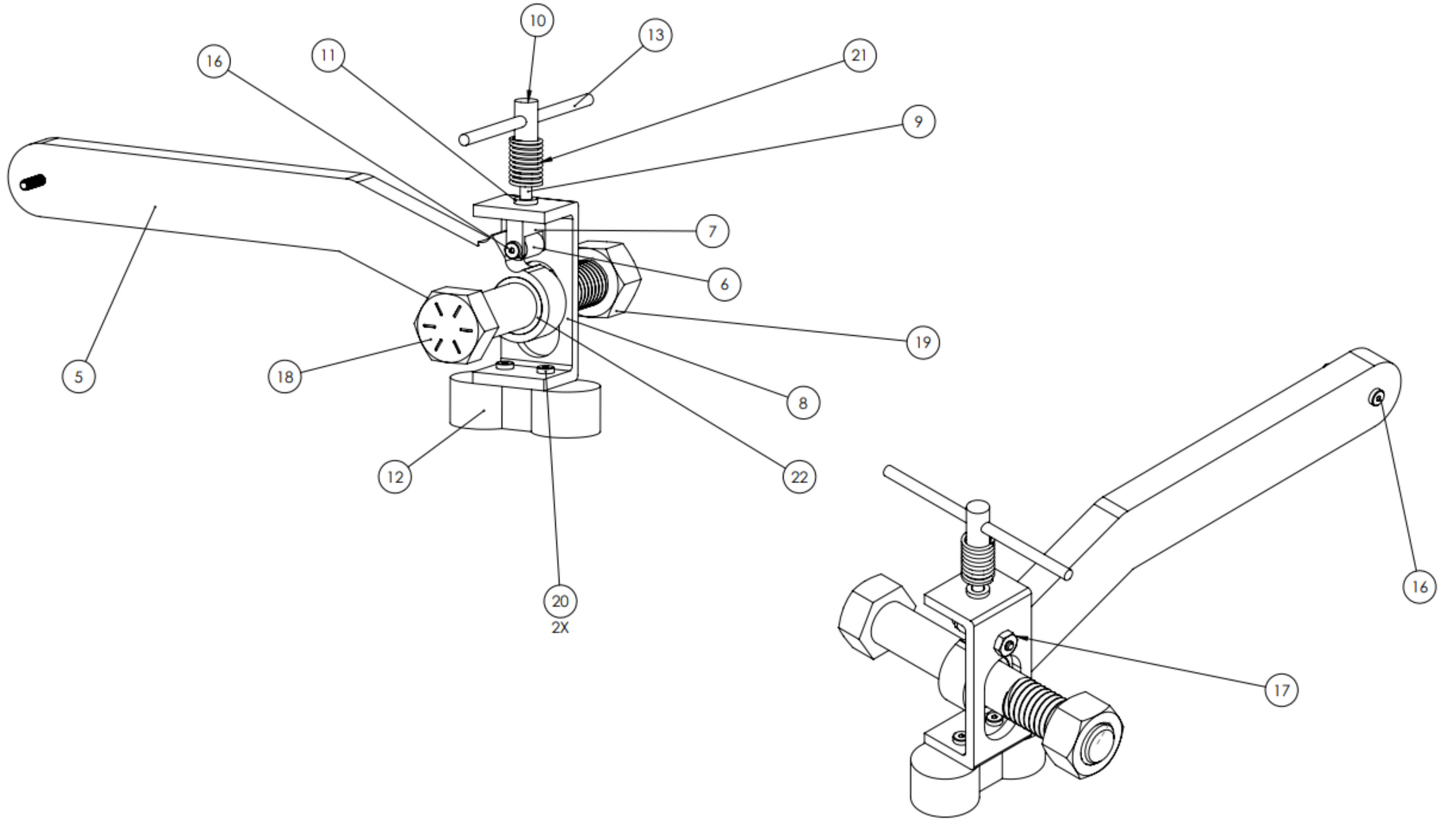
NOTES

THIS PART IS TO BE WATERJET OR A CNC MILLED.

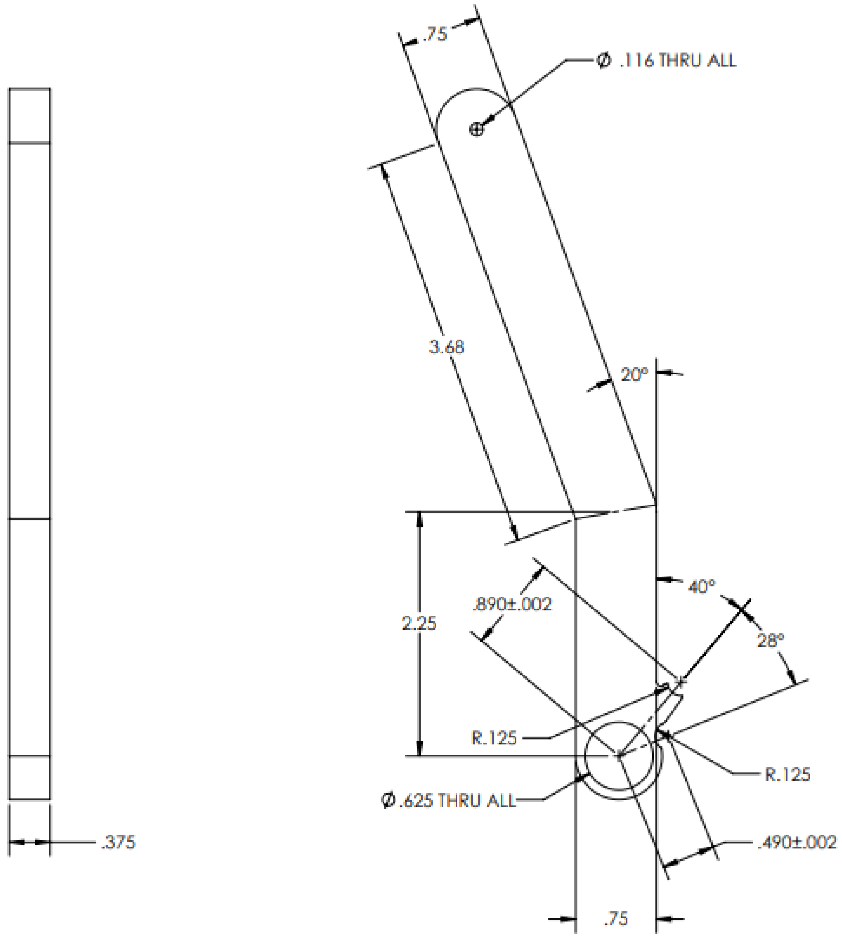
UNLESS OTHERWISE SPECIFIED:

1. DIMS IN INCHES
2. TOLERANCES:
   X.XX = ±.01
   X.XXX = ±.005
   ANGLES = ±1°
3. MATERIAL: 6061-T651 ALUMINUM

Cal Poly Mechanical Engineering ME 430 - SPRING 2021	Lab Section: 07	Senior Project	Title: Double Pin		Drwn. By: JACOB WINKLER
	Part #: 112000	Nxt Asb: A	Date: 4/4/2021	Scale: 2:1	Chkd. By: ALEX KUZNIK



Cal Poly Mechanical Engineering	Lab Section: 07	Senior Project	Title: Actuation Assembly		Drwn. By: JACOB WINKLER
ME 430 - SPRING 2021	Part #: 113000	Nxt Asb: A	Date: 6/3/2021	Scale: 1:1	Chkd. By: ALEX KUZNIK

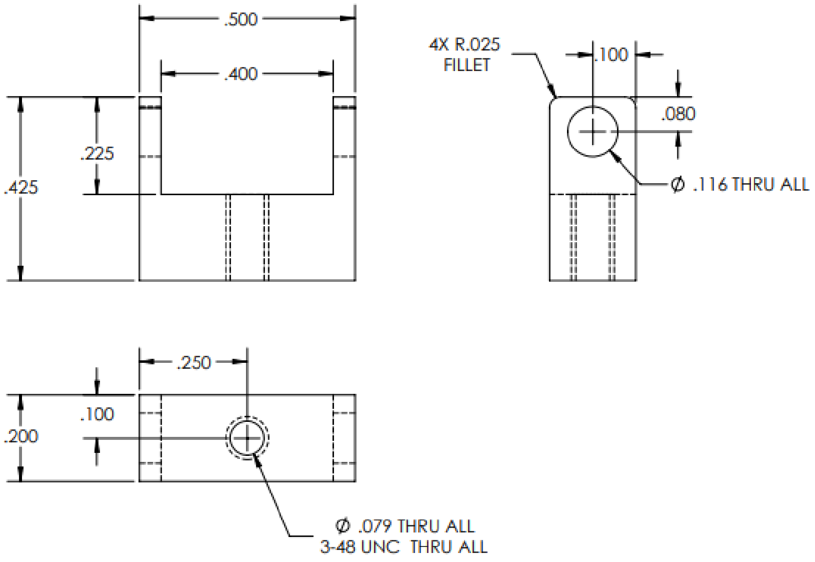


NOTES
THIS PART IS TO BE WATERJET OR A CNC MILLED.
UNLESS OTHERWISE SPECIFIED:

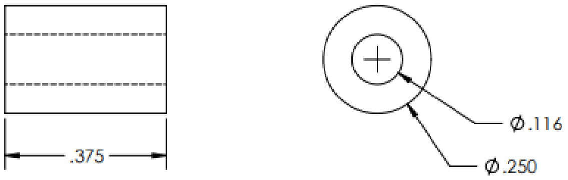
1. DIMS IN INCHES
2. TOLERANCES:
    X.XX = ±.01
    X.XXX = ±.005
    ANGLES = ±1°
3. MATERIAL: 6061-T651 ALUMINUM

Cal Poly Mechanical Engineering ME 430 - SPRING 2021	Lab Section: 07	Senior Project	Title: Cam Lever Arm		Drwn. By: JACOB WINKLER
	Part #: 113100	Nxt Asb: A	Date: 4/4/2021	Scale: 1:1	Chkd. By: ALEX KUZNIK

CAM FLOLLOWER MOUNT
(PART #: 113200)



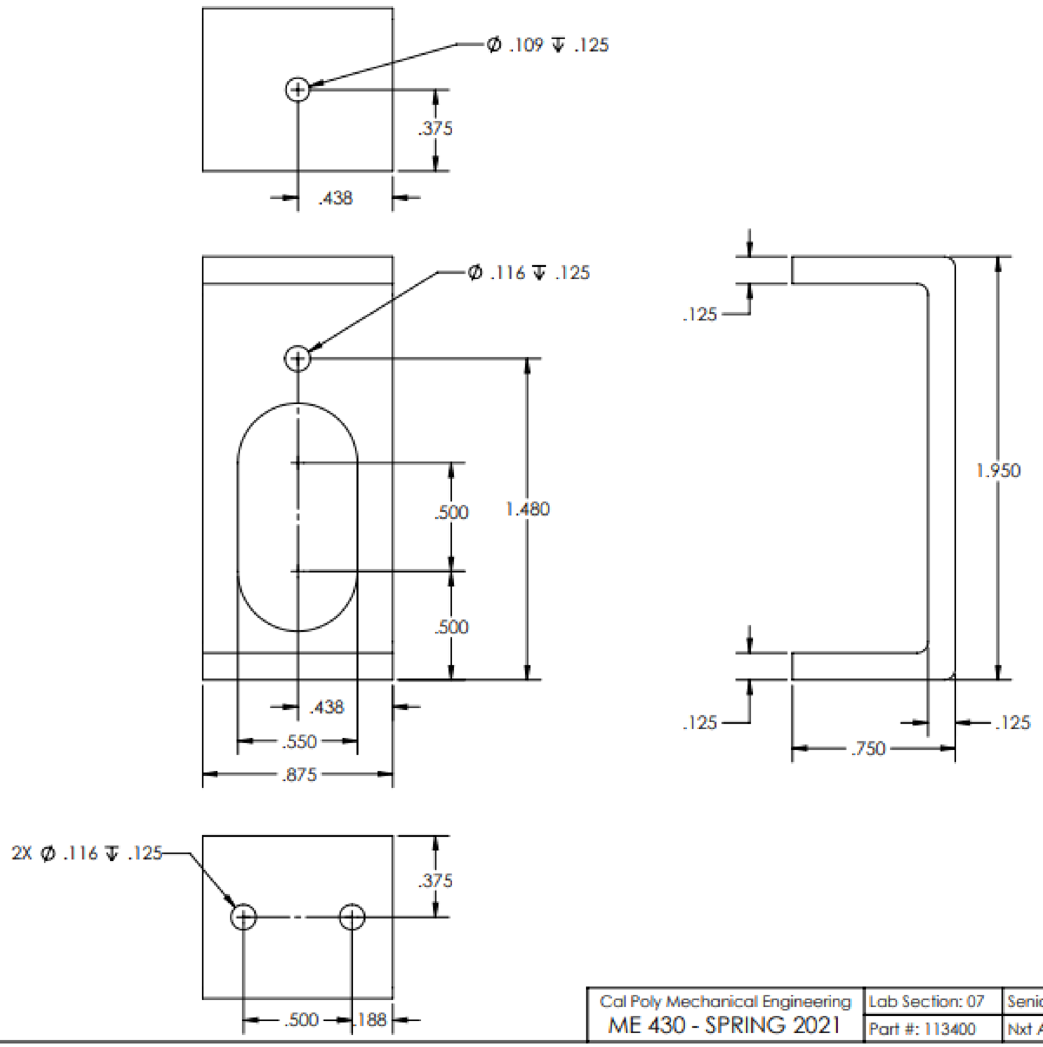
CAM FOLLOWER
(PART #: 113300)



NOTES
WHEN MANUFACTURING THE MOUNT, ONE
EDGE MAY NEED TO BE FLLETED (FILED DOWN)
TO FIT WITH FOLLOWER FRAME.

UNLESS OTHERWISE SPECIFIED:
1. DIMS IN INCHES
2. TOLERANCES:
   X.XX = ±.01
   X.XXX = ±.005
   ANGLES = ±1°
3. MATERIAL: 6061-T651 ALUMINUM

Cal Poly Mechanical Engineering	Lab Section: 07	Senior Project	Title: Cam Follower & Mount		Drwn. By: JACOB WINKLER
ME 430 - SPRING 2021	Part #: [See Above]	Nxt Asb: A	Date: 4/4/2021	Scale: 4:1	Chkd. By: ALEX KUZNIK

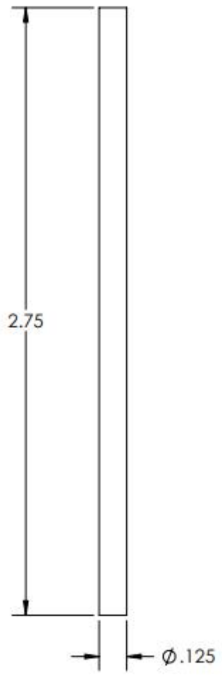


NOTES
PART WILL BE MANUFACTURED FROM 1/8" SHEET METAL. HOLES AND SLOT WILL BE DRILLED FIRST, AND THEN THE PART WILL BE BENT (USING A BRAKE).

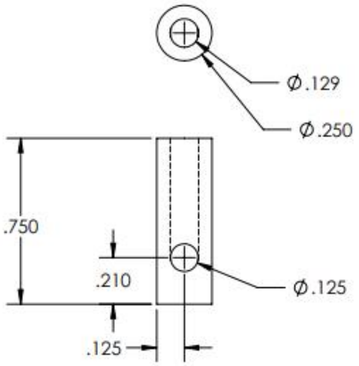
UNLESS OTHERWISE SPECIFIED:
1. DIMS IN INCHES
2. TOLERANCES:
    X.XX = ±.01
    X.XXX = ±.005
    ANGLES = ±1°
3. MATERIAL: 6061-T651 ALUMINUM

Cal Poly Mechanical Engineering	Lab Section: 07	Senior Project	Title: Follower Frame		Drwn. By: JACOB WINKLER
ME 430 - SPRING 2021	Part #: 113400	Nxt Asb: A	Date: 4/4/2021	Scale: 2:1	Chkd. By: ALEX KUZNIK

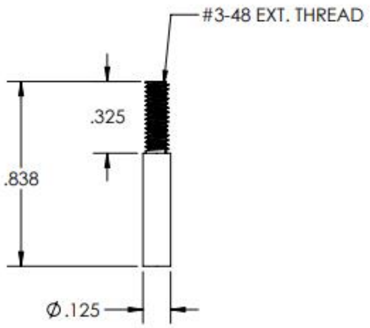
SPRING GUIDE MOUNT PIN
(PART #: 113600)



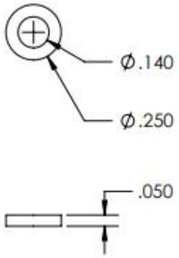
SPRING GUIDE: FEMALE



SPRING GUIDE: MALE

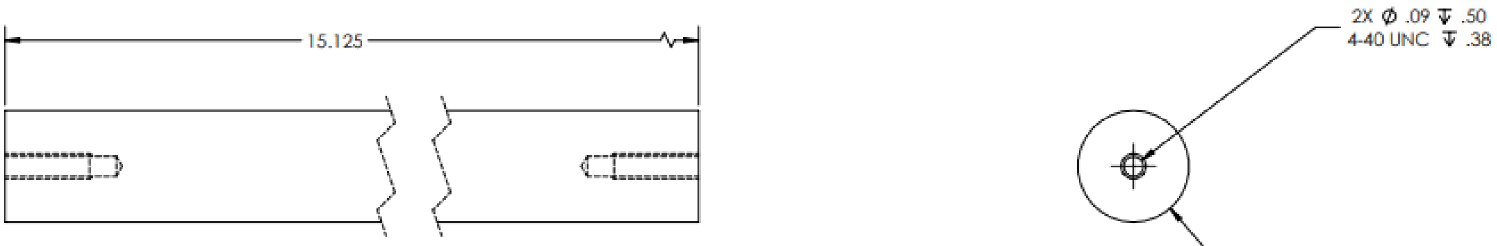


SPRING GUIDE SPACER



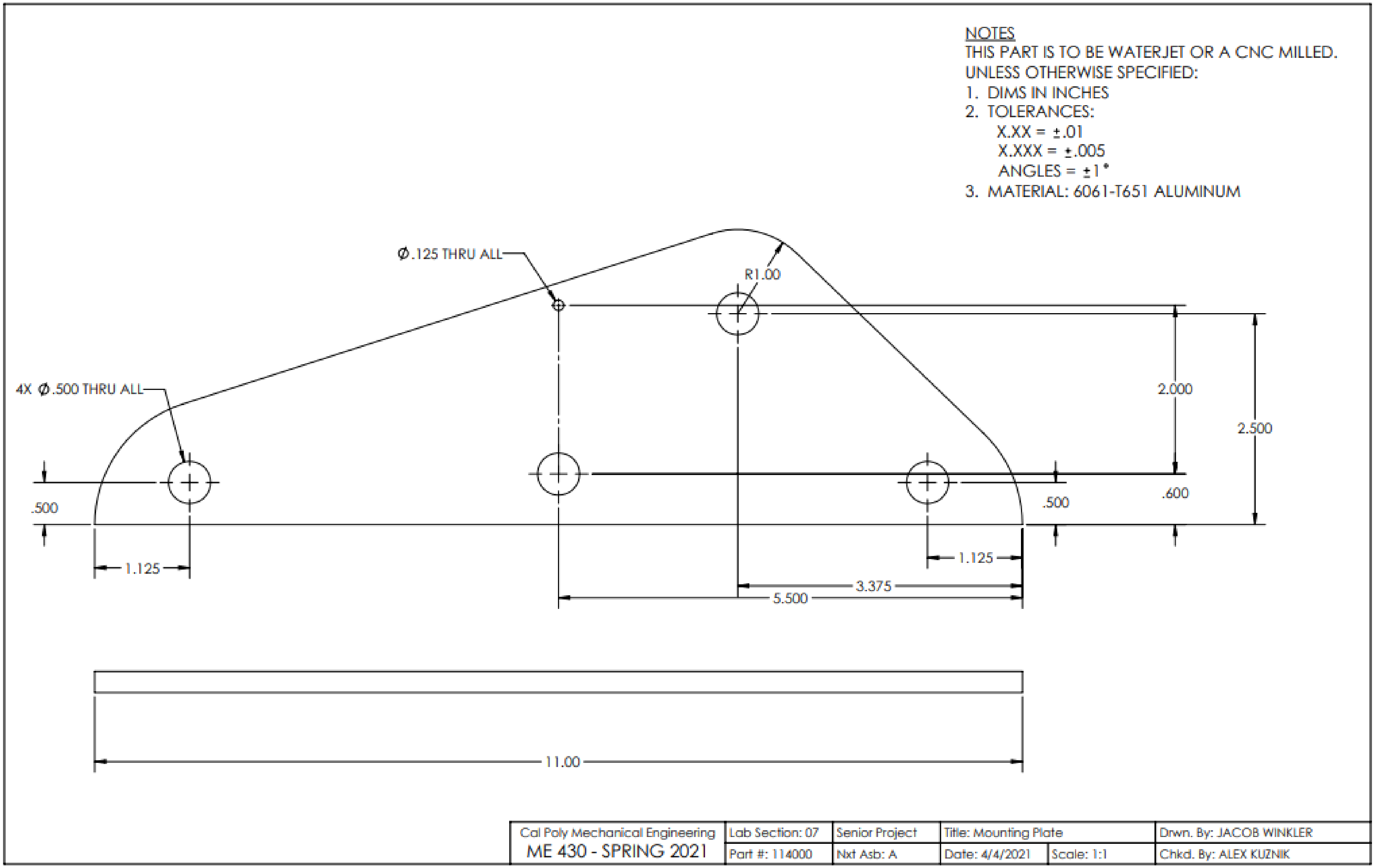
NOTES
UNLESS OTHERWISE SPECIFIED:
1. DIMS IN INCHES
2. TOLERANCES:
    X.XX = ±.01
    X.XXX = ±.005
    ANGLES = ±1°
3. MATERIAL: 6061-T651 ALUMINUM

Cal Poly Mechanical Engineering	Lab Section: 07	Senior Project	Title: Cam Spring Guide Pins		Drwn. By: JACOB WINKLER
ME 430 - SPRING 2021	Part #: 113500	Nxt Asb: A	Date: 4/4/2021	Scale: 2:1	Chkd. By: ALEX KUZNIK



NOTES
UNLESS OTHERWISE SPECIFIED:
1. DIMS IN INCHES
2. TOLERANCES:
  X.XX = ±.01
  X.XXX = ±.005
  ANGLES = ±1°
3. MATERIAL: 6061-T651 ALUMINUM

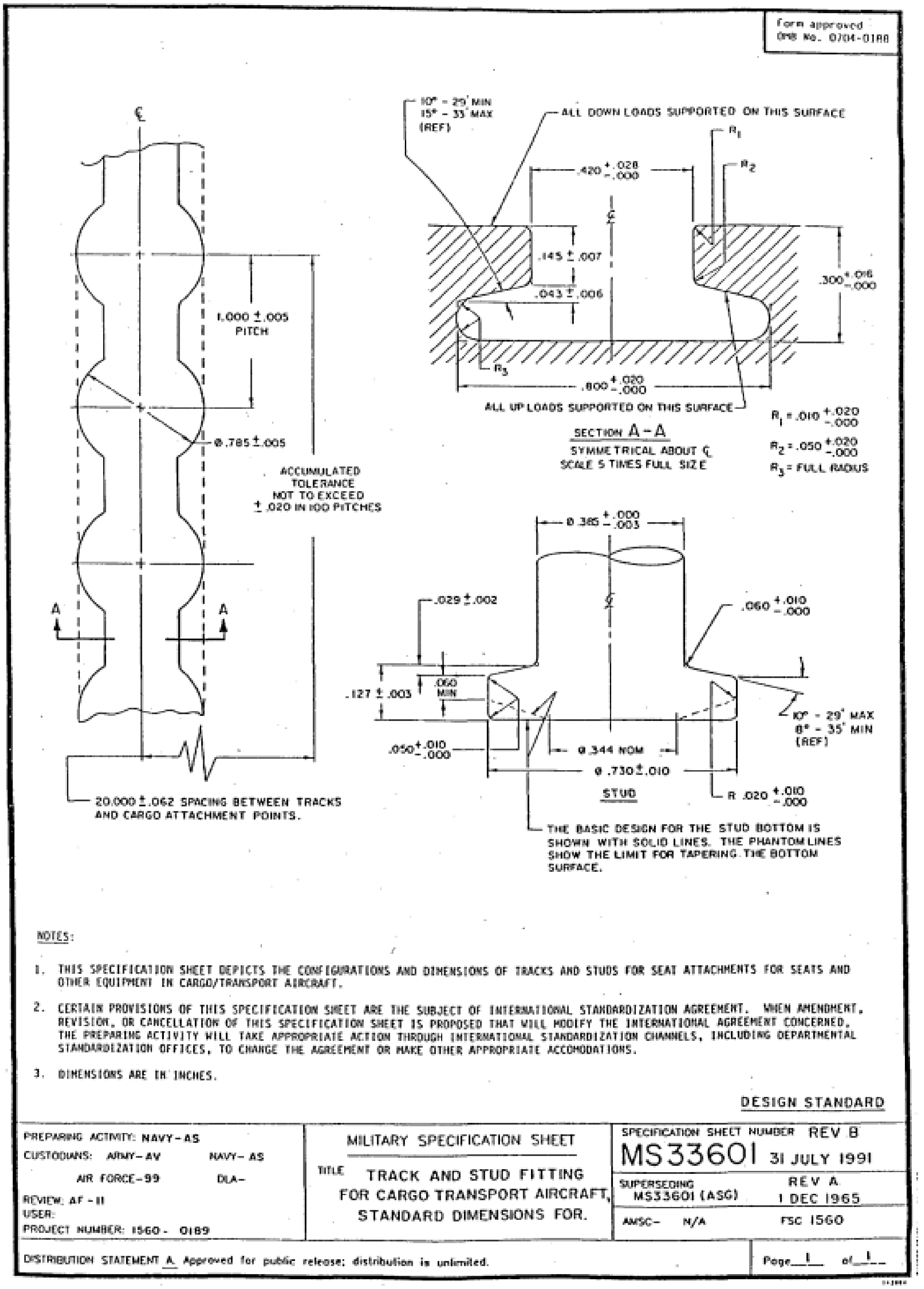
Cal Poly Mechanical Engineering ME 430 - SPRING 2021	Lab Section: 07	Senior Project	Title: Back Bar		Drwn. By: JACOB WINKLER
	Part #: 113700	Nxt Asb: A	Date: 4/4/2021	Scale: 2:1	Chkd. By: KAI QUIZON



NOTES
THIS PART IS TO BE WATERJET OR A CNC MILLED.
UNLESS OTHERWISE SPECIFIED:
1. DIMS IN INCHES
2. TOLERANCES:
   X.XX = ±.01
   X.XXX = ±.005
   ANGLES = ±1°
3. MATERIAL: 6061-T651 ALUMINUM

Cal Poly Mechanical Engineering	Lab Section: 07	Senior Project	Title: Mounting Plate		Drwn. By: JACOB WINKLER
ME 430 - SPRING 2021	Part #: 114000	Nxt Asb: A	Date: 4/4/2021	Scale: 1:1	Chkd. By: ALEX KUZNIK

Below are the Airline Track Specs from Aircraft Extrusion Co.



Form approved
OMB No. 0704-0188

NOTES:

1. THIS SPECIFICATION SHEET DEPICTS THE CONFIGURATIONS AND DIMENSIONS OF TRACKS AND STUDS FOR SEAT ATTACHMENTS FOR SEATS AND OTHER EQUIPMENT IN CARGO/TRANSPORT AIRCRAFT.
2. CERTAIN PROVISIONS OF THIS SPECIFICATION SHEET ARE THE SUBJECT OF INTERNATIONAL STANDARDIZATION AGREEMENT. WHEN AMENDMENT, REVISION, OR CANCELLATION OF THIS SPECIFICATION SHEET IS PROPOSED THAT WILL MODIFY THE INTERNATIONAL AGREEMENT CONCERNED, THE PREPARING ACTIVITY WILL TAKE APPROPRIATE ACTION THROUGH INTERNATIONAL STANDARDIZATION CHANNELS, INCLUDING DEPARTMENTAL STANDARDIZATION OFFICES, TO CHANGE THE AGREEMENT OR MAKE OTHER APPROPRIATE ACCOMODATIONS.
3. DIMENSIONS ARE IN INCHES.

DESIGN STANDARD

PREPARING ACTIVITY: NAVY-AS
CUSTODIANS: ARMY-AV NAVY-AS
AIR FORCE-99 DLA-
REVIEW: AF-11
USER:
PROJECT NUMBER: 1560- 0189

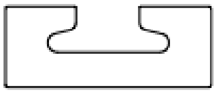
MILITARY SPECIFICATION SHEET

TITLE TRACK AND STUD FITTING
FOR CARGO TRANSPORT AIRCRAFT,
STANDARD DIMENSIONS FOR.

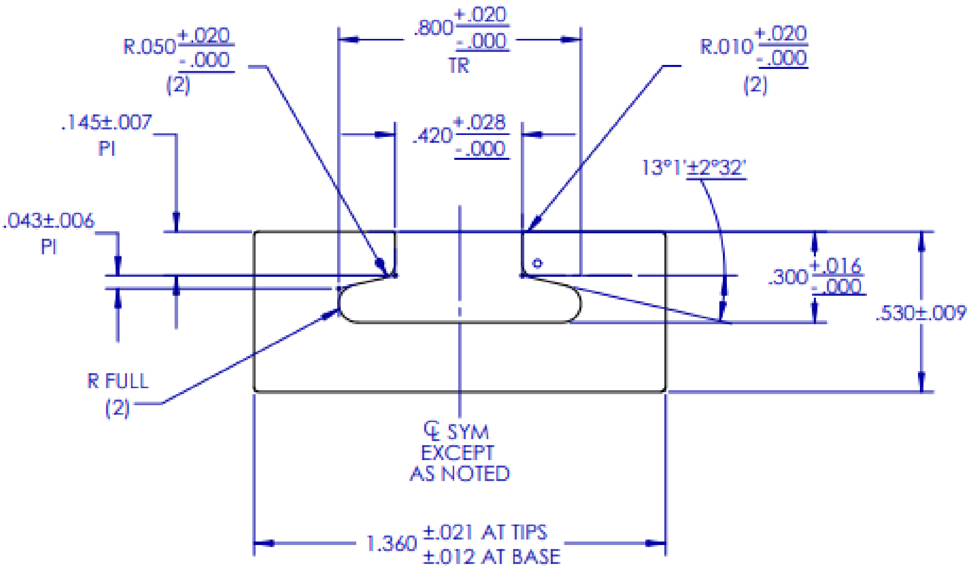
SPECIFICATION SHEET NUMBER REV B
MS33601 31 JULY 1991
SUPERSEDING MS33601 (ASG) REV A 1 DEC 1965
AMSC- N/A FSC 1560

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

Page 1 of 1



ACTUAL SIZE



.016 ± .016 CORNER RADII TYP. EXCEPT AS SHOWN.

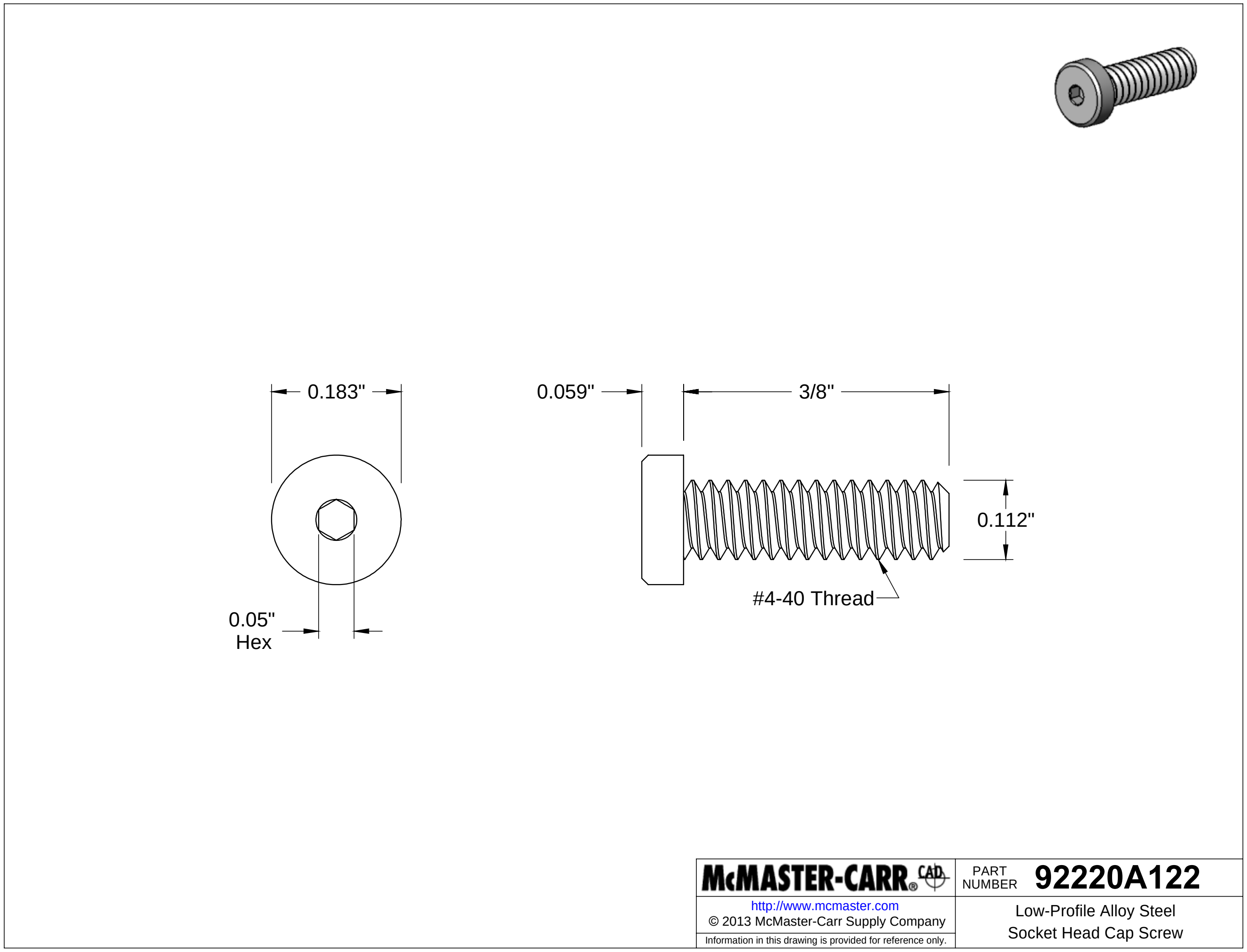
STRAIGHTNESS: .0125 PER FOOT OF LENGTH.
FLATNESS: .004 PER INCH OF WIDTH.
TWIST: 1° PER FOOT: 7° MAX.

	PART NUMBER	
	AS33601-EXT	
	MS33601-EXT	
	40467-11-144	
	BAC1520-841	
	AVAILABLE ALLOY/TEMPER	
	7075-T6511 AMS-QQ-A-200/11	
	7075-T73511 AMS-QQ-A-200/11	
REV	*REVISIONS*	*DATE*

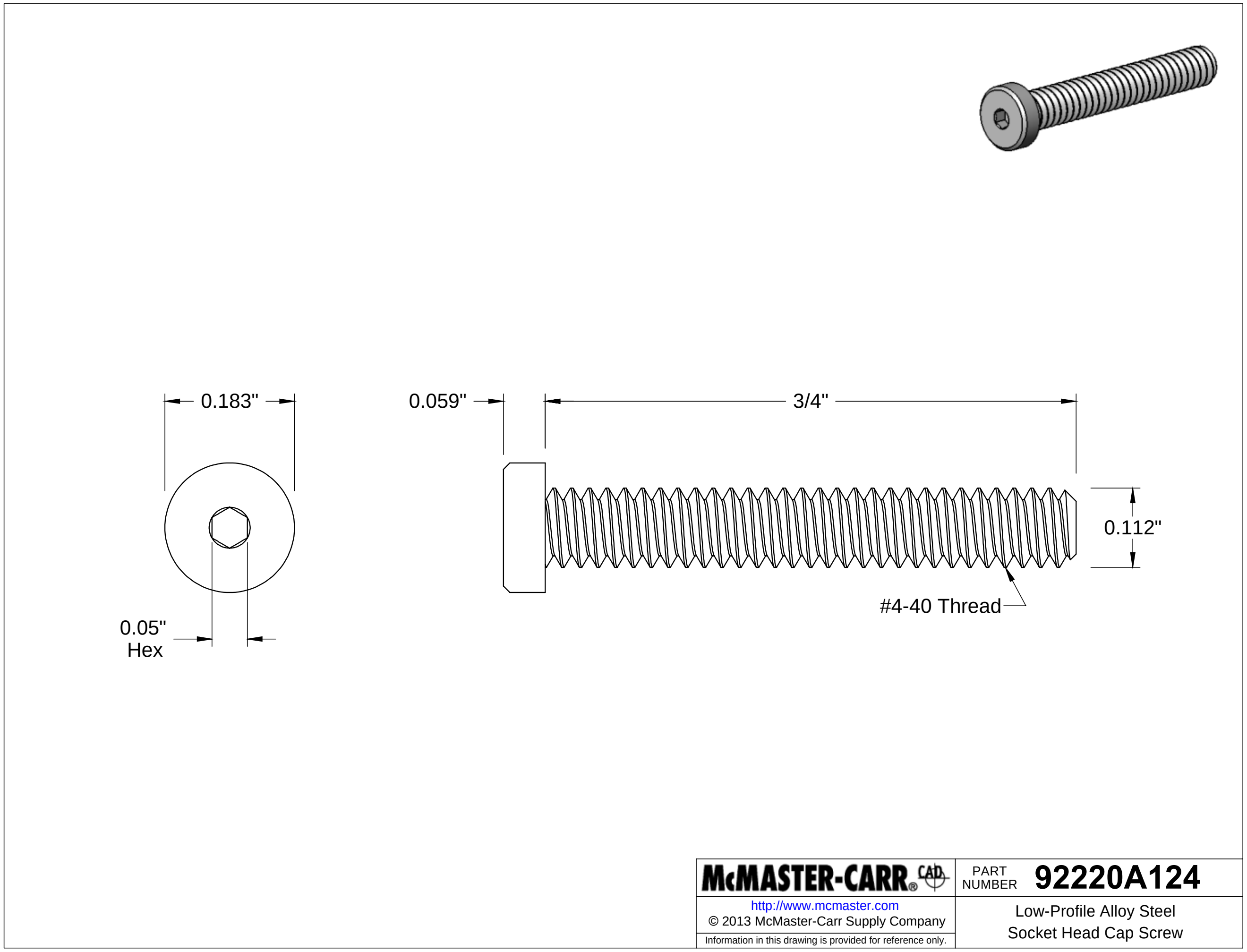
***AIRCRAFT* EXTRUSION CO.**
180 Erma Court, Unit 160
Chico, CA 95928
PH: 323-813-4105 FX: 877-639-4154

CODE:	SET	*AREA:*	.536	*ALLOY:*	7075
STANDARD COMMERCIAL TOLERANCES PER FEDERAL STANDARD 245 AND ANSI H35.2 FOR EXTRUDED PRODUCTS TO APPLY UNLESS SPECIFICALLY SHOWN OTHERWISE.		*WT/FT:*	.643	*SHAPE:*	SOLID
		PERI:	4.907	*DRAWN:*	S.LAI
		FACTOR:	7.6	*CHK'D:*	HA L.
		C/S:	1.4	*DATE:*	12/5/2016

Below are the specs for McMaster #4-40-3/8 Screws



Below are the specs for McMaster #4-40-3/4 Screws



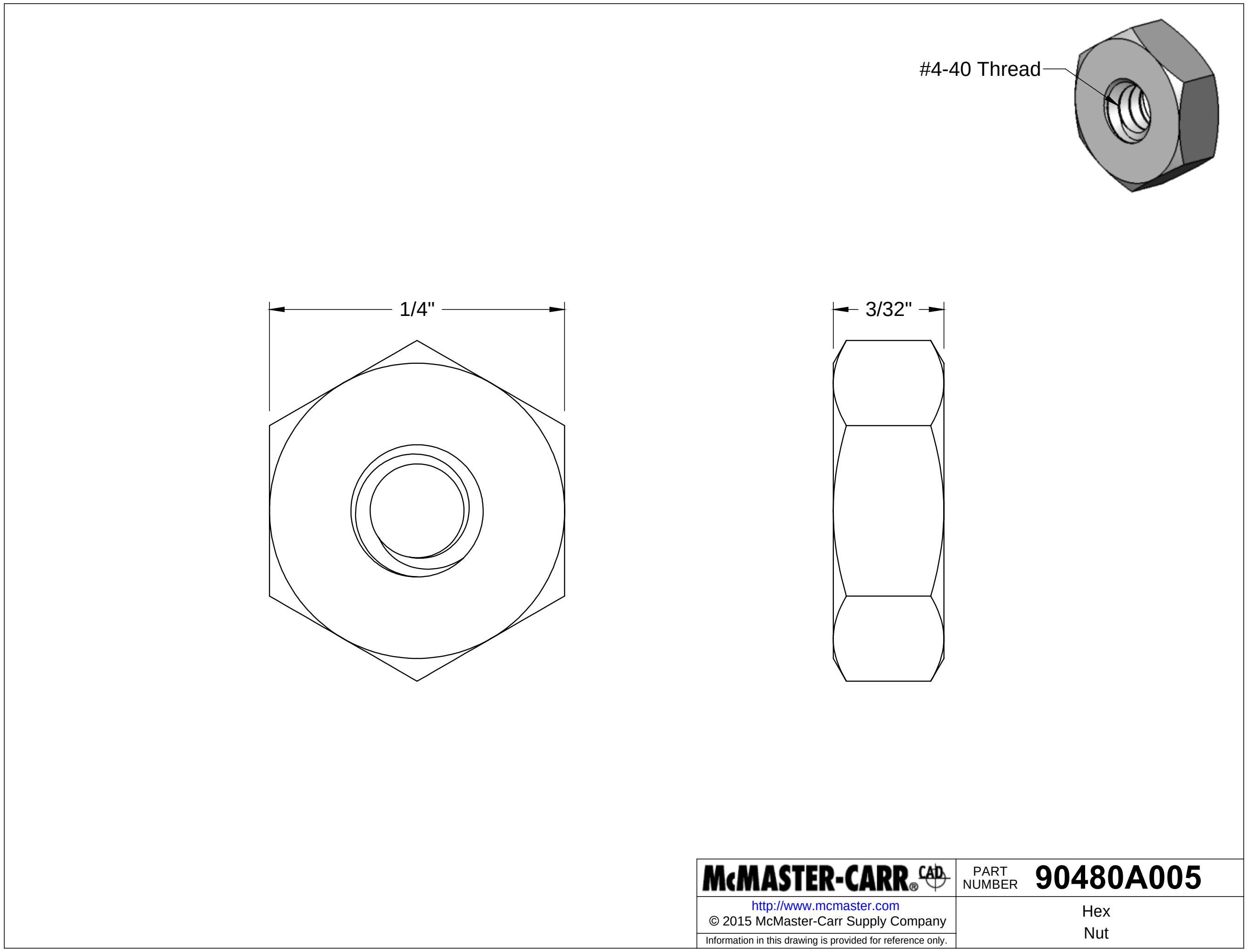
MCMASTER-CARR® CAD

PART NUMBER 92220A124

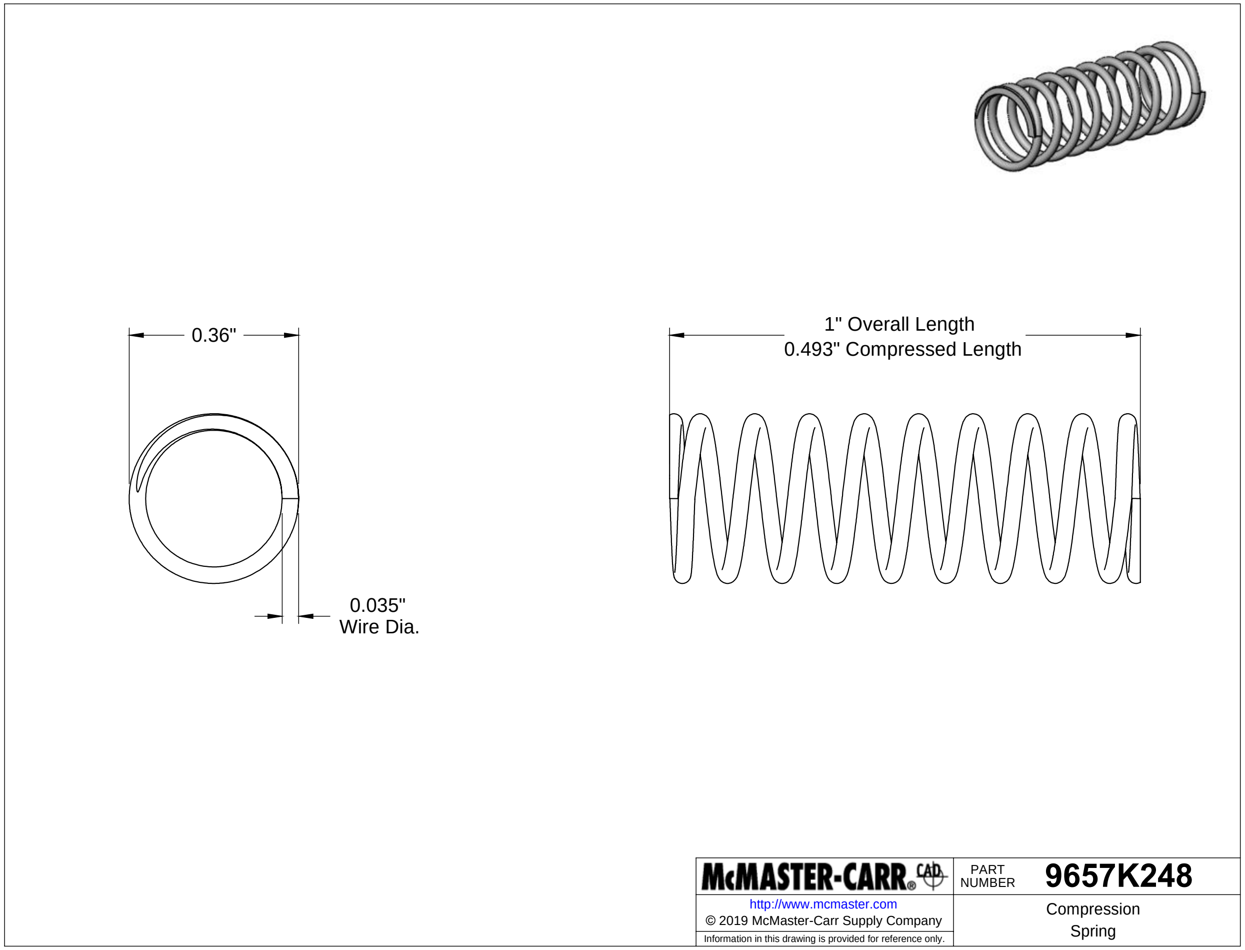
http://www.mcmaster.com

Low-Profile Alloy Steel
Socket Head Cap Screw

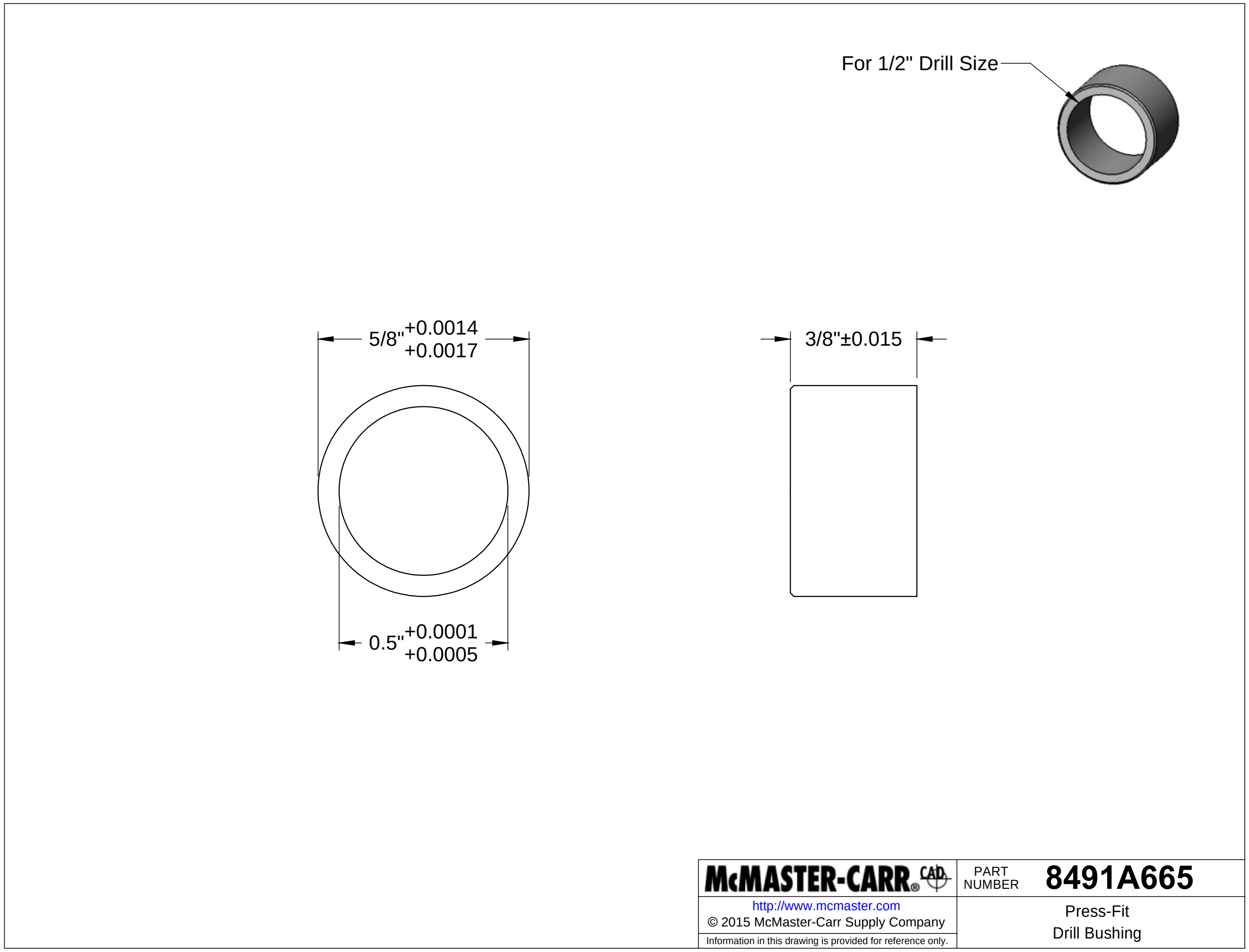
Below are the specs for McMaster #4-40 Hex Nut



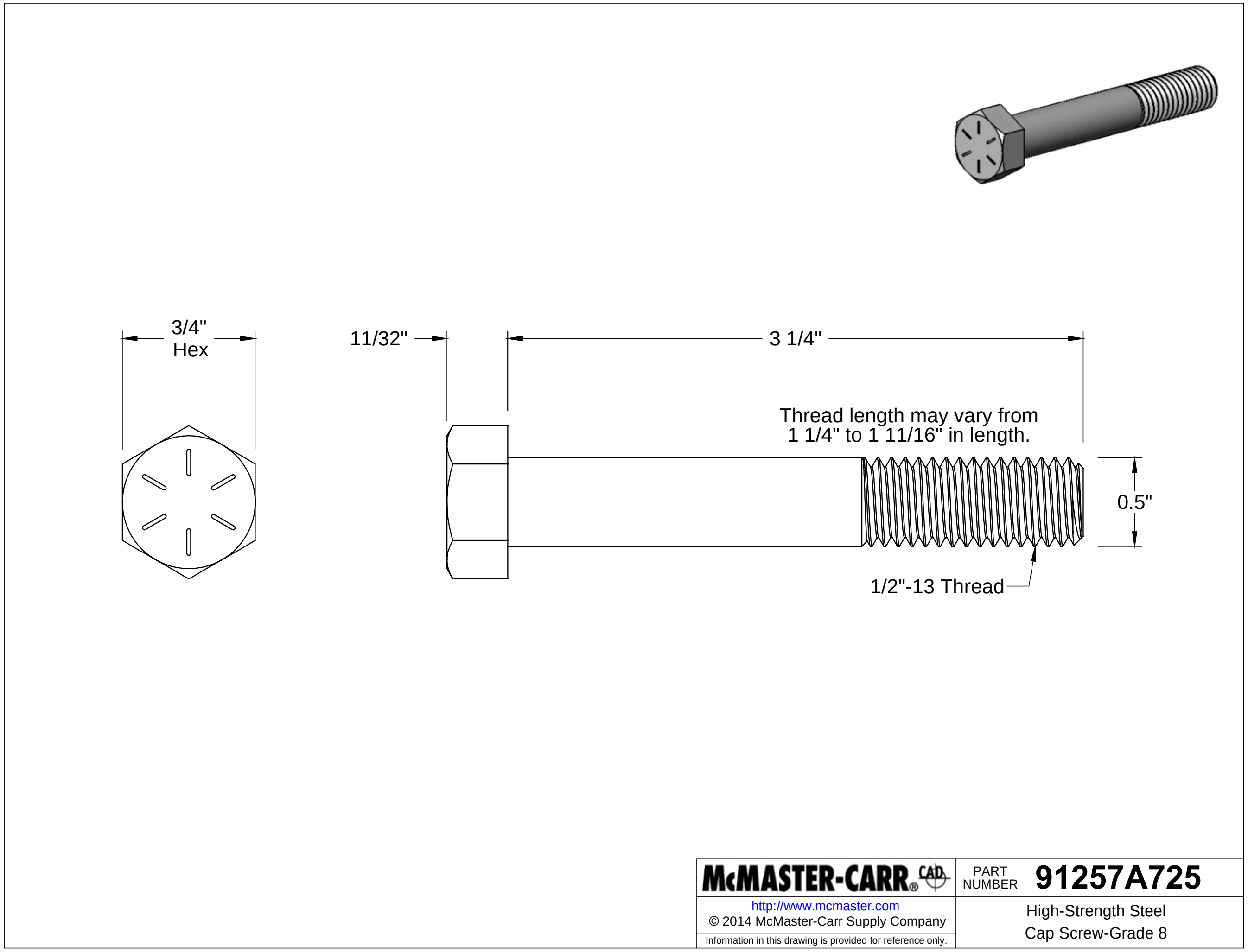
Below are the specs for McMaster Compression Spring



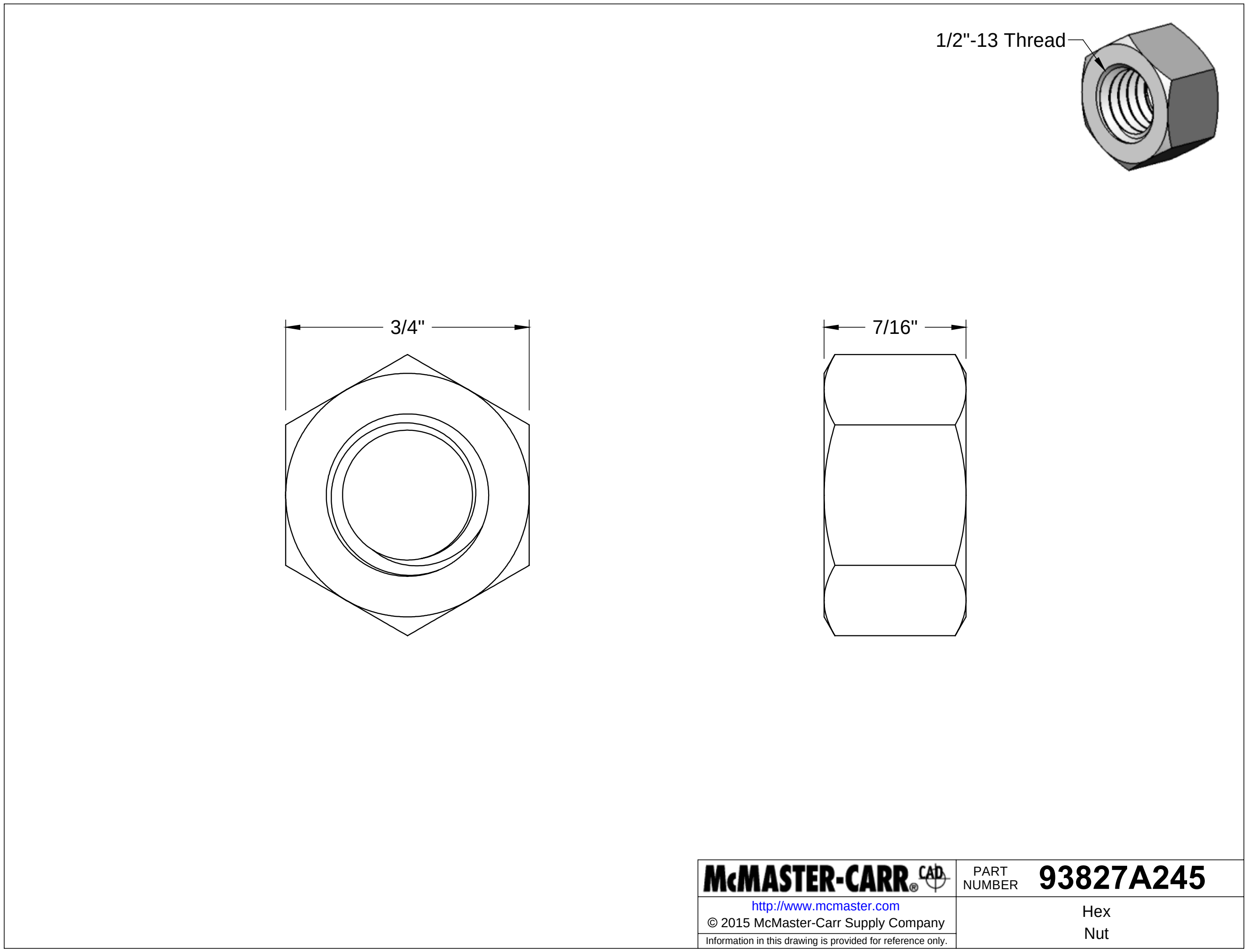
Below are the specs for McMaster Drill Bushing



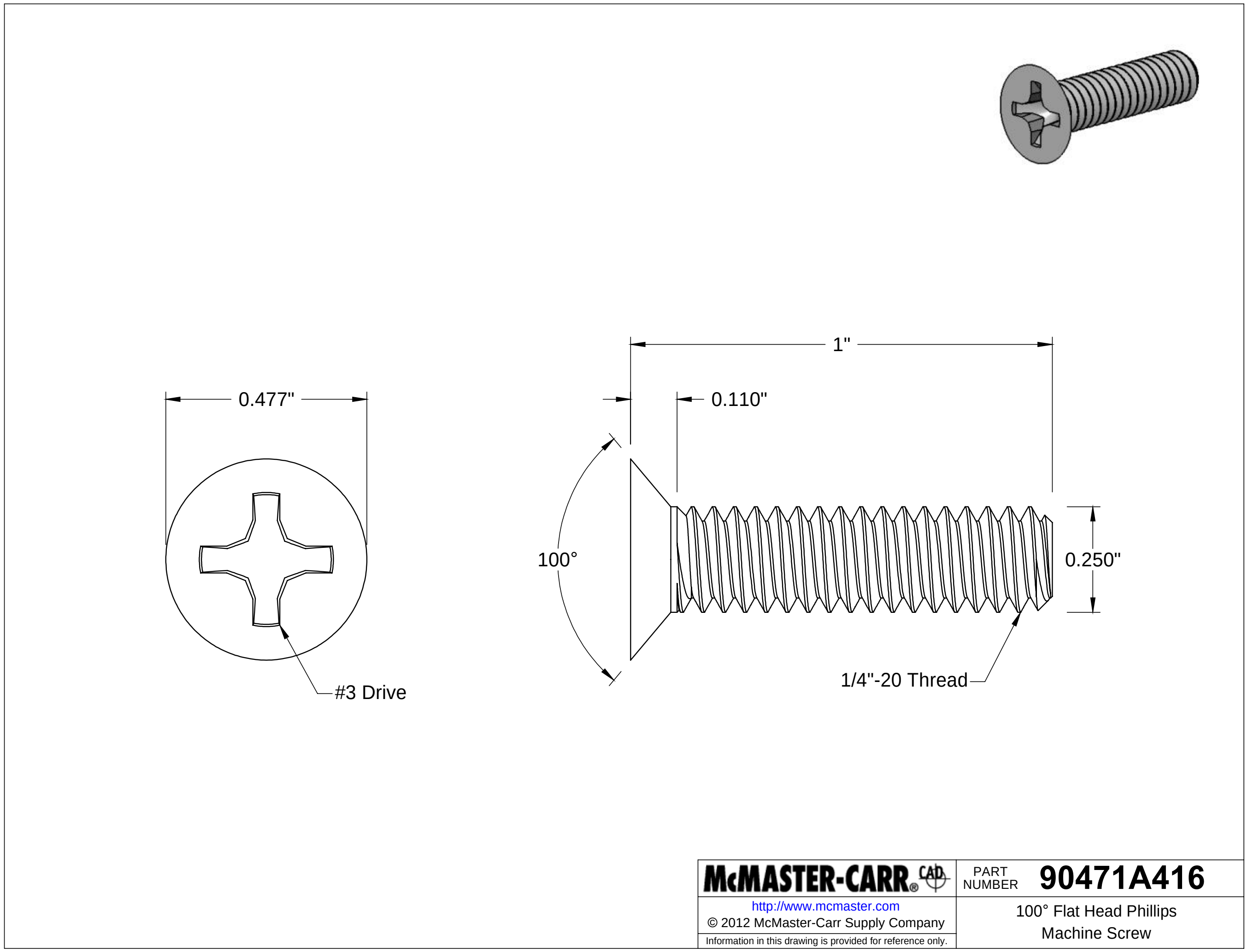
Below are the specs for McMaster ½-13-3.25 Cap Screw



Below are the specs for McMaster ½-13 Hex Nut



Below are the specs for McMaster ¼-20 Bolts



Appendix Y: Track and Latch Team Hazard Checklist

Y	N	
×		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
×		2. Can any part of the design undergo high accelerations/decelerations?
×		3. Will the system have any large moving masses or large forces?
	×	4. Will the system produce a projectile?
	×	5. Would it be possible for the system to fall under gravity creating injury?
	×	6. Will a user be exposed to overhanging weights as part of the design?
×		7. Will the system have any sharp edges?
	×	8. Will any part of the electrical systems not be grounded?
	×	9. Will there be any large batteries or electrical voltage in the system above 40 V?
	×	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	×	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	×	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	×	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
×		14. Can the system generate high levels of noise?
×		15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
×		16. Is it possible for the system to be used in an unsafe manner?
	×	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any “Y” responses, on the reverse side add:

1. a complete description of the hazard,
2. the corrective action(s) you plan to take to protect the user, and
3. a date by which the planned actions will be completed.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
The actuation of lock could create pinch points	During design create a shield around lock mechanism	2/9	2/9
In a crash scenario the latch would have to undergo high accelerations of at least 5gs	Create a strong lock mechanism and use materials that can undergo high accelerations	2/9	2/10
The seat could be considered a large mass	Use lightweight material to make movement of the system easy	2/9	2/12
The area between latch meets the track could have sharp edges that could cut and injury someone	Design the track with fillets such that they wouldn’t cut or injury anyone	1/7	1/7
While the vehicle is moving a lot of noise could be generated in the track and latch mechanism	Design the mechanism and interface to have a larger natural frequency than would be generated on the road with a factor of safety of 2.5	2/9	2/9
At high outside temperatures the track and latch could heat up and burn someone if they touch it	Choose a material that has low conductivity to not transfer heat to the user	2/9	2/9
At below freezing outside temperatures the lock mechanism might get stuck and lock up	Create a reliable actuation system that inputs enough force to deal with cold temperatures/choose reliable material that doesn’t change at 30 degrees Fahrenheit	2/9	2/9

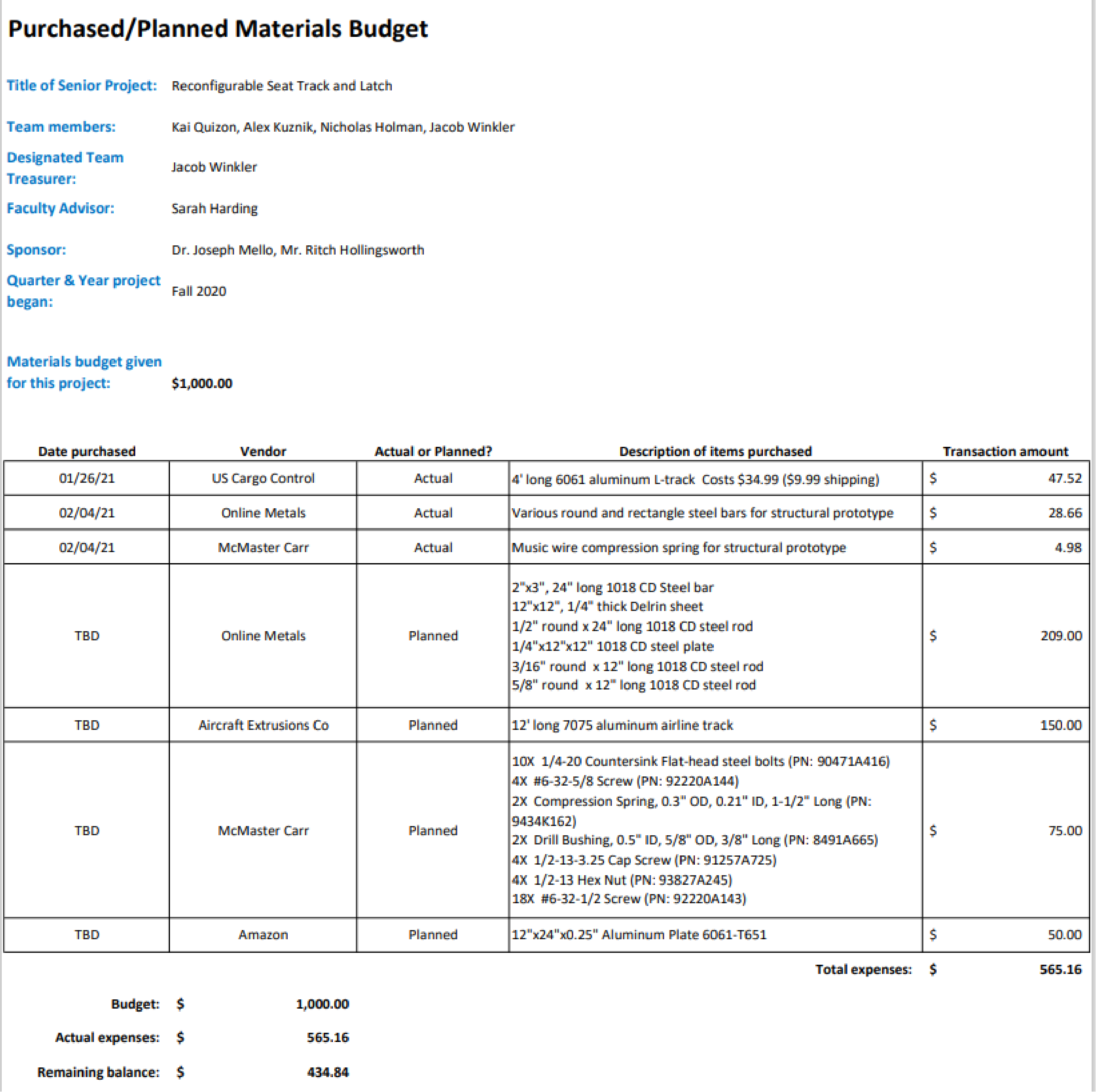
Unsafe usage could result in injury if the user stands in the wrong spot or performs unsafe practices	Create an easy 2-3 step set of instruction such that the user can reliable actuate the device safely	2/9	5/1

Appendix Z: Track and Latch Team FMEA

												Action Results			
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	Actions Taken	Severity	Occurence	Criticality
Track/ Allow for seat articulation	Rail Breaks	Seat is free to move about cabin	10	1) Excessive force on latch pins yields rail. 2) Heavy/sharp object dropped on rail yields rail	1) Pin designed to distribute forces on rail body. 2) Operator instruction on acceptable materials to lay on rail and visual inspection techniques.	1	Visual inspection	2	20						
	Rail guides wear down	Seat has additional "play" and is not secured to rail strictly.	5	Extended operation of seat without proper maintenance or cleaning	Operator instruction on maintenance and cleaning, as well as visual inspection techniques	3	Visual inspection/ Life predictions in operators manual	3	45	Following recommendations on periodic inspection and replacing rail guides if necessary	Kai- 5/12	Inspection and part replacement outlined in user manual	8	2	1
	Rail guides get jammed	Operator is unable to move seat from jammed position	7	Extended operation of seat without proper maintenance or cleaning	Operator instruction on maintenance and cleaning, as well as visual inspection techniques.	4	Visual inspection	1	28						
Latch/ Hold seat to latching system	Latch breaks	Seat is free to move along rail	10	1) Execessive force on latch pins yields latch pins. 2) External item dropped on pins yields latch pins.	1) Latch pins designed to distribute load and indicate massive failure. 2) Latch pins safely covered to prevent external drops.	1	LED shows when system is engaged and undamaged	1	10						
	Latch wears	Seat has additional "play" and is not secured to rail strictly.	5	Extended operation of seat outside of predicted life.	Owner/Operator instruction on allowable lifetime of latch.	2	Manual counter to count how many times have been engaged and disengaged	4	40	Endurance strength testing of seat latches, as well as following recommendations for periodic inspection	Kai-5/12	Inspection outlined in user manual	8	2	1
	Seat detaches from latch	Seat is free to move about the cabin	10	Excessive force on seat leg-latch interface yields interface.	Seat leg-latch interface designed to withstand crash level forces without detrimental failure. Operator instruction on when to retire latches after damaging scenarios.	1	Vertical Physical Inspection and maintenance procedures provided to operators for routine visual inspection.	1	10						
	Seat becomes free to rotate from latch	Seat has an additional degree of rotational freedom	7	Excessive force on latch joint yields connection hardware	Seat leg-latch to eliminate any single	2	Visual Inspection	2	28						
Latch/ Secure latch to rail	latch breaks	Seat is no longer guided by rail.	8	Excessive upward vertical force yields latch-rail connection.	Latch-rail connection designed to support full seat load when inverted. Operator instruction on not flipping vehicle.	1	Confirmation signal shows unlocked in all scenarios	2	16						
	Latch wears	Seat has additional "play" and is not secured to rail strictly.	5	Extended operation of seat without proper maintenance or cleaning	Operator instruction on maintenance and cleaning, as well as visual inspection techniques.	2	Manual counter to count how many times have been engaged and disengaged	5	50	Endurance strength testing of seat latches, as well as following recommendations for periodic inspection	Nicholas- 5/12	Inspection outlined in user manual	8	2	1
Lock/ Support users weight and dynamic forces	Lock buckles	Latch is no longer secured in either position	8	1.) Car crash 2.) Excessive force on locking mechanism	Design for a high safety factor in impact load cases	1	Confirmation signal shows unlocked in all scenarios	3	24						
	Lock Shears	Latch is no longer secured in either position	8	excessive forces on locking mechanism	Design for a high safety factor in impact load cases	1	Confirmation signal shows unlocked in all scenarios	3	24						

												Action Results			
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	Actions Taken	Severity	Occurence	Criticality
Lock/ Provide cofirmation of locking	Confirmation fails	User is unclear whether latch is engaged or disenngaged	5	wear on confirmation device	1.) Fatigue/Failure anlysis	1	Audible inspection ("No Click")	6	30						
	Confirmation shows when system is not locked	User believes system is engaged despite actual system state being ambigous	9	1.) Missuse of locking device 2.) Wear of confirmation system	1.) Design a simple system 2.) Create a simple instruction manual	1	Operator shakes seat to confirm lock	6	54	Recommending a test wiggle of the seat after locking it in place in the user manual	Nicholas- 5/12	Inspection outlined in user manual	8	4	1
Lock/ Detach lock from rail	Seat gets stuck in place	Operator is unable to move seat from jammed position	7	1.) Lock becomes stiff and difficult to operate 2.) Jamming of locking device	1.) Keep lock well lubricated	1	Physical Inspection	1	7						
General/ Provide ease of use	System requires too much force to actuate	Operator is injured in attempt to move seat.	10	Improper actuation design	1.) Simple Design testing 2.) Stress Analysis	3	Seat does not move when baby arms Jacob pushes it	1	30						
General/ Holds components together	Components break apart	Seat is free to move about cabin	10	1.) Poor welds 2.) Improper bolt specs	1.) Inspect welds 2.) Inspect parts 3.) Provide visual inspection techniques	2	Visual Inspection	1	20						
General/ Attaches rail to vehicle	Rail shears off floor	Entire seating system can move about cabin	10	Bolts snap	Ensure proper safety factors are used	1	Visual and Physical Inspection	1	10						
	car frame yeilds	A. car becomes deformed B. rail system becomes deformed	10	Improper mounting of rail	Will design rail mounting for structural part of car frame	1	Visual inspection	2	20						
General/ Maintain apperance	Looks bad	Customers do not trust product based on appearance	2	Customers opinions' do not align with designers'	Send out design to potential customers for aesthetic approval	2	Visual inspection	3	12						
General/ Protect metal	Plastic coverings create sharp edges when broken	User injures/lacerates themself on exposed plastic edge	8	1.) User steps on covering and cracks it 2.) Heavy object is dropped on cover 3.) Latch breaks (see above failure modes)	Flexible enough plastic coverings are used	1	Visual inspection	1	8						
	Metal corrodes	User lacerates themselves on metal corrosion and contracts tetnis	4	1.) Oxidation 2.) Weather 3.) Over time	Ensure that ferrus metals are coated	3	Visual inspection	3	36						

Appendix AA. Track and Latch Team Purchased/Planned Materials Budget



Purchased/Planned Materials Budget

Title of Senior Project:	Reconfigurable Seat Track and Latch
Team members:	Kai Quizon, Alex Kuznik, Nicholas Holman, Jacob Winkler
Designated Team Treasurer:	Jacob Winkler
Faculty Advisor:	Sarah Harding
Sponsor:	Dr. Joseph Mello, Mr. Ritch Hollingsworth
Quarter & Year project began:	Fall 2020
Materials budget given for this project:	**$1,000.00**

Date purchased	Vendor	Actual or Planned?	Description of items purchased	Transaction amount	
01/26/21	US Cargo Control	Actual	4' long 6061 aluminum L-track Costs $34.99 ($9.99 shipping)	$	47.52
02/04/21	Online Metals	Actual	Various round and rectangle steel bars for structural prototype	$	28.66
02/04/21	McMaster Carr	Actual	Music wire compression spring for structural prototype	$	4.98
TBD	Online Metals	Planned	2"x3", 24" long 1018 CD Steel bar 12"x12", 1/4" thick Delrin sheet 1/2" round x 24" long 1018 CD steel rod 1/4"x12"x12" 1018 CD steel plate 3/16" round x 12" long 1018 CD steel rod 5/8" round x 12" long 1018 CD steel rod	$	209.00
TBD	Aircraft Extrusions Co	Planned	12' long 7075 aluminum airline track	$	150.00
TBD	McMaster Carr	Planned	10X 1/4-20 Countersink Flat-head steel bolts (PN: 90471A416) 4X #6-32-5/8 Screw (PN: 92220A144) 2X Compression Spring, 0.3" OD, 0.21" ID, 1-1/2" Long (PN: 9434K162) 2X Drill Bushing, 0.5" ID, 5/8" OD, 3/8" Long (PN: 8491A665) 4X 1/2-13-3.25 Cap Screw (PN: 91257A725) 4X 1/2-13 Hex Nut (PN: 93827A245) 18X #6-32-1/2 Screw (PN: 92220A143)	$	75.00
TBD	Amazon	Planned	12"x24"x0.25" Aluminum Plate 6061-T651	$	50.00
			Total expenses:	**$**	**565.16**

Budget:	**$**	**1,000.00**
Actual expenses:	**$**	**565.16**
Remaining balance:	**$**	**434.84**

Appendix AB. Articulation Static Load MATLAB and Derivation

MATLAB Linkage Position and Load

```
%----- F74 Senior Project Config. Seat Articulation Linkage Load Tool ----%
%                                                                         %
%      Script by: Rick Hall                                               %
%      Developed: 02-10-2021                                              %
%                                                                         %
%-------------------------------------------------------------------------%

clc; clear; close all;


OX = 0;

Th2 = 10;
```

Define Geometry

```
% Known Pin Locations:
pF = [0;
      0];
pE = pF + [-2;
           36-2.5];


O2 = pE;
O4 = pF;

% Known Link Lengths
[L1,Th1] = MagVec(pE, pF);
L2 = 25.77;     %Angle Follower
L3 = 8.29;      %Connector
L4 = 1.75;      %D-Brace Prot.
L5 = 17.54;     %D-Brace Ext.
dA = deg2rad(105);

Th2 = deg2rad(Th2 + 90) - Th1;

% Seat Bottom
[L6,Th7] = MagVec([-8.70;1.06]); % Relative Location of Pins in Seat when Horizontal
Th7 = pi - Th7;
L7 = 16.70; % Total length of seat

% Seat Back
L8 = 23.0 + 1.3;    % Length of Seat Back
o8 = (1 + 1.06);      % Offset between pin and slider
```

```
L = [L1, L2, L3, L4, L5, L6, L7, L8];
clear L1 L2 L3 L4 L5 L6 L7;
```

Define Load Case

```
Pm = 600;
tPm = deg2rad(90);

Pk = 0;
tPk = deg2rad(0);
```

Run Linkage Analysis

```
% Algebraic Simplifications:
    K1 = L(1)/L(2);
    K2 = L(1)/L(4);
    K3 = (L(2)^2 - L(3)^2 + L(4)^2 + L(1)^2)/(2*L(2)*L(4));
    K4 = L(1)/L(3);
    K5 = (L(4)^2 - L(1)^2 - L(2)^2 - L(3)^2)/(2*L(2)*L(3));

    K = [K1, K2, K3, K4, K5];
    clear K1 K2 K3 K4 K5;

    A = cos(Th2) - K(1) - K(2).*cos(Th2) + K(3);
    B = -2.*sin(Th2);
    C = K(1) - (K(2) + 1).*cos(Th2) + K(3);
    D = cos(Th2) - K(1) + K(4).*cos(Th2) + K(5);
    E = -2.*sin(Th2);
    F = K(1) + (K(4) - 1).*cos(Th2) + K(5);

theta = [0, Th2];

if OX == 1
    theta(4) =  2.*atan((-B - sqrt(B.^2 - 4.*A.*C))/(2.*A));
    theta(3) =  2.*atan((-E - sqrt(E.^2 - 4.*D.*F))/(2.*D));
else
    theta(4) =  2.*atan((-B + sqrt(B.^2 - 4.*A.*C))/(2.*A));
    theta(3) =  2.*atan((-E + sqrt(E.^2 - 4.*D.*F))/(2.*D));
end

clear A B C D E F K;

% Compute Linkage Position Vectors
Rd  = [ 0, L(1);
        0,   0];

Ra  = [ 0, L(2)*cos(theta(2));
```

```
        0, L(2)*sin(theta(2))];

Rb  = [ L(2)*cos(theta(2)), L(2)*cos(theta(2)) + L(3)*cos(theta(3));
        L(2)*sin(theta(2)), L(2)*sin(theta(2)) + L(3)*sin(theta(3))];

Rc  = [ Rd(:,2), (Rd(:,2)+[L(4)*cos(theta(4));
                           L(4)*sin(theta(4))])];

Re  = [Rc(:,1), (Rc(:,1)+[L(5)*cos(theta(4)-dA);
                          L(5)*sin(theta(4)-dA)])];


Rd = ShiftVec(RotVec(Rd,Th1-pi),O2);
Ra = ShiftVec(RotVec(Ra,Th1-pi),O2);
Rb = ShiftVec(RotVec(Rb,Th1-pi),O2);
Rc = ShiftVec(RotVec(Rc,Th1-pi),O2);
Re = ShiftVec(RotVec(Re,Th1-pi),O2);

theta = theta + (Th1-pi);

% Compute position of seat bottom and seat back

xe = Rd(1,1) + o8*cos(pi/2 + theta(2));
ye = Rd(2,1) + o8*sin(pi/2 + theta(2));
xa = Re(1,2);
ya = Re(2,2);

beta = tan(theta(2));

% Find intersection numerically
cir = @(x) (sqrt(L(6).^2 - (x - xa).^2) + ya);
ln = @(x) (beta.*(x-xe) + ye);
clear beta;

rng = (xa-L(6)):(0.01/12):xa;
[~,inx] = min(abs(cir(rng) - ln(rng)));

xd = rng(inx);
yd = cir(xd);

Rf = [Re(:,2), [xd;
                yd]];
[~,Th6] = MagVec(Rf(:,1),Rf(:,2));

Rf = [Rf, Rf(:,2) + L(7).*[cos(Th6 + Th7);
                           sin(Th6 + Th7)]];

Rg = [Rf(:,2), Rf(:,2) - L(8).*[cos(theta(2));
                                sin(theta(2))]];

figure (1);
```

```
hold on;
axis equal;
ylim([-2.5/12, 48])

p1 = plot(Ra(1,:),Ra(2,:),'Color',[0.01 0.68 0.33]);
p2 = plot(Rb(1,:),Rb(2,:),'Color',[0.01 0.68 0.33]);
p3 = plot(Rc(1,:),Rc(2,:),'Color',[0.01 0.68 0.33]);
p4 = plot(Rd(1,:),Rd(2,:),'-.','Color',[0.01 0.68 0.33]);
p5 = fill([Re(1,:),Rc(1,2)],[Re(2,:),Rc(2,2)],[0.01 0.68 0.33],'edgecolor',[0.01 0.68 0.33]);
p5.FaceAlpha = 0.25;
p6 = fill(Rf(1,:),Rf(2,:),'b','edgecolor','b');
p6.FaceAlpha = 0.25;
P7 = plot(Rg(1,:),Rg(2,:),'b');
plot(xe,ye,'or')
plot(xd,yd,'or')

% Define Pin Locations for Load Analysis:
A  = Re(:,2);
B  = Rc(:,2);
C  = Ra(:,2);
D  = Rf(:,2);
E  = Rd(:,1);
Ep = [xe;ye];
F  = Rd(:,2);
P  = Rf(:,3);

% Relative location simplifications:

xfa = A(1) - F(1);
yfa = A(2) - F(2);
xfb = B(1) - F(1);
yfb = B(2) - F(2);
xbc = C(1) - B(1);
ybc = C(2) - B(2);
xec = C(1) - E(1);
yec = C(2) - E(2);
 xdE = Ep(1) - D(1);
 ydE = Ep(2) - D(2);
 xda = A(1) - D(1);
 yda = A(2) - D(2);
xfe = E(1) - F(1);
yfe = E(2) - F(2);
xfd = D(1) - F(1);
yfd = D(2) - F(2);
xfg = xfd;
yfg = yfd;
 xdp = P(1) - D(1);
 ydp = P(2) - D(2);
xdk = 0;
ydk = 0;
 xfk = 0;
```

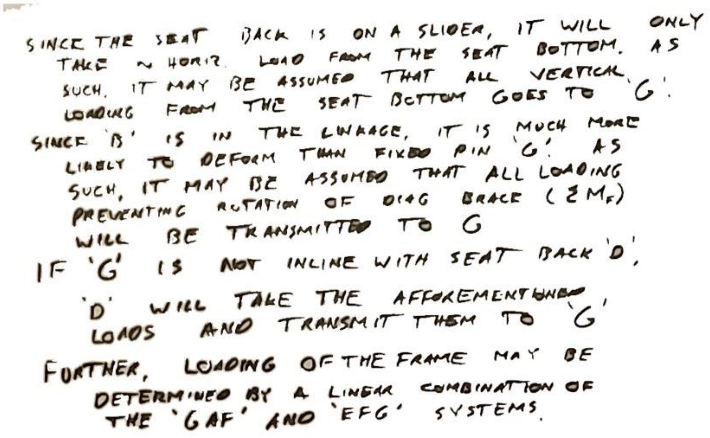
```
 yfk = 0;
 xfp = P(1) - F(1);
 yfp = P(2) - F(2);
%
% t2 = tan(theta(2) + pi/2);


ThA = theta(4)-dA;
ThD = theta(2)+pi/2;

% Statics for Rigid System
Pmx = Pm*cos(tPm);
Pmy = Pm*sin(tPm);
Pmt = [Pm;tPm];
Pm  = [Pmx;Pmy];

Pkx = Pk*cos(tPk);
Pky = Pk*sin(tPk);

V = Pmx + Pkx;
R = Pmy + Pky;
M = (Pmy*xfp - Pmx*yfp) + (Pkx*yfk - Pky*xfk);


%                   Fa,              Fgmx,  Fgmy
SysM = [         cos(ThA),             1, 0;
                 sin(ThA),             0, 1;
        (sin(ThA)*xda - cos(ThA)*yda), 0, 0];

EqM = [Pmx;
       Pmy;
       -Pmx*ydp + Pmy*xdp];

SolnM = SysM\EqM;

SysK = [         cos(ThD),             1, 0;
                 sin(ThD),             0, 1;
        (sin(ThD)*xdE - cos(ThD)*ydE), 0, 0];

EqK  = [Pkx;
        Pky;
        -Pkx*ydk + Pky*xdk];

SolnK = SysK\EqK;

Fa = SolnM(1).*[cos(ThA);
                sin(ThA)];
Fe = SolnK(1).*[cos(ThD);
                sin(ThD)];

Fgm = [SolnM(2);
```

```
       SolnM(3)];
Fgk = [SolnK(2);
       SolnK(3)];
Fg = Fgk + Fgm;

Ff  = -Fa;

Fc  = [0;0];
Fe  = [0;0];

Fat = [SolnM(1);
         ThA  ];
Fet = [   SolnK(1) ;
       ThD + 3*pi/2];
[X,T] = MagVec(Fg(:,1));
Fgt = [X;T];
Fft = [Fat(1);(Fat(2) - pi/2)];

Chk = [(-Fe(1) - Fg(1) - Fa(1) + V);
       (-Fe(2) - Fg(2) - Fa(2) + R);
       (Fe(1)*yfe - Fe(2)*xfe +Fg(1)*yfd - Fg(2)*xfg + M)];

V = PlotForce(Fa,A,0,0.001);
plot(V(:,1),V(:,2),'r');

clear inx rng X T t2;

function [V] = PlotForce(F,Pt,type,scale)

    if exist('scale','var')
        S = scale;
    else
        S = 1;
    end

    if exist('type','var') && type == 1
        V = [Pt(1), Pt(1) + F(1)*cos(F(2))*S;
             Pt(2), Pt(2) + F(1)*sin(F(2))*S];
    else
        V = [Pt(1), Pt(1) + F(1)*S;
             Pt(2), Pt(2) + F(2)*S];
    end
end

function [Vout] = RotVec(Vin,dTh,O)
% Rotates inputs (in x-y pairs) about a local origin. If no local origin
% is provided, the global origin is assumed.
Vout = Vin;
for n = 1:length(Vin(1,:))
    if exist('O','var')
        x  = Vin(1,n) - O(1);
```

```
        y  = Vin(2,n) - O(2);
    else
        x  = Vin(1,n);
        y  = Vin(2,n);
    end
    r  = sqrt(x^2 + y^2);
    Th = atan2(y,x);
    if Th < 0
        Th = Th + 2*pi;
    end
    Th = Th + dTh;

    if exist('O','var')
        Vout(1,n) = r*cos(Th) + O(1);
        Vout(2,n) = r*sin(Th) + O(2);
    else
        Vout(1,n) = r*cos(Th);
        Vout(2,n) = r*sin(Th);
    end
end
end

function [M,Th] = MagVec(V,O)
% Provides the magnitude and direction of a vector relative to a given
% origin. If no origin is provided, the global origin will be assumed.
M = V(1,:).*0;
Th = M;
for n = 1:length(V(1,:))
    if exist('O','var')
        x  = V(1,n) - O(1);
        y  = V(2,n) - O(2);
    else
        x  = V(1,n);
        y  = V(2,n);
    end
    M(n)  = sqrt(x^2 + y^2);
    Th(n) = atan2(y,x);
    if Th(n) < 0
        Th(n) = Th(n) + 2*pi;
    end
end
end

function [Vout] = ShiftVec(Vin,O)
% Shifts a vector such that the output is relative to global point O,
% assuming an input relative to a local origin.
Vout = Vin.*0;
for n = 1:length(Vin(1,:))
    if exist('O','var')
        x  = Vin(1,n) + O(1);
        y  = Vin(2,n) + O(2);
```

```
    else
        x  = Vin(1,n);
        y  = Vin(2,n);
    end

    Vout(:,n) = [x;y];

end
end
```

Published with MATLAB® R2018b



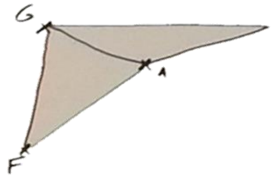
SINCE THE SEAT BACK IS ON A SLIDER, IT WILL ONLY TAKE ~ HORIZ. LOAD FROM THE SEAT BOTTOM. AS SUCH, IT MAY BE ASSUMED THAT ALL VERTICAL LOADING FROM THE SEAT BOTTOM GOES TO 'G'.

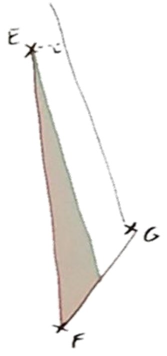
SINCE 'B' IS IN THE LINKAGE, IT IS MUCH MORE LIKELY TO DEFORM THAN FIXED PIN 'G'. AS SUCH, IT MAY BE ASSUMED THAT ALL LOADING PREVENTING ROTATION OF DIAG BRACE (ΣM_F) WILL BE TRANSMITTED TO G

IF 'G' IS NOT INLINE WITH SEAT BACK 'D', 'D' WILL TAKE THE AFFOREMENTIONED LOADS AND TRANSMIT THEM TO 'G'

FURTHER, LOADING OF THE FRAME MAY BE DETERMINED BY A LINEAR COMBINATION OF THE 'GAF' AND 'EFG' SYSTEMS.

SIMPLE MODEL:





E :

$$\Sigma F_x = -P_{M_x} + F_{A_x} + F_{G_{M_x}} = 0$$

$$\Sigma F_Y = -P_{M_y} + F_{A_y} + F_{G_{M_Y}} = 0$$

$$\Sigma M_G = P_{M_x} Y_{GM} - P_{M_y} X_{GM} \overbrace{- F_{A_x} Y_{GA} + F_{A_y} X_{GA}}^{\substack{-F\, c\, Y_{GA} + F \cdot s\, X_{GA} \\ (s \cdot X_{GA} \cdot c \cdot Y_{GA})F}} = 0$$

A :

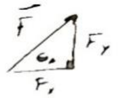
$$-\vec{F}_A = -(-\vec{F}_F) \Rightarrow \vec{F}_F = -\vec{F}_A$$

D :

$$\Sigma F_x = -P_{K_x} + F_{G_{K_x}} + F_{E_x} = 0$$

$$\Sigma F_Y = -P_{K_y} + F_{G_{K_y}} + F_{E_Y} = 0$$

$$\Sigma M_G = P_{M_x} Y_{GK} - P_{M_y} X_{GK} \underbrace{- F_{E_x} Y_{GE} + F_{E_y} X_{GE}}_{\substack{-F \cdot c \cdot Y_{GE} + F \cdot s \cdot X_{GE} \\ (s X_{GE} - c Y_{GF})F}}$$



$$F_y = F_x \tan\theta_A$$

$$F_x = F \cos\theta$$

$$F_y = F \sin\theta$$

Appendix AC. Articulation Stress-Strength MATLAB and Derivation

Stresses (Strength)

yield strength of carbon steel = 71,100 psi

yield strength of aluminum 6061 = 276 MPa (40,000 psi)

spLinkTookMKIII;

```
% Load Inputs
Pnx = Pm(1);
Pny = Pm(2);
% Pkx = Pk(1);
% Pky = Pk(2);
Fax = Fa(1);
Fay = Fa(2);
Fbx = 0;
Fby = 0;
Fcx = 0;
Fcy = 0;
Fdx = Fg(1);
Fdy = Fg(2);
Fex = Fe(1);
Fey = Fe(2);
Ffx = Ff(1);
Ffy = Ff(2);
Fgx = Fg(1);
Fgy = Fg(2);
```

Geometry inputs

```
lan = P-A;
lan = lan(1);
%lad = ;
laf1 = A-F;
laf = sqrt(laf1(1)^2 + laf1(2)^2);
%lbf = ;
%lbc = ;
%lce = ;
%ldk = ;
```

Seat Bottom

```
w = 19;
t = 1/4;
As = w*t;
```

```
I = (1/12)*w*t^3;
y = t/2;
M1 = -lan*Pny;
V = Pny;
Ps = Fdx;

sig_s_axial = Ps/As                      % Axial stress
sig_s_bending = M*y/I                    % bending stress @ A
tau_s = 3*V/(2*As)                       % Transverse Shear
```

```
sig_s_axial =

 -210.7642


sig_s_bending =

   6.1506e+04


tau_s =

  189.4737
```

Diagonal Brace

```
b = 2;
h = 1/4;
L = laf;
Ad = b*h;
th_d = 2*pi+ThA;
E = 10000e3;                % Aluminum
% E = 29700e3;              % Steel
y = b/2;
I = (1/12)*b^3*h;
Mf = -Fay*(laf*cos(th_d))+Fax*(laf*sin(th_d));
Pd = sqrt(Fay^2+Fax^2);

sig_d_axial = -Pd/Ad                    % Compression in diagonal brace
sig_d_bending = Mf*y/I                  % Bending stress in diagonal brace
Pcr_d = (4*pi^2*E*b*h^3)/(12*L^2)       % Buckling (compare Pcr to )
Faf = Pd
```

```
sig_d_axial =

  -2.8602e+03
```

```
sig_d_bending =

  -4.3656e-11


Pcr_d =

   3.3417e+03


Faf =

   1.4301e+03
```

Side Frame

```
w = 8;
t = 0.25;
Asf = w*t;
y = w/2;
I = (1/12)*w^3*t;
Rf = R + Ffy;
Vf = V + Ffx;
Mf = M;

sig_sf_axial = -Rf/Asf                      % Compression in side frame
sig_sf_bending = Mf*y/I                     % Bending stress @ bottom of seat frame
tau_sf = 3*Vf/(2*Asf)                       % Transverse Shear
```

```
sig_sf_axial =

  210.6323


sig_sf_bending =

   4.5649e+03


tau_sf =

 -300.8474
```

% Connector b = 2; h = 0.25; A = b*h; P = sqrt(Fcy^2*Fcx^2); L = 8.29;

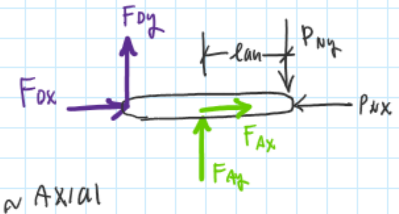
sig_c = -P/A; % Compression in connector Pcr_c = (4*pi^2*E*b*h^3)/(12*L^2); % Buckling (compare Pcr to) Fbc = P;

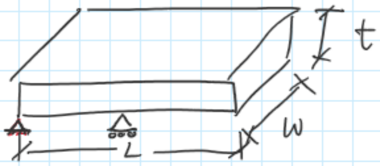
```
% % Angle Follower
% b = ;
% h = ;
% A = b*h;
% y = b/2;
% th_a = deg2rad();
% I = (1/12)*b^3*h;
% Mr = -Fcy*(lce*cos(th_a))-Fcx*(lce*sin(th_a));
% Fr = (Fcy+Fey)/(sin(90*(pi/180)-th_a));
% P = sqrt(Fcx^2+Fcy^2);
%
% sig_a1 = -P/A;                          % Compression in angle follower
% sig_a2 = Mr*y/I;                        % Bending stress @ roller
% tau_a = 3*Fr/(2*A);                     % Transverse Shear
%
% % Seat Back
% w = ;
% t = ;
% A = w*t;
% y = ;
% I = ;
% L = ldk;
% P = sqrt(Fkx^2+Fy^2);
%
% sig_back1 = -P/A;                       % Compression in seat back
% sig_back2 = Mr*y/I;                     % Bending stress @ roller
% tau_back = 3*Fr/(2*A);                  % Transverse Shear
```

Published with MATLAB® R2020b

Stress Analysis (Strength)

↳ Seat Bottom



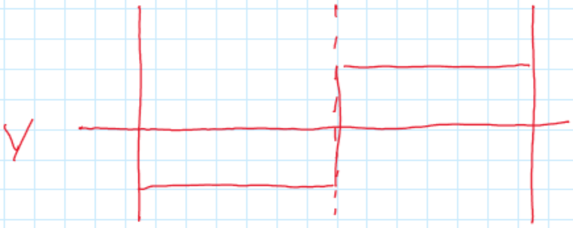


~ Axial

$$\boxed{\sigma = P/A} \quad \left\{ \begin{array}{l} P = F_{Dx} \\ A = wt \end{array} \right.$$

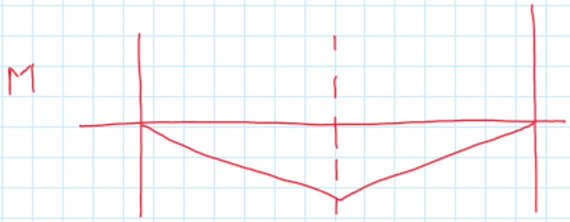
~ Bending (max @ A)

$$\boxed{\sigma = \frac{My}{I}} \quad \left\{ \begin{array}{l} M = P_{Ny}\, l_{an} \\ y = t/2 \\ I = \frac{1}{12} wt^3 \end{array} \right.$$

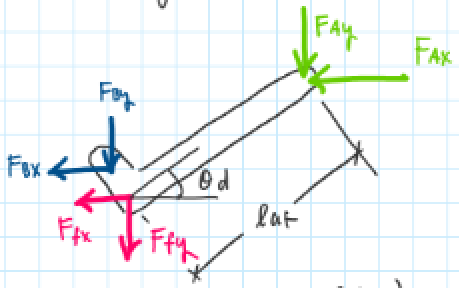


~ Transverse shear

$$\boxed{\tau_{xy} = \frac{3V}{2A}} \quad \left\{ \begin{array}{l} V = P_{Ny} \\ A = wt \end{array} \right.$$



↳ Diagonal Brace



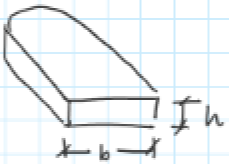
$$\circlearrowleft \Sigma M : -F_{Ay}(\ell_{fa}\cos\theta) + F_{ax}(\ell_{fa}\sin\theta) - M_f$$

$$M_f = -F_{ay}(\ell_{fa}\cos\theta) + F_{ax}(\ell_{fa}\sin\theta)$$

~ Axial (compression)

$$\boxed{\sigma_{By} = \frac{-P}{A}}$$

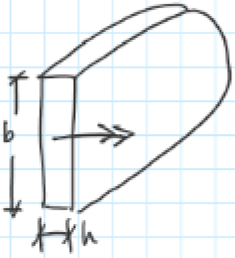
$$\begin{cases} P = \sqrt{F_{Ay}^2 + F_{Ax}^2} \\ A = bh \end{cases}$$



~ Bending (max @ F)

$$\boxed{\sigma_d = \frac{My}{I}}$$

$$\begin{cases} M = M_f \\ y = b/2 \\ I = \frac{1}{12}hb^3 \end{cases}$$



~ Buckling

↳ buckling will occur in the direction of least thickness

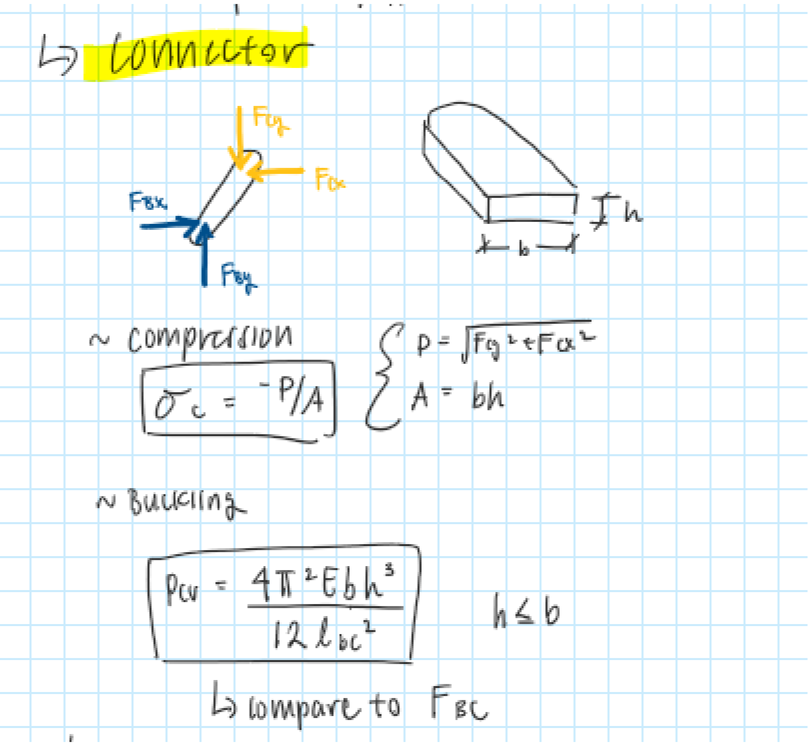
↳ $C = 4$ (fixed-fixed)

$$\frac{P_{cr}}{A} = \frac{C\pi^2 E}{(\ell/k)^2} \qquad k^2 = h^2/12$$

$$A = bh$$

$$\boxed{P_{cr} = \frac{4\pi^2 E b h^3}{12\,\ell_{af}^2}} \qquad h \leq b$$

↳ compare to F_{AF}



↳ Connector

~ compression

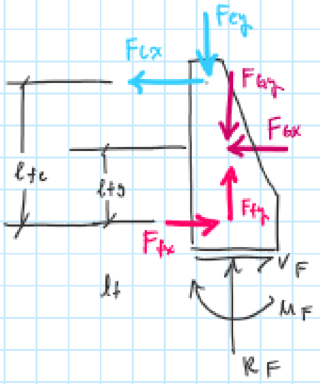
$$\boxed{\sigma_c = -P/A} \quad \begin{cases} P = \sqrt{F_{cy}^2 + F_{cx}^2} \\ A = bh \end{cases}$$

~ Buckling

$$\boxed{P_{cr} = \frac{4\pi^2 E b h^3}{12 \ell_{bc}^2}} \qquad h \le b$$

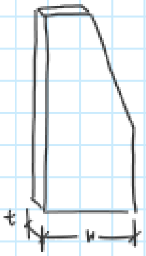
↳ compare to F_{BC}

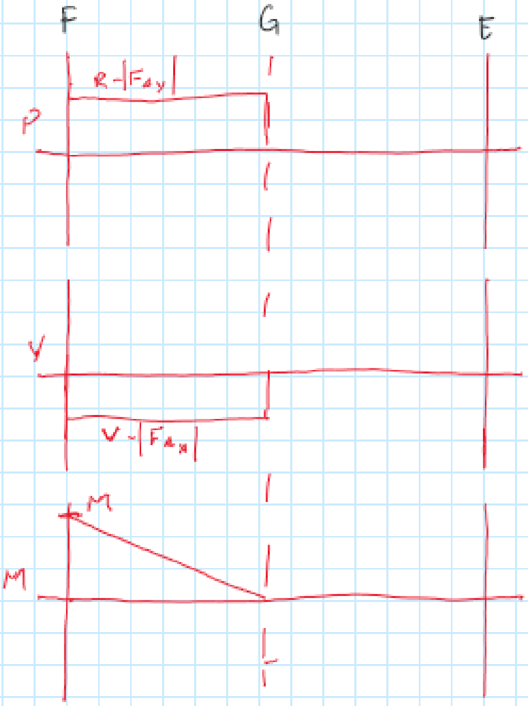
↳ Side Frame



$V_f = V + F_{fx}$

$R_f = R + F_{fy}$





~ Axial

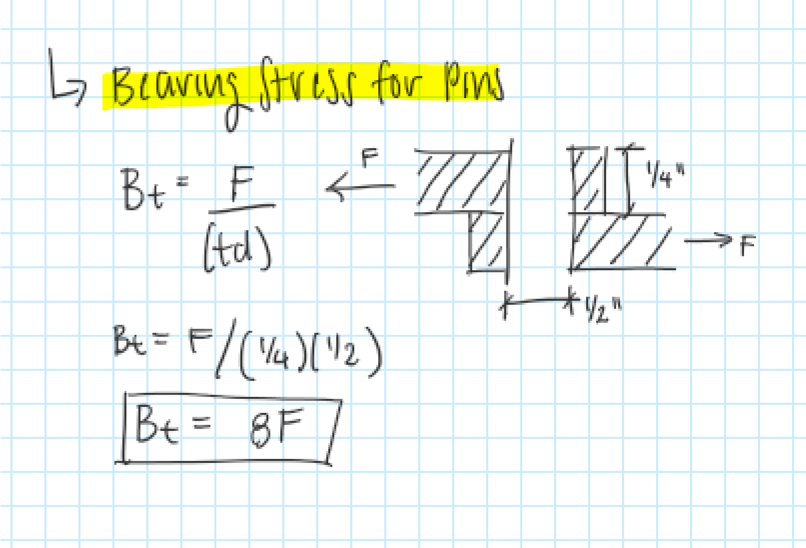
$\boxed{\sigma = P/A}$ $\begin{cases} P = R_f \\ A = wt \end{cases}$

~ Bending (@ Bottom of frame)

$\boxed{\sigma = \frac{My}{I}}$ $\begin{cases} M = M_F \\ y = w/t \\ I = \frac{1}{12} w^3 t \end{cases}$

~ Transverse Shear

$\boxed{\tau = \frac{3V}{2A}}$ $\begin{cases} V = V_f \\ A = wt \end{cases}$



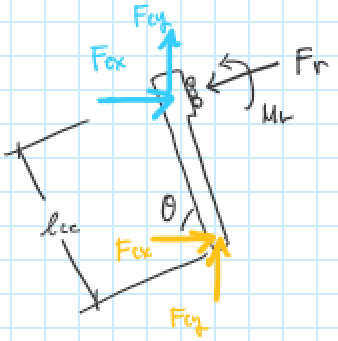
↳ Bearing Stress for Pins

$$B_t = \frac{F}{(td)}$$

$$B_t = F/(1/4)(1/2)$$

$$\boxed{B_t = 8F}$$

↳ Angle Follower



$$\Sigma F_y: -F_r \sin(90-\theta) + F_{cy} + F_{cy} = 0$$

$$F_r = \frac{F_{cy} + F_{cy}}{\sin(90-\theta)}$$

$$\Sigma M: M_r + F_{cy}(\ell_{cc}\cos\theta) + F_{cx}(\ell_{cc}\sin\theta) = 0$$

$$M_r = -F_{cy}(\ell_{cc}\cos\theta) - F_{cx}(\ell_{cc}\sin\theta)$$

~ Axial

$$\boxed{\sigma = P/A} \quad \begin{cases} P = \sqrt{F_{cx}^2 + F_{cy}^2} \\ A = bh \end{cases}$$

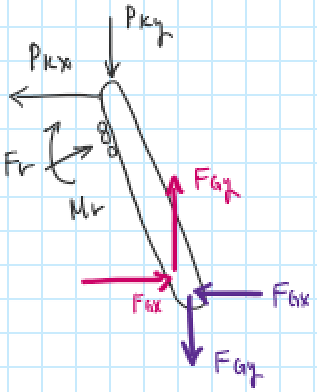
~ Bending (@ roller)

$$\sigma = \frac{My}{I} \quad \begin{cases} M = M_r \\ y = b/2 \\ I = \frac{1}{12} b^3 h \end{cases}$$

~ Transverse Shear

$$\tau = \frac{3V}{2A} \quad \begin{cases} V = F_r \\ A = bh \end{cases}$$

↳ Seat Back



~ compression

$$\boxed{\sigma_c = -P/A} \quad \begin{cases} P = \sqrt{F_{Kx}^2 + F_{Ky}^2} \\ A = bh \end{cases}$$

~ Bending (@ roller)

$$\boxed{\sigma = \frac{My}{I}} \quad \begin{cases} M = Mr \\ y = t/2 \\ I = \frac{1}{12} wt^3 \end{cases}$$

~ Transverse Shear

$$\tau = \frac{3V}{2A} \quad \begin{cases} V = Fr \\ A = Wt \end{cases}$$

~ Buckling

$$\boxed{P_{cr} = \frac{4\pi^2 E b h^3}{12 l_{AK}^2}} \qquad h \leq b$$

Appendix AD. Articulation Design Hazard Checklist

Y	N	
Y		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
	N	2. Can any part of the design undergo high accelerations/decelerations?
	N	3. Will the system have any large moving masses or large forces?
	N	4. Will the system produce a projectile?
	N	5. Would it be possible for the system to fall under gravity creating injury?
	N	6. Will a user be exposed to overhanging weights as part of the design?
Y		7. Will the system have any sharp edges?
	N	8. Will any part of the electrical systems not be grounded?
	N	9. Will there be any large batteries or electrical voltage in the system above 40 V?
	N	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	N	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
Y		12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	N	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	N	14. Can the system generate high levels of noise?
	N	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
Y		16. Is it possible for the system to be used in an unsafe manner?
	N	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, on the reverse side add:

1. a complete description of the hazard,
2. the corrective action(s) you plan to take to protect the user, and
3. a date by which the planned actions will be completed.

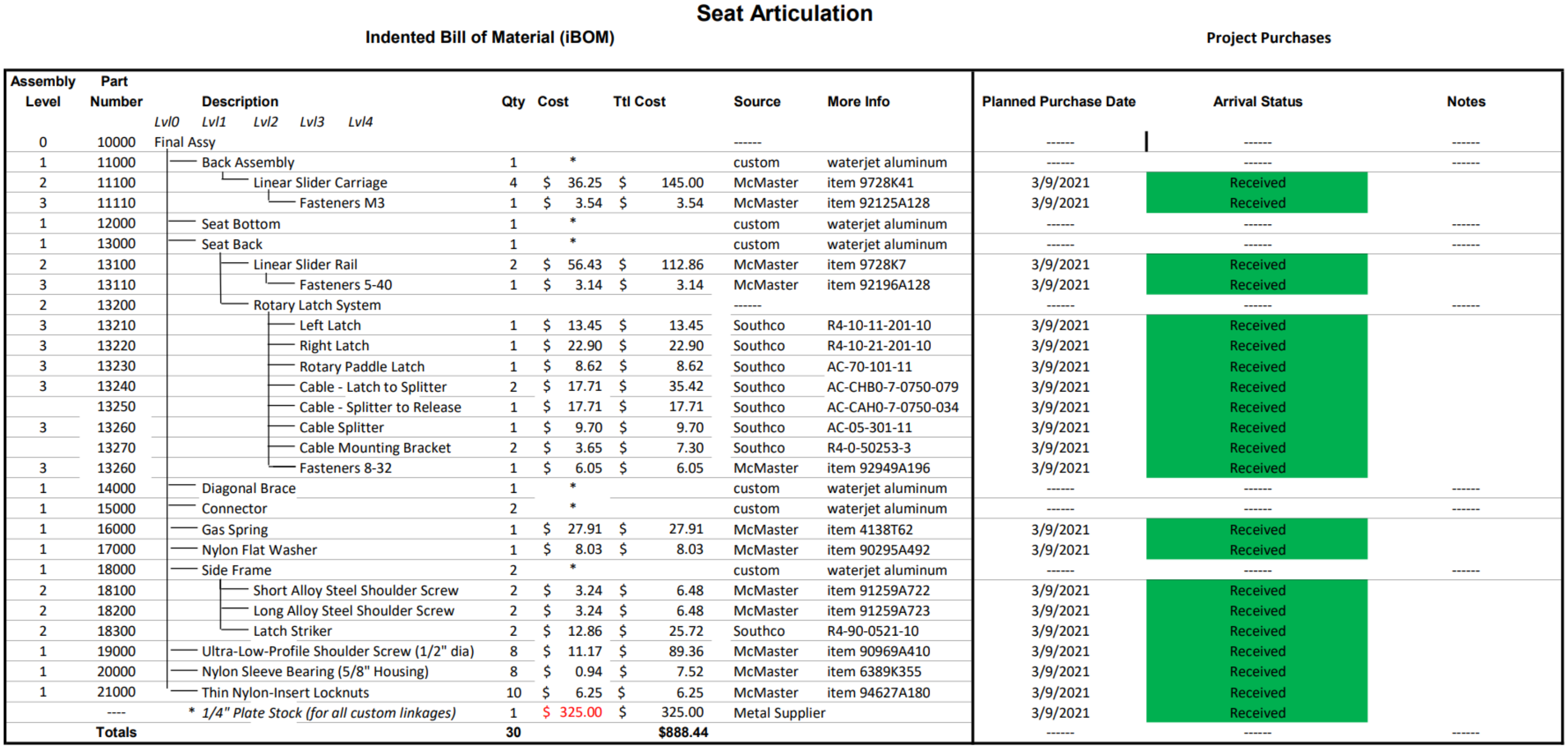
Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Pinch Points	1. Cover/Shield 2. Remove user exposure to pinch point	2/10/2021	n/a
Sharp edges	3. Powder coat all linkages 4. Fillet or round out all sharp edges in design	2/10/2021	n/a
Physical effort Exerted	1. Gas Spring will be implemented to aid in lifting the seat 2. Reduce weight of prototype	2/10/2021	6/3/21
Used in Unsafe Manner	3. Intuitive design that is easy to use 4. addition of a warning label	5/13/2021	n/a

Appendix AE. Articulation Failure Mode and Effects Analysis (FMEA)

												Action Results			
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**	**Actions Taken**	**Severity**	**Occurence**	**Criticality**
Seat/Articulate	Seat does not nest / articulate	a) linkage binds (completely) b) linage siezes	7	1) Seat not assembled correctly 2) Linkages misaligned 3) Seat too large	1) Clear Assembly plan 2) Alignment check 3) Catalog of Parts for Assembly	3	Operator Testing	1	21						
Seat/Support User	Seat frame buckles/fails	a) Frames buckle b) Frames crack c) Sharp Edges Exposed d) Unusable/Potential User Injury	10	1) Seat not assembled correctly 2) Seat too thin 3) Fastener holes shear	1) Clear Assembly plan 2) Alignment check 3) Failure Analysis and Testing 4) Assess probable weight of users	2	Testing	2	40						
	Seat flexes excessively	Seat feels unsafe	4	1) Seat not assembled correctly 2) Seat too thin 3) Fastener holes shear	1) Assess probable weight of users 2) Failure Analysis 3) Deflection Analysis	3	Testing	2	24						
Linkage/Achieve End Constraints	Linkage does not reach constraints	a) Linkage binds prior to constraint b) Slot obstructed	6	1) Seat not assembled correctly 2) Slot misaligned 3) Linkages wrong lengths	1) Linkage Development Analysis (To double check and optimize dimensions) 2) Ensure sufficient precision in manufacturing is achieved.	3	Operator Testing	2	36						
	Linkage exceeds expected constraints	a) linkage falls out of guide slots	8	1) Seat not assembled correctly 2) Slot misaligned 3) Linkages wrong lengths	1) Linkage Development Analysis (To double check and optimize dimensions) 2) Ensure sufficient precision in manufacturing is achieved.	1	Operator Testing	2	16						
Linkage/Support Loads	Linkage Breaks	a) Linkage fractures b) Potential chair collapse c) Linkage will not articulate d) User may be injured	9	1) Linkage too thin 2) Fasterners shear 3) Pins fail	1) Assess probable weight of users 2) Failure Analysis 3) Deflection Analysis	3	Testing	2	54	1) Ensure linkage failure is separated from seat failure (seat won't collapse)	Rick - 5/6/21	FEA Used to design seat with safety factor in mind, Load testing will confirm FEA validity	9	3	5
	Linkage flexes	Seat moves due to inadequate support, Seat feels unsafe	5	1) Linkage too thin 2) Fasterners shear 3) Pins fail	1) Assess probable weight of users 2) Failure Analysis 3) Deflection Analysis	7	Testing	3	105	1) Redesign frame for Hard Stops on Brace	Rick - 5/6/21	Hard Stops Implemented in Design	5	7	7
Linkage/Minimize Movement Effort	Linkage binds	a) paired linkages move at different rates b) link damage (bent)	4	1) Seat not assembled correctly b) Linkage wrong lengths c) Linkage misaligned d) Pins get stuck	1) Clear Assembly plan 2) Alignment check 3) Proper testing	5	Operator Testing	5	100	1) Design links for transverse stiffness 2) Strength test links for Buckling 3) Design paired linkages to minimize twisting	Anil - 5/11/21	User Testing will confirm safety	4	5	10
	Linkage system is excessively stiff	a) Seat is difficult to articulate b) User is inconvenienced	5	1) Seat not assembled correctly b) Linkage wrong lengths c) Linkage misaligned d) Pins get stuck	1) Clear Assembly plan 2) Alignment check 3) Proper testing	2	Operator Testing	3	30						
General/Concealable	Articulation mechanics not covered	a) Seat not marketable b) User is injured c) Linkage is unattractive d) exposes pinch points c) linkage exposes sharp edges	5	1) Shieding falls off 2) Sheilding does not properly cover exposed linkages	1) Ensure proper shielding exsists 2) Ensure sufficient precision in manufacturing is achieved.	1	User Survey	2	10						
General/Hold Assembly together	Fasteners fail	a) Seat falls apart b) User is injured	9	1) Pins break 2) Fasteners are not torqued properly 3) Fasteners shear	1) Torque check all fasteners 2) Fastenser Shear analysis	1	Operator Testing	3	27						
	Press fits fail	a) linkage may fall apart b) lost motion impedes articulation	6	1) Pins break 2) Press fits do not fit 3) Pins or holes worn	1) Stress Analysis	1	Operator Testing	2	12						
General/Facilitate Smooth Movement	Bearing surfaces fail	Articulation becomes dificult (friction increase)	4	1) Bearings are worn 2) Bearing are not lubricated	1) Lifetime Analysis as possible 2) Lubrication 3) Clear Assembly Paln	2	Operator Testing	3	24						

G3 Engineering

Appendix AF. Articulation Indented Bill of Materials (iBOM)



Seat Articulation

Indented Bill of Material (iBOM)

Project Purchases

Assembly Level	Part Number	Description	Qty	Cost	Ttl Cost	Source	More Info	Planned Purchase Date	Arrival Status	Notes
		Lvl0 Lvl1 Lvl2 Lvl3 Lvl4								
0	10000	Final Assy				------		------	------	------
1	11000	Back Assembly	1	*		custom	waterjet aluminum	------	------	------
2	11100	Linear Slider Carriage	4	$ 36.25	$ 145.00	McMaster	item 9728K41	3/9/2021	Received	
3	11110	Fasteners M3	1	$ 3.54	$ 3.54	McMaster	item 92125A128	3/9/2021	Received	
1	12000	Seat Bottom	1	*		custom	waterjet aluminum	------	------	------
1	13000	Seat Back	1	*		custom	waterjet aluminum	------	------	------
2	13100	Linear Slider Rail	2	$ 56.43	$ 112.86	McMaster	item 9728K7	3/9/2021	Received	
3	13110	Fasteners 5-40	1	$ 3.14	$ 3.14	McMaster	item 92196A128	3/9/2021	Received	
2	13200	Rotary Latch System				------		------	------	------
3	13210	Left Latch	1	$ 13.45	$ 13.45	Southco	R4-10-11-201-10	3/9/2021	Received	
3	13220	Right Latch	1	$ 22.90	$ 22.90	Southco	R4-10-21-201-10	3/9/2021	Received	
3	13230	Rotary Paddle Latch	1	$ 8.62	$ 8.62	Southco	AC-70-101-11	3/9/2021	Received	
3	13240	Cable - Latch to Splitter	2	$ 17.71	$ 35.42	Southco	AC-CHB0-7-0750-079	3/9/2021	Received	
	13250	Cable - Splitter to Release	1	$ 17.71	$ 17.71	Southco	AC-CAH0-7-0750-034	3/9/2021	Received	
3	13260	Cable Splitter	1	$ 9.70	$ 9.70	Southco	AC-05-301-11	3/9/2021	Received	
	13270	Cable Mounting Bracket	2	$ 3.65	$ 7.30	Southco	R4-0-50253-3	3/9/2021	Received	
3	13260	Fasteners 8-32	1	$ 6.05	$ 6.05	McMaster	item 92949A196	3/9/2021	Received	
1	14000	Diagonal Brace	1	*		custom	waterjet aluminum	------	------	------
1	15000	Connector	2	*		custom	waterjet aluminum	------	------	------
1	16000	Gas Spring	1	$ 27.91	$ 27.91	McMaster	item 4138T62	3/9/2021	Received	
1	17000	Nylon Flat Washer	1	$ 8.03	$ 8.03	McMaster	item 90295A492	3/9/2021	Received	
1	18000	Side Frame	2	*		custom	waterjet aluminum	------	------	------
2	18100	Short Alloy Steel Shoulder Screw	2	$ 3.24	$ 6.48	McMaster	item 91259A722	3/9/2021	Received	
2	18200	Long Alloy Steel Shoulder Screw	2	$ 3.24	$ 6.48	McMaster	item 91259A723	3/9/2021	Received	
2	18300	Latch Striker	2	$ 12.86	$ 25.72	Southco	R4-90-0521-10	3/9/2021	Received	
1	19000	Ultra-Low-Profile Shoulder Screw (1/2" dia)	8	$ 11.17	$ 89.36	McMaster	item 90969A410	3/9/2021	Received	
1	20000	Nylon Sleeve Bearing (5/8" Housing)	8	$ 0.94	$ 7.52	McMaster	item 6389K355	3/9/2021	Received	
1	21000	Thin Nylon-Insert Locknuts	10	$ 6.25	$ 6.25	McMaster	item 94627A180	3/9/2021	Received	
	----	* *1/4" Plate Stock (for all custom linkages)*	1	$ 325.00	$ 325.00	Metal Supplier		3/9/2021	Received	
	Totals		**30**		**$888.44**			------	------	------

Appendix AG. Articulation Manufacturing Plan

Subsystem	Component	Purchase (P) Modify from Purchase (MP) Made from Raw Material (RM)	Raw Materials Needed to make/modify the part (for MP and RM only)	Where/how procured?	Equipment and Operations anticipate using to make the component	Key limitations of this operation places on any parts made from it
Linkages	Connector	RM	Steel Plate	Raw stock from metal supplier	Water Jet to: 1) cut the shape of linkage Reamer to: 1) to finish holes	Hole surface finish
	Diagonal Brace	RM	Steel Plate	Raw stock from metal supplier		Hole surface finish
	Angle Follower	RM	Steel Plate	Raw stock from metal supplier		Hole surface finish
	Pins	P	--	McMaster-Carr	--	--
	Carriage and Rail	P	--	McMaster-Carr	--	--
Support Frame	Side Frame	RM	Steel Plate	Raw stock from metal supplier	Water Jet to: 1) cut the shape of linkage Reamer to: 1) to finish holes	Hole surface finish
Seat Frames	Seat Bottom Frame	RM	Steel Plate	Raw stock from metal supplier	Water Jet to: 1) cut the shape of linkage Reamer to: 1) to finish holes	Hole surface finish
	Seat Back Frame	RM	Steel Plate	Raw stock from metal supplier		Hole surface finish
Locking	Latches	P	--	McMaster-Carr	--	--
	Remote Activation	P	--	McMaster-Carr	--	--
Fasteners	Bolts/Nuts/Washers	P	--	Home Depot	--	--
					Plate Metal: Steel or Aluminum	
					Dimensions: 4' x 4', 1/4" thick	

Appendix AH. Articulation Drawing Package

10000 – Top Level Assembly

11000 – Back Assembly

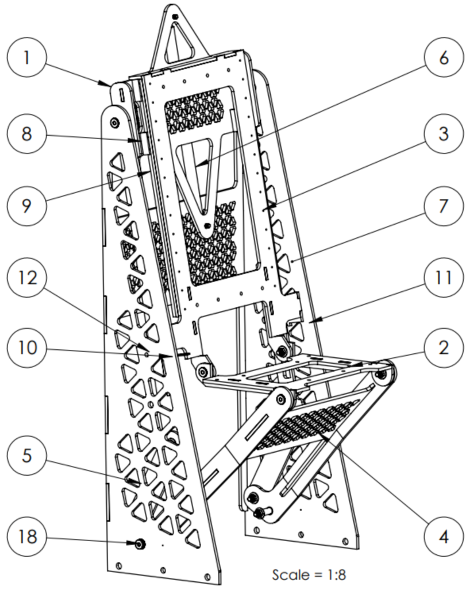
12000 – Seat Bottom

13000 – Seat Back

14000 – Diagonal Brace

15000 – Connector

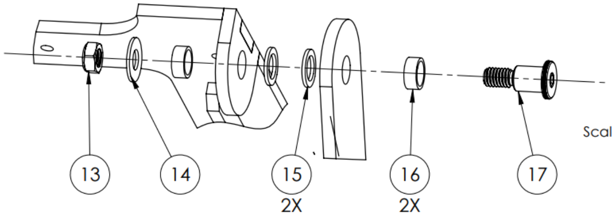
18000 – Side Frame



Scale = 1:8

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	11000	Angle Follower	1
2	12000	Seat Bottom Frame	1
3	13000	Seat Back Frame	1
4	14000	Diagonal Brace	1
5	15000	Connector Link	2
6	16000	Gas Spring	1
7	18000	Support Frame	1
8	11100	Linear Slider Carriage	4
9	13100	Linear Slider Rail	2
10	13220	Southco-R4-10-11-201-10 Rotary Latch	1
11	13210	Southco-R4-10-21-201-10 Rotary Latch	1
12	18300	Southco-R4-90-124-10 Latch Striker	2
13	21000	3/8" Thin Nylon-Insert Locknut	12
14	22000	3/8" Washer	12
15	17000	1/2" Nylon Washer	16
16	20000	Nylon Sleeve Bearing	20
17	19000	Ultra-Low-Profile Shoulder Screw	10
18	18200	Long Shoulder Screw	2

Typical Joint Assembly:



Scale = 1:2

Note: Dimensions are only included for critical features; complex features and/or aesthetic components are defined in DXF files for waterjet machining.

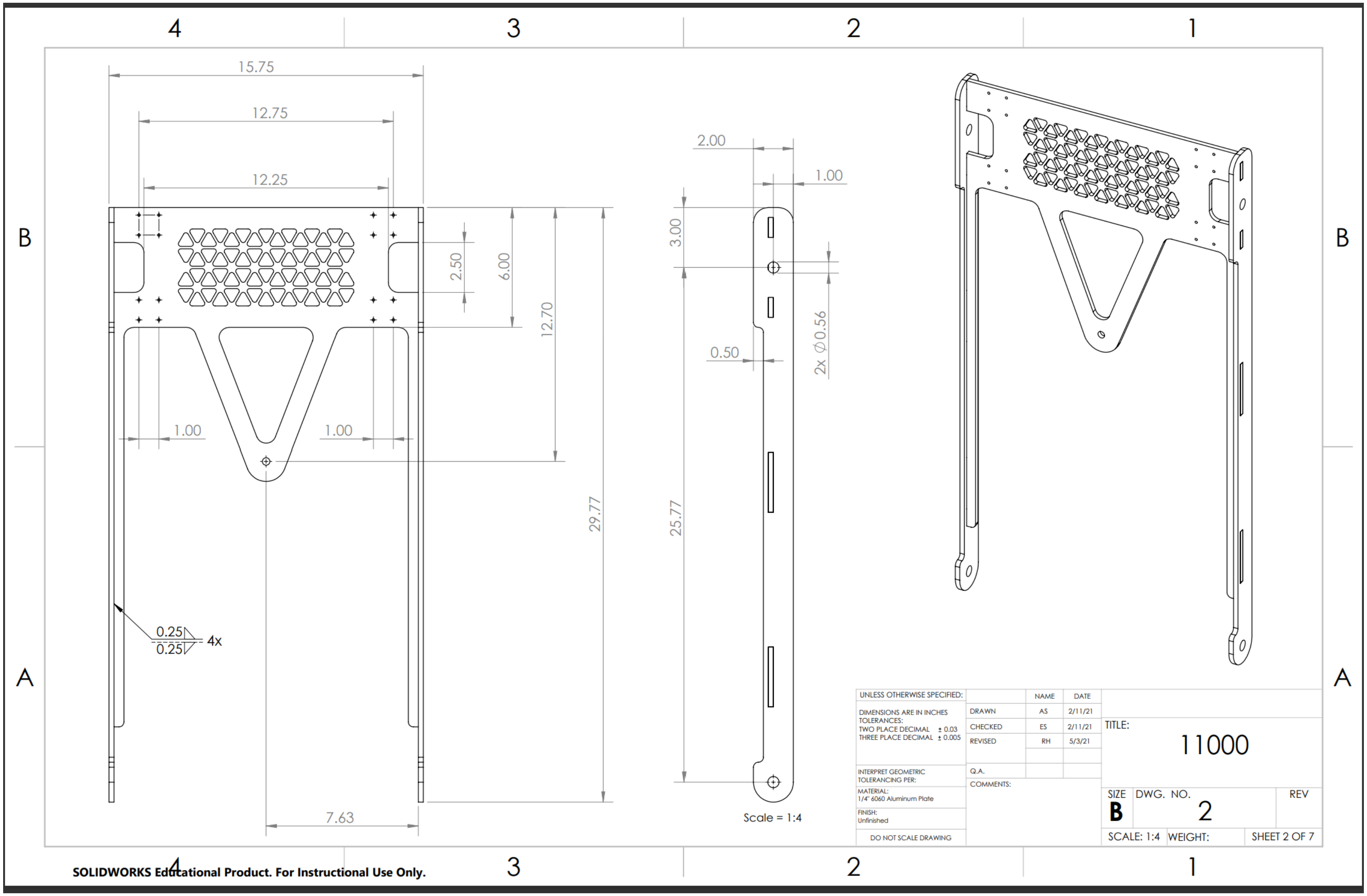
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ± 0.03
THREE PLACE DECIMAL ± 0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL:
1/4" 6060 Aluminum Plate
FINISH:
Unfinished
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AS	2/11/21
CHECKED	ES	2/11/21
REVISED	RH	5/3/21
Q.A.		

COMMENTS:

TITLE:
10000

SIZE B
DWG. NO. 1
REV
SCALE: 1:12
WEIGHT:
SHEET 1 OF 7



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ± 0.03
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL:
1/4" 6060 Aluminum Plate

FINISH:
Unfinished

DO NOT SCALE DRAWING

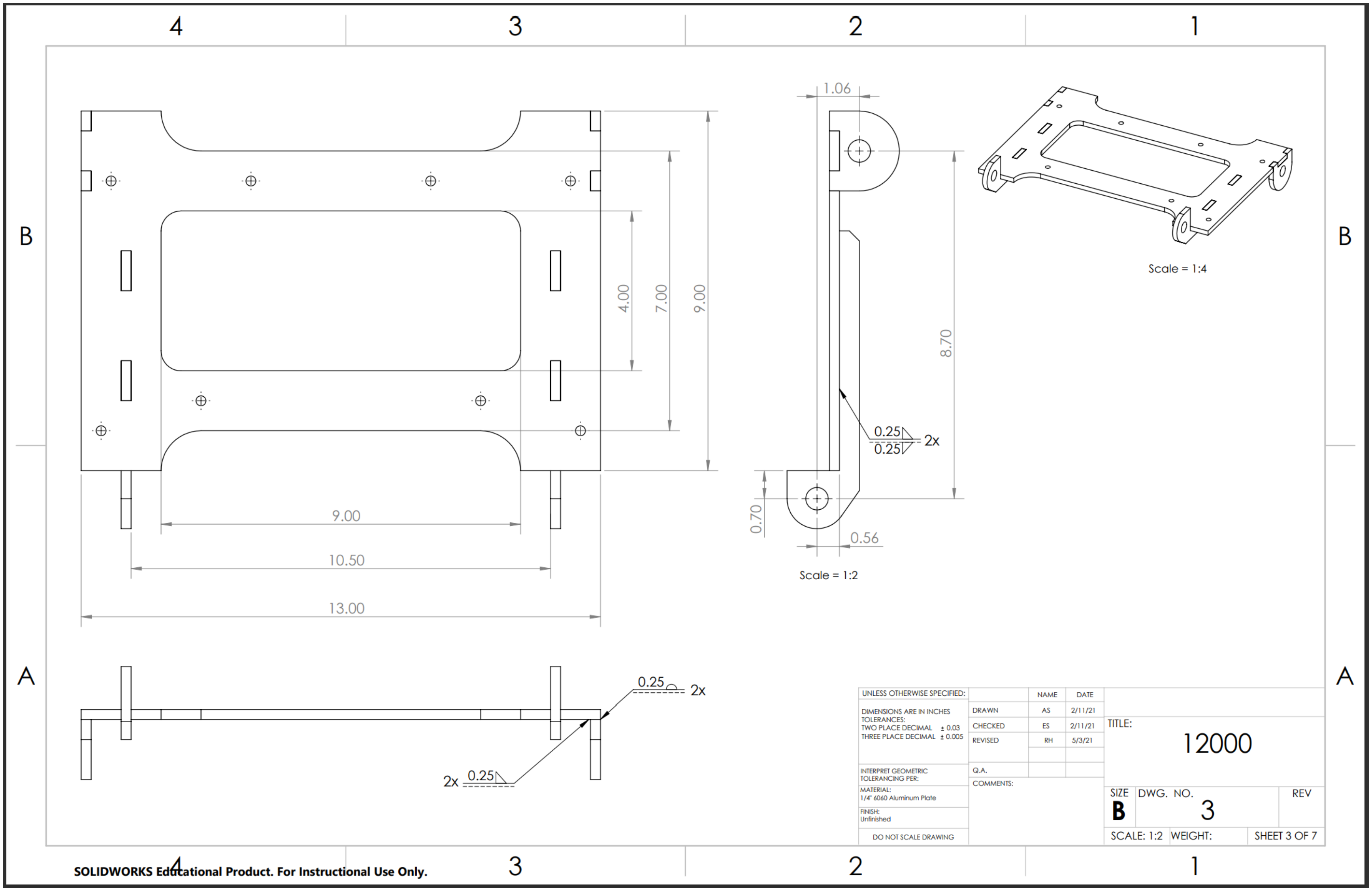
	NAME	DATE
DRAWN	AS	2/11/21
CHECKED	ES	2/11/21
REVISED	RH	5/3/21
Q.A.		

COMMENTS:

TITLE:
11000

SIZE B
DWG. NO. 2
REV

SCALE: 1:4
WEIGHT:
SHEET 2 OF 7



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ± 0.03
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL:
1/4" 6060 Aluminum Plate

FINISH:
Unfinished

DO NOT SCALE DRAWING

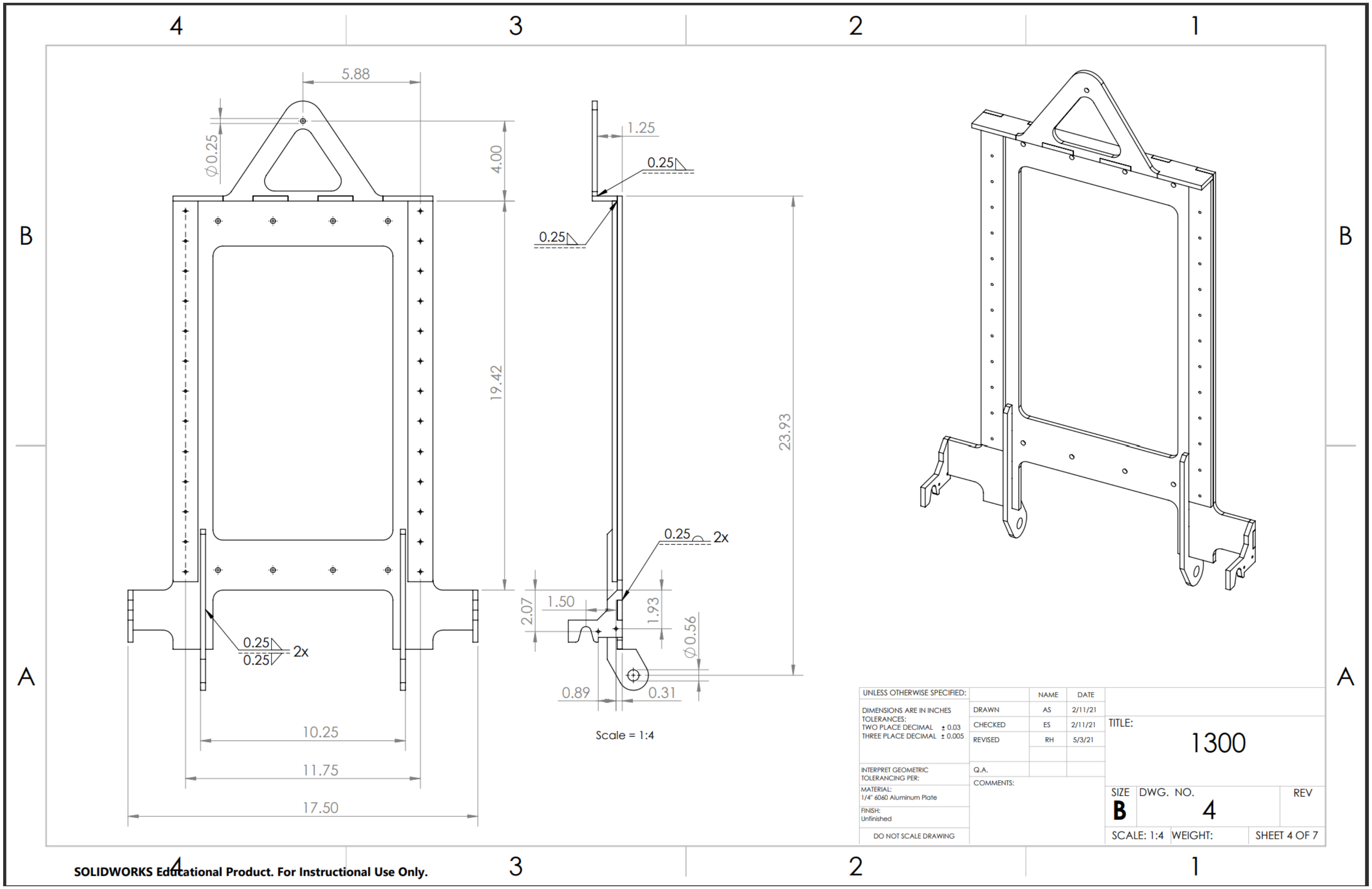
	NAME	DATE
DRAWN	AS	2/11/21
CHECKED	ES	2/11/21
REVISED	RH	5/3/21
Q.A.		

COMMENTS:

TITLE:
12000

SIZE
B
DWG. NO.
3
REV

SCALE: 1:2
WEIGHT:
SHEET 3 OF 7



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ± 0.03
THREE PLACE DECIMAL ± 0.005

	NAME	DATE
DRAWN	AS	2/11/21
CHECKED	ES	2/11/21
REVISED	RH	5/3/21
Q.A.		

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL:
1/4" 6060 Aluminum Plate

FINISH:
Unfinished

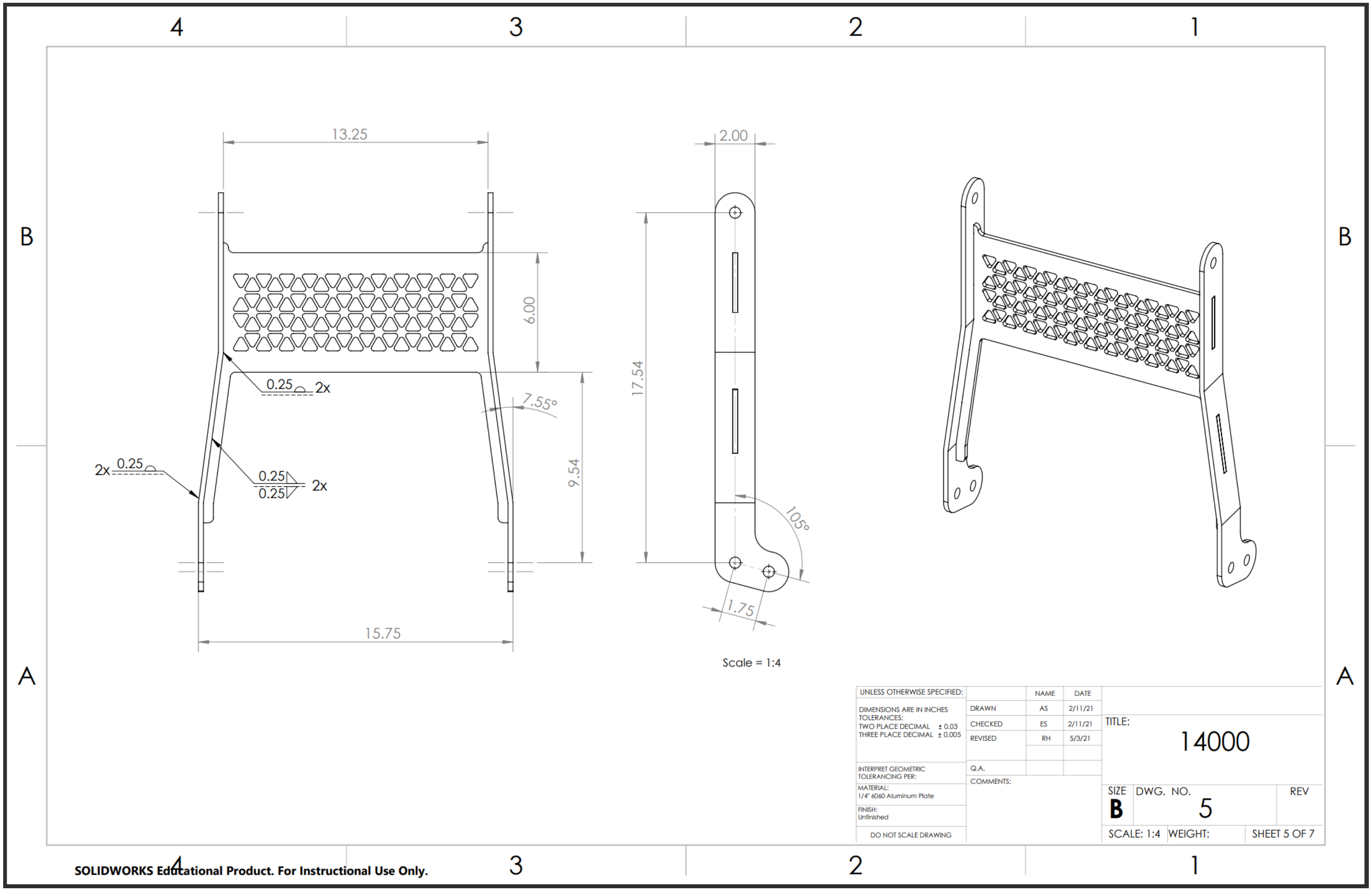
DO NOT SCALE DRAWING

COMMENTS:

TITLE:
1300

SIZE B
DWG. NO. 4
REV

SCALE: 1:4
WEIGHT:
SHEET 4 OF 7



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ± 0.03
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL:
1/4" 6060 Aluminum Plate

FINISH:
Unfinished

DO NOT SCALE DRAWING

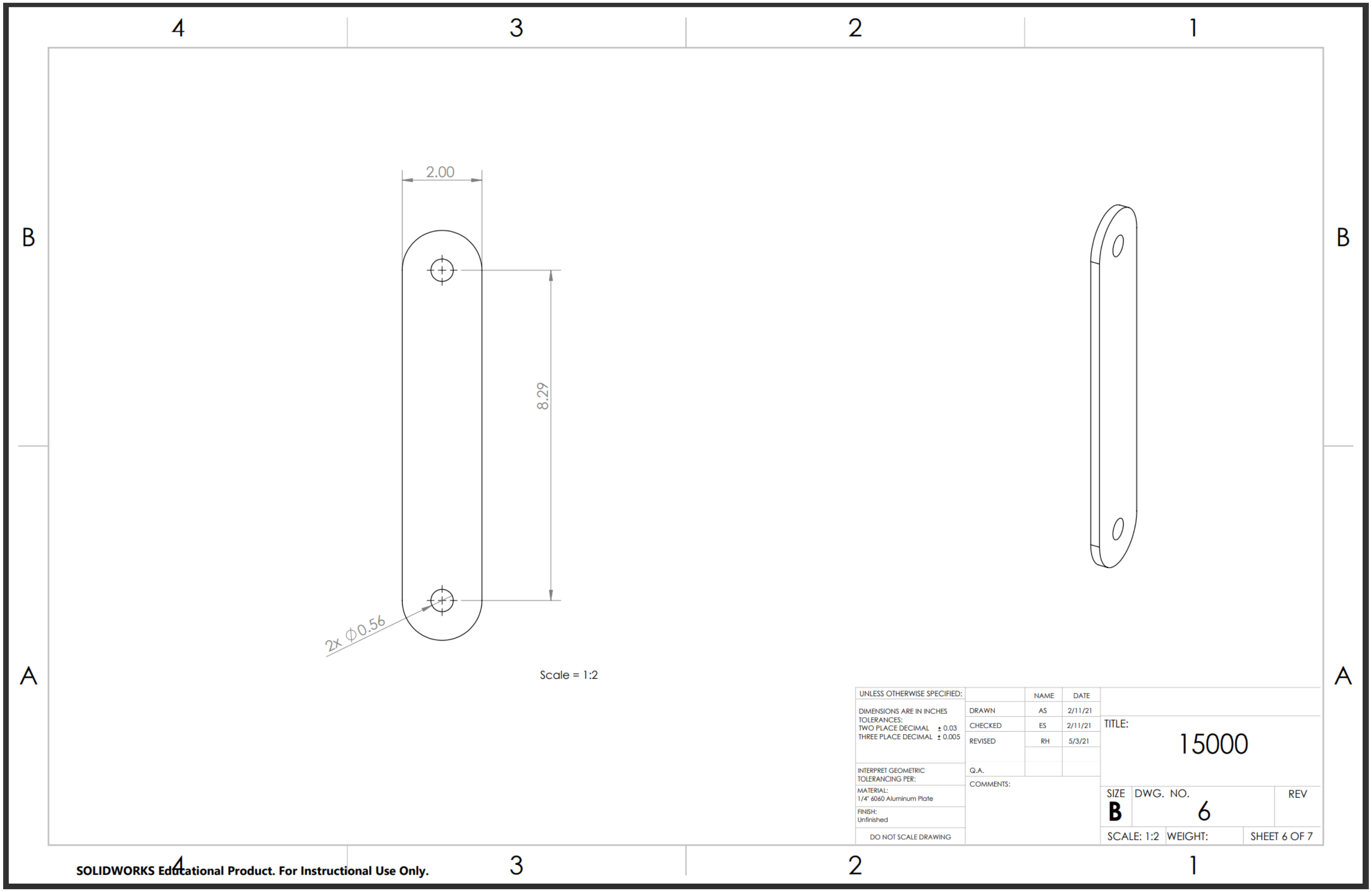
	NAME	DATE
DRAWN	AS	2/11/21
CHECKED	ES	2/11/21
REVISED	RH	5/3/21
Q.A.		

COMMENTS:

TITLE:
14000

SIZE B
DWG. NO. 5
REV

SCALE: 1:4
WEIGHT:
SHEET 5 OF 7



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ± 0.03
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL:
1/4" 6060 Aluminum Plate

FINISH:
Unfinished

DO NOT SCALE DRAWING

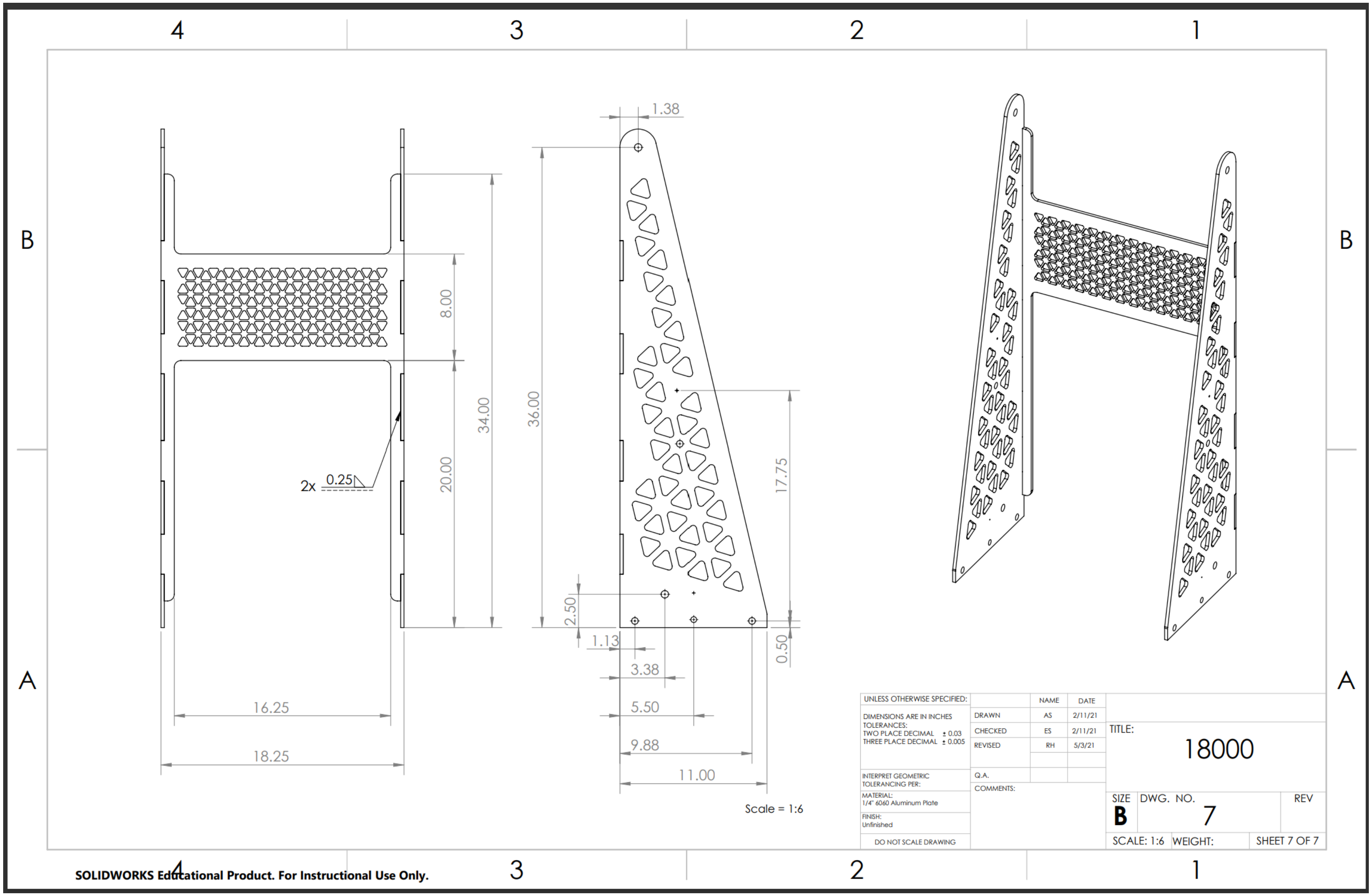
	NAME	DATE
DRAWN	AS	2/11/21
CHECKED	ES	2/11/21
REVISED	RH	5/3/21
Q.A.		

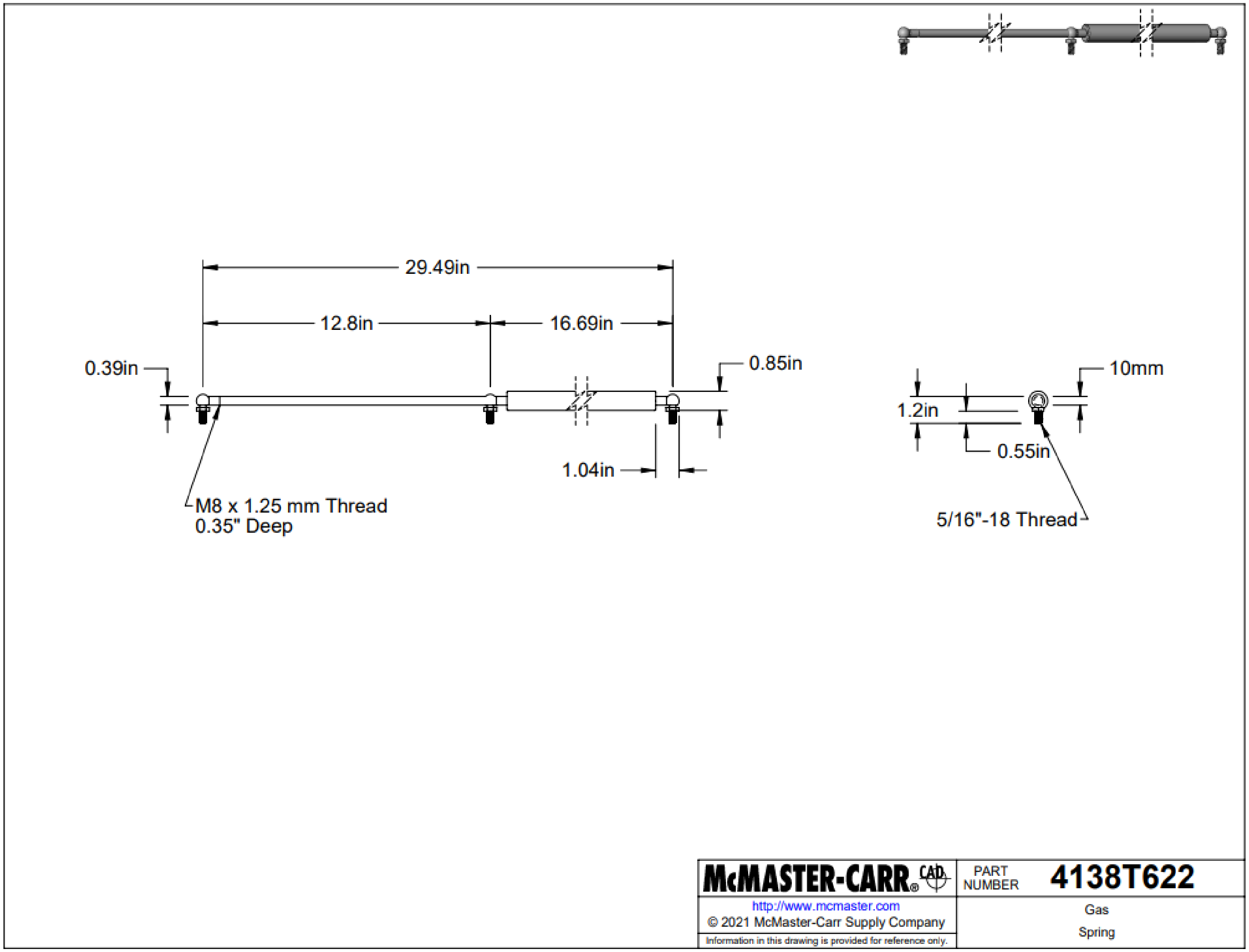
COMMENTS:

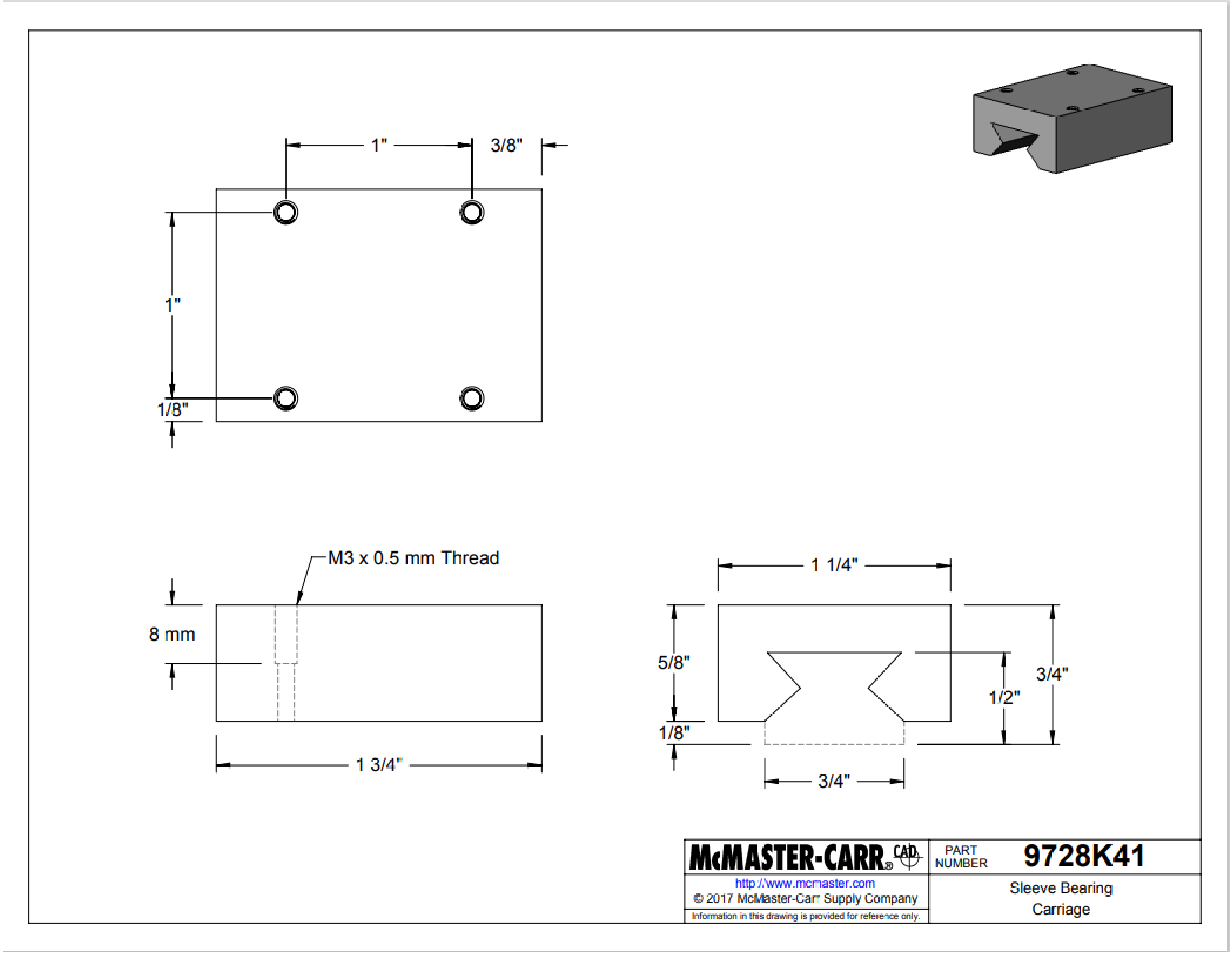
TITLE: 15000

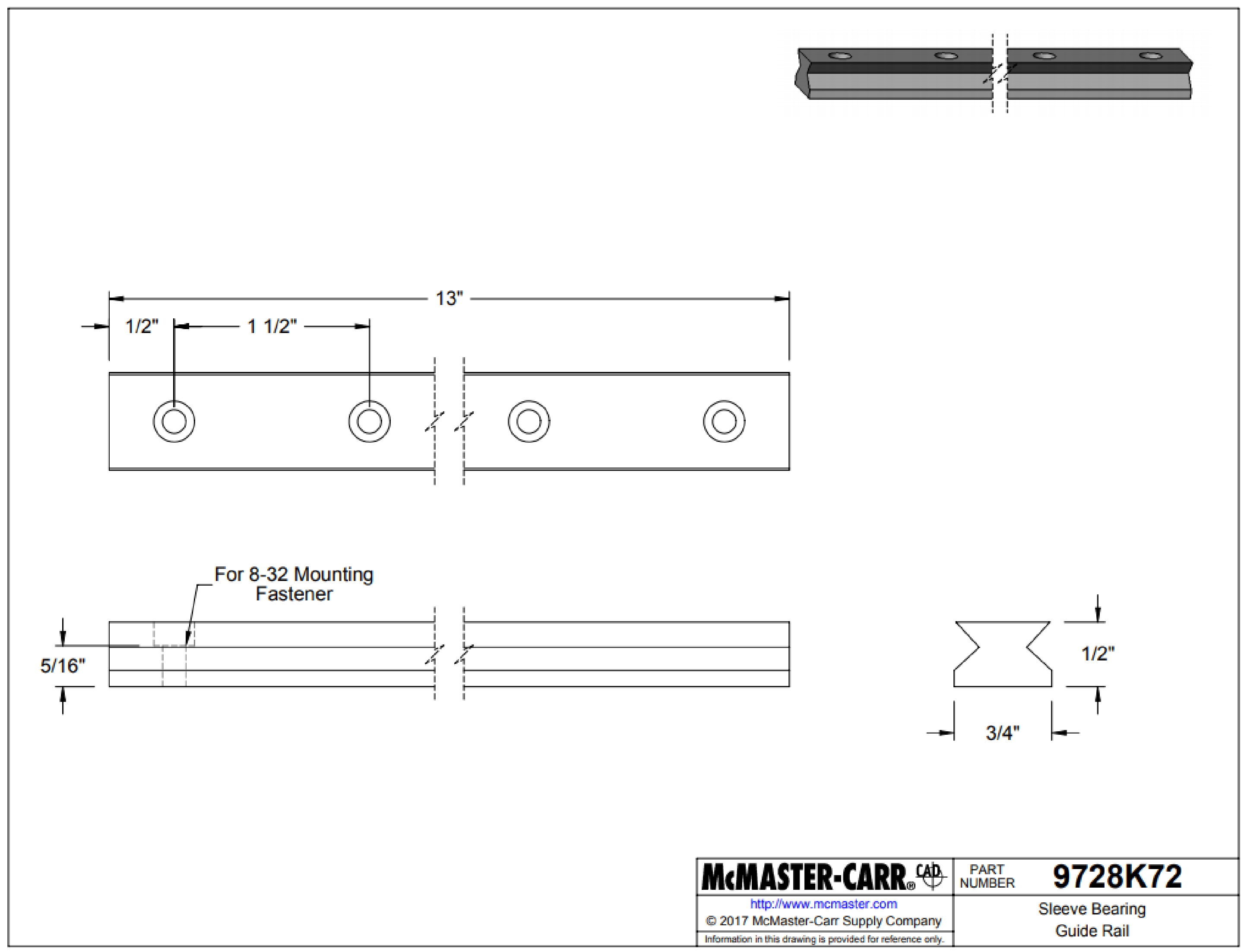
SIZE B
DWG. NO. 6
REV

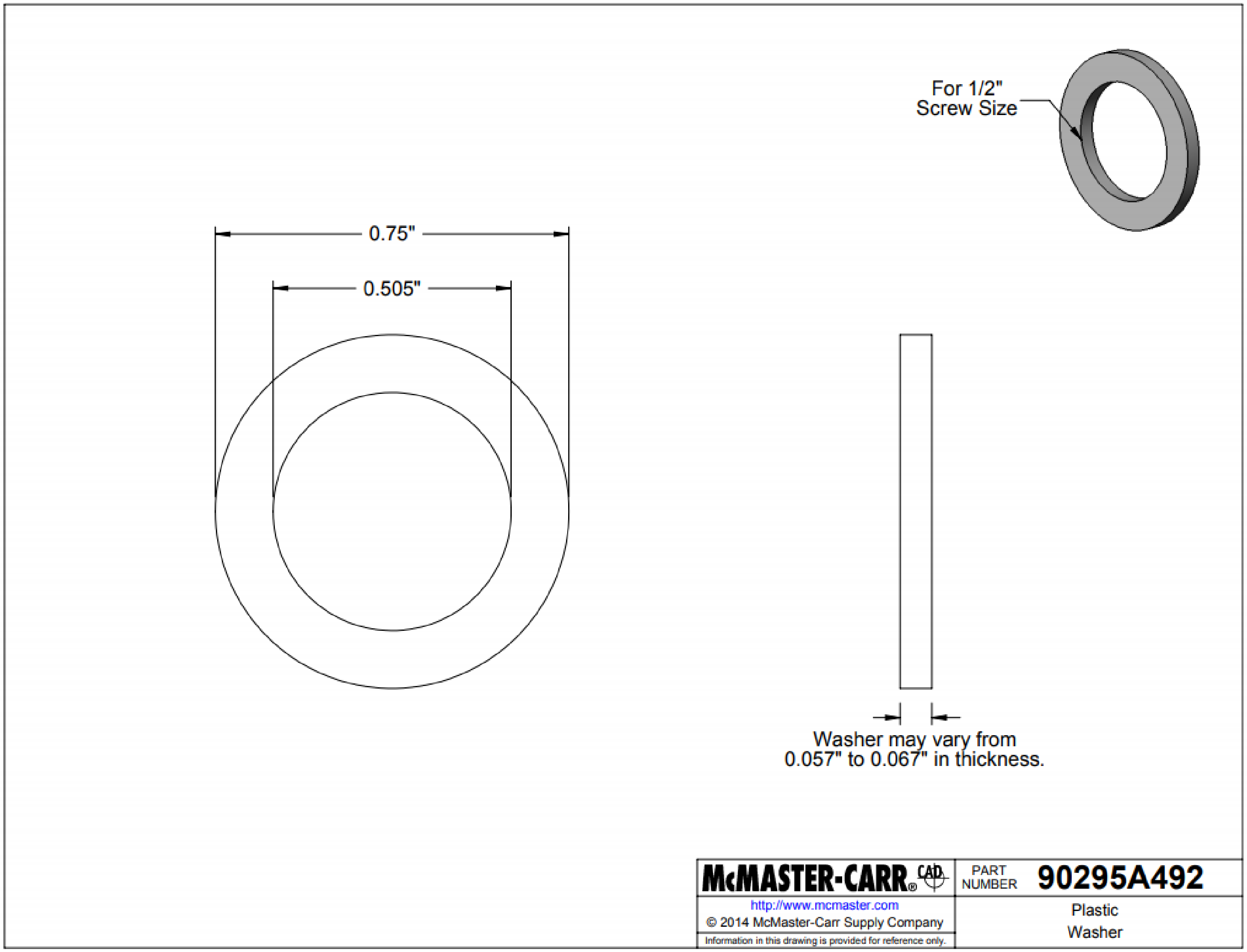
SCALE: 1:2
WEIGHT:
SHEET 6 OF 7


4
3
2
1
B
A
8.00
34.00
20.00
2x 0.25
16.25
18.25
1.38
36.00
17.75
2.50
1.13
0.50
3.38
5.50
9.88
11.00
Scale = 1:6
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ± 0.03
THREE PLACE DECIMAL ± 0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL:
1/4" 6060 Aluminum Plate
FINISH:
Unfinished
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
AS
2/11/21
CHECKED
ES
2/11/21
REVISED
RH
5/3/21
Q.A.
COMMENTS:
TITLE:
18000
SIZE
B
DWG. NO.
7
REV
SCALE: 1:6
WEIGHT:
SHEET 7 OF 7


29.49in
12.8in
16.69in
0.39in
0.85in
1.04in
M8 x 1.25 mm Thread
0.35" Deep
10mm
1.2in
0.55in
5/16"-18 Thread
McMASTER-CARR
CAD
PART NUMBER
4138T622
http://www.mcmaster.com
© 2021 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Gas
Spring


1"
3/8"
1"
1/8"
M3 x 0.5 mm Thread
8 mm
1 3/4"
1 1/4"
5/8"
1/8"
3/4"
1/2"
3/4"
McMASTER-CARR CAD
http://www.mcmaster.com
© 2017 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
9728K41
Sleeve Bearing Carriage


13"
1/2"
1 1/2"
For 8-32 Mounting Fastener
5/16"
1/2"
3/4"
McMASTER-CARR CAD
http://www.mcmaster.com
© 2017 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
9728K72
Sleeve Bearing Guide Rail



Washer may vary from 0.057" to 0.067" in thickness.

McMASTER-CARR CAD

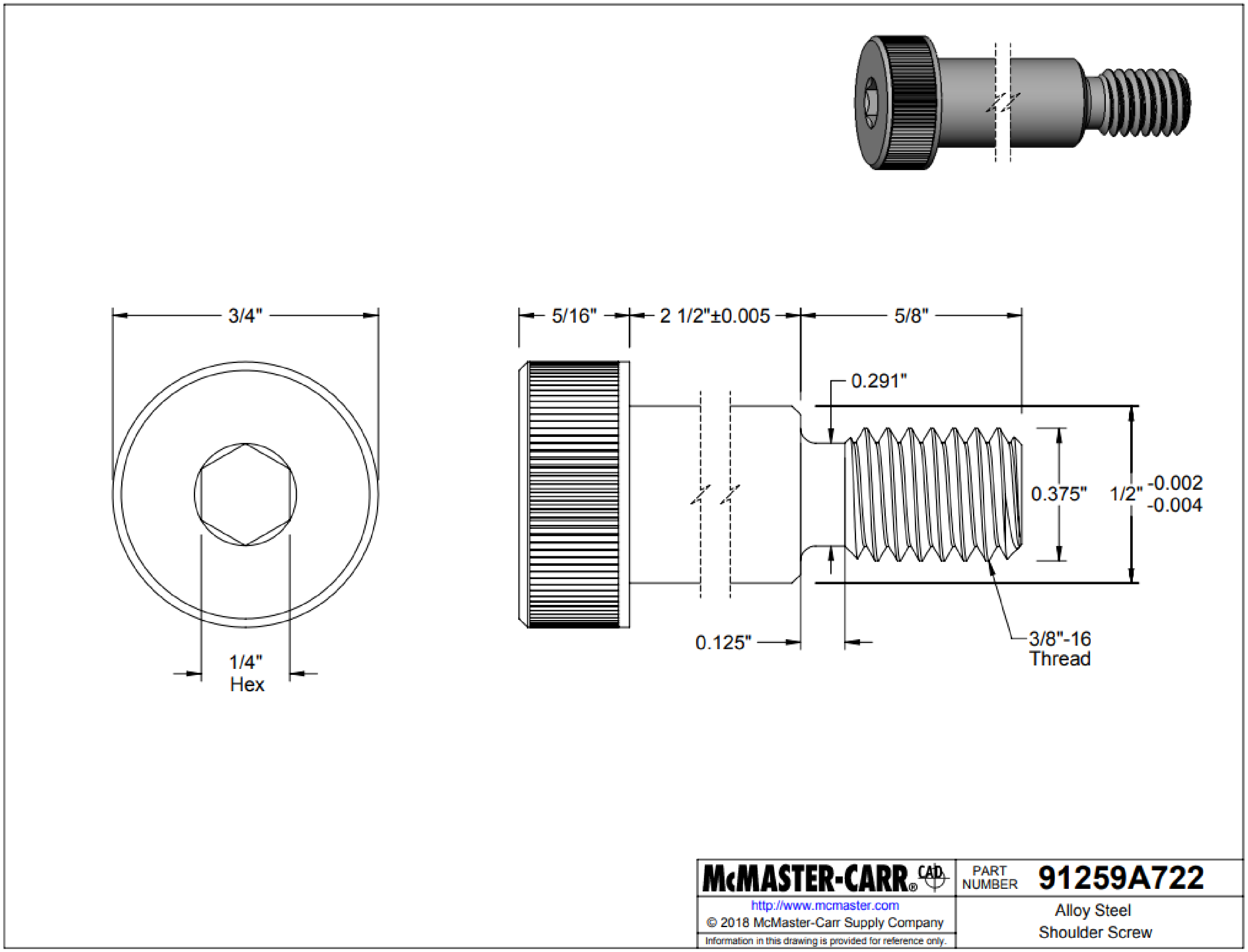
http://www.mcmaster.com

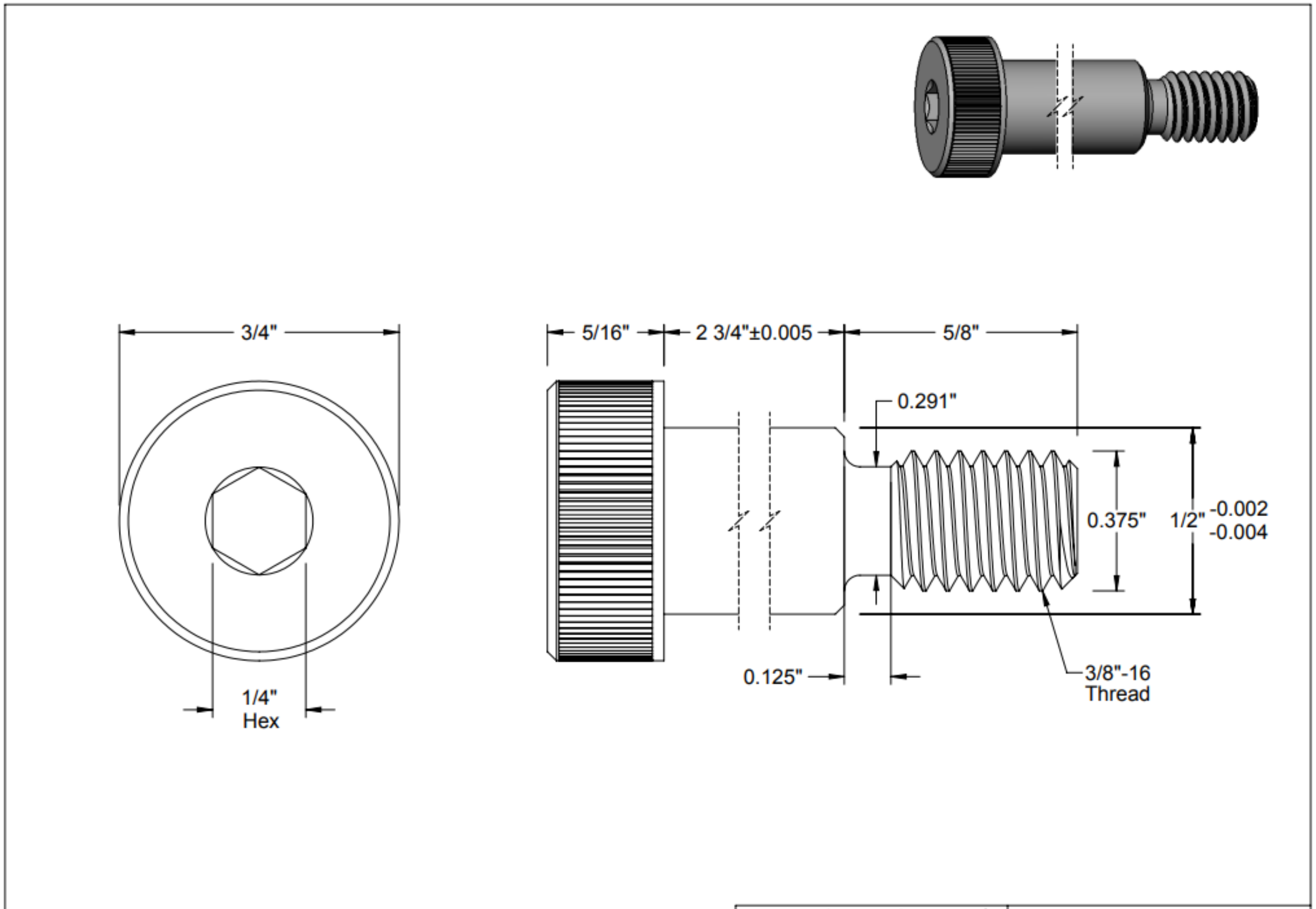
© 2014 McMaster-Carr Supply Company

Information in this drawing is provided for reference only.

PART NUMBER **90295A492**

Plastic Washer


3/4"
1/4"
Hex
5/16"
2 1/2"±0.005
5/8"
0.291"
0.375"
1/2" -0.002 -0.004
0.125"
3/8"-16 Thread
McMASTER-CARR® CAD
http://www.mcmaster.com
© 2018 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
PART NUMBER
91259A722
Alloy Steel Shoulder Screw

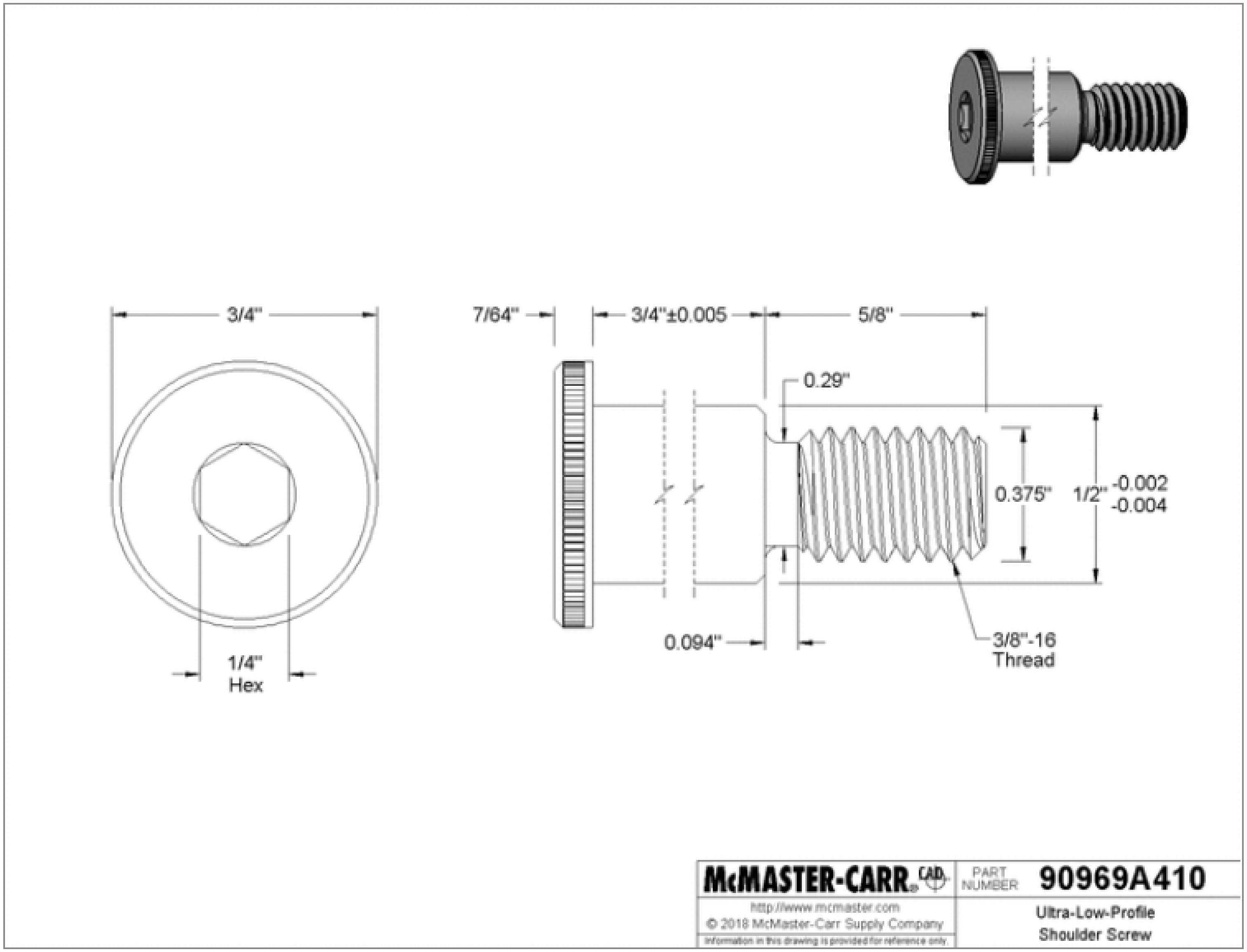


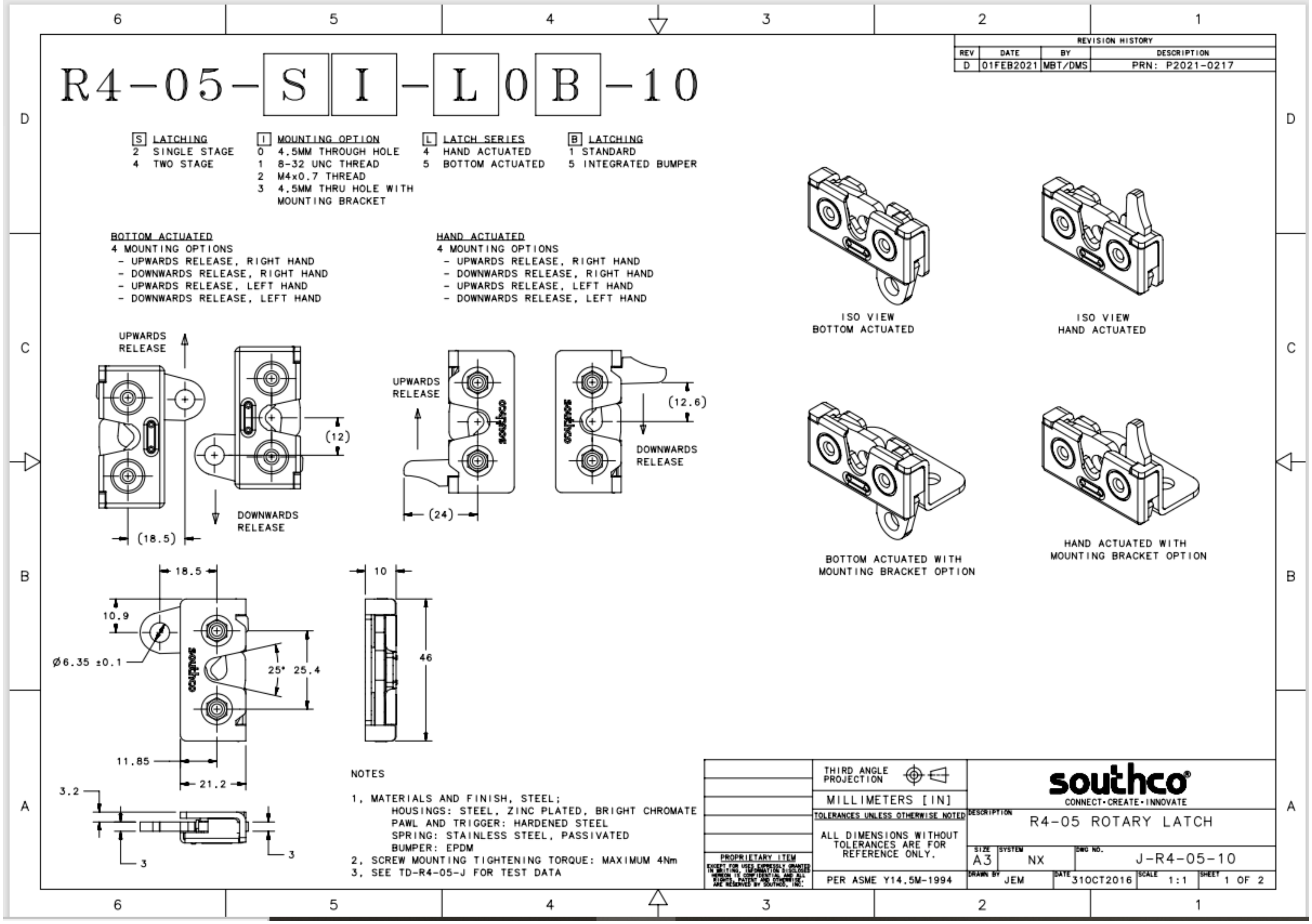
McMASTER-CARR® CAD

http://www.mcmaster.com

PART NUMBER **91259A723**

Alloy Steel
Shoulder Screw


3/4"
1/4"
Hex
7/64"
3/4"±0.005
5/8"
0.29"
0.375"
1/2" -0.002
-0.004
0.094"
3/8"-16
Thread
McMASTER-CARR
CAD
PART NUMBER
90969A410
http://www.mcmaster.com
© 2018 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Ultra-Low-Profile
Shoulder Screw



R4-05-S I-L 0 B-10

S LATCHING
- 2 SINGLE STAGE
- 4 TWO STAGE

I MOUNTING OPTION
- 0 4.5MM THROUGH HOLE
- 1 8-32 UNC THREAD
- 2 M4x0.7 THREAD
- 3 4.5MM THRU HOLE WITH MOUNTING BRACKET

L LATCH SERIES
- 4 HAND ACTUATED
- 5 BOTTOM ACTUATED

B LATCHING
- 1 STANDARD
- 5 INTEGRATED BUMPER

BOTTOM ACTUATED
4 MOUNTING OPTIONS
- UPWARDS RELEASE, RIGHT HAND
- DOWNWARDS RELEASE, RIGHT HAND
- UPWARDS RELEASE, LEFT HAND
- DOWNWARDS RELEASE, LEFT HAND

HAND ACTUATED
4 MOUNTING OPTIONS
- UPWARDS RELEASE, RIGHT HAND
- DOWNWARDS RELEASE, RIGHT HAND
- UPWARDS RELEASE, LEFT HAND
- DOWNWARDS RELEASE, LEFT HAND

REVISION HISTORY

REV	DATE	BY	DESCRIPTION
D	01FEB2021	MBT/DMS	PRN: P2021-0217

NOTES

1. MATERIALS AND FINISH, STEEL;
   HOUSINGS: STEEL, ZINC PLATED, BRIGHT CHROMATE
   PAWL AND TRIGGER: HARDENED STEEL
   SPRING: STAINLESS STEEL, PASSIVATED
   BUMPER: EPDM
2. SCREW MOUNTING TIGHTENING TORQUE: MAXIMUM 4Nm
3. SEE TD-R4-05-J FOR TEST DATA

THIRD ANGLE PROJECTION

MILLIMETERS [IN]

TOLERANCES UNLESS OTHERWISE NOTED

ALL DIMENSIONS WITHOUT TOLERANCES ARE FOR REFERENCE ONLY.

PER ASME Y14.5M-1994

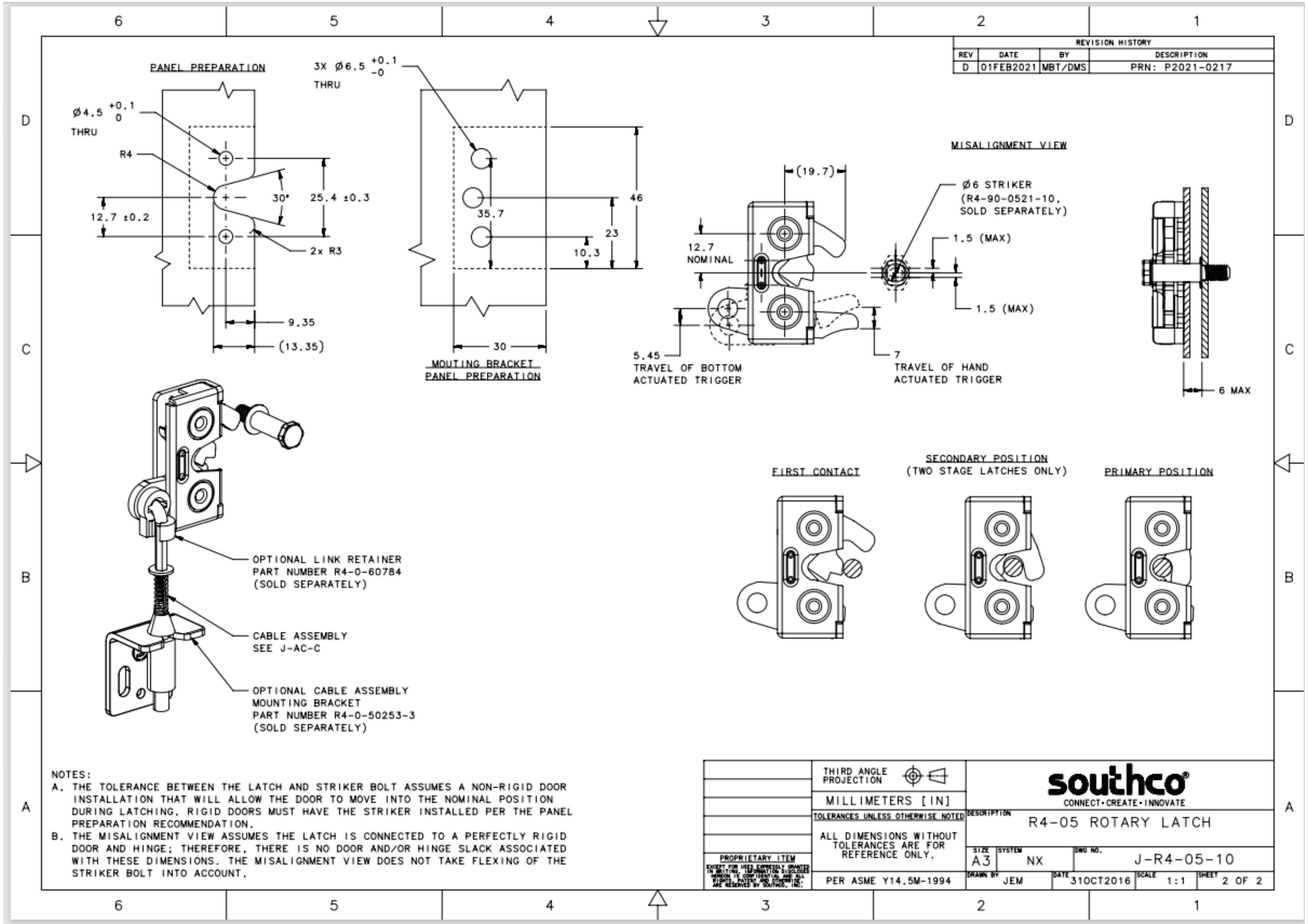
PROPRIETARY ITEM

southco®
CONNECT·CREATE·INNOVATE

DESCRIPTION: R4-05 ROTARY LATCH

SIZE	SYSTEM	DWG NO.
A3	NX	J-R4-05-10

DRAWN BY	DATE	SCALE	SHEET
JEM	31OCT2016	1:1	1 OF 2



NOTES:

A. THE TOLERANCE BETWEEN THE LATCH AND STRIKER BOLT ASSUMES A NON-RIGID DOOR INSTALLATION THAT WILL ALLOW THE DOOR TO MOVE INTO THE NOMINAL POSITION DURING LATCHING. RIGID DOORS MUST HAVE THE STRIKER INSTALLED PER THE PANEL PREPARATION RECOMMENDATION.

B. THE MISALIGNMENT VIEW ASSUMES THE LATCH IS CONNECTED TO A PERFECTLY RIGID DOOR AND HINGE; THEREFORE, THERE IS NO DOOR AND/OR HINGE SLACK ASSOCIATED WITH THESE DIMENSIONS. THE MISALIGNMENT VIEW DOES NOT TAKE FLEXING OF THE STRIKER BOLT INTO ACCOUNT.

THIRD ANGLE PROJECTION

MILLIMETERS [IN]

TOLERANCES UNLESS OTHERWISE NOTED

ALL DIMENSIONS WITHOUT TOLERANCES ARE FOR REFERENCE ONLY.

PER ASME Y14.5M-1994

PROPRIETARY ITEM

southco®
CONNECT•CREATE•INNOVATE

DESCRIPTION R4-05 ROTARY LATCH

SIZE A3 | SYSTEM NX | DWG NO. J-R4-05-10

DRAWN BY JEM | DATE 31OCT2016 | SCALE 1:1 | SHEET 2 OF 2

255A

R4 Rotary Latch

Micro · Concealed · Single and two stage

- Ideal for space limited applications
- Compatible with wide array of actuators
- Integrated bumper for anti-vibration feature

Material and Finish

Steel, zinc plated or
304 stainless steel, passivated

Performance Details

Average ultimate load:
2600 N (590 lbf)

Installation Notes

See page 259

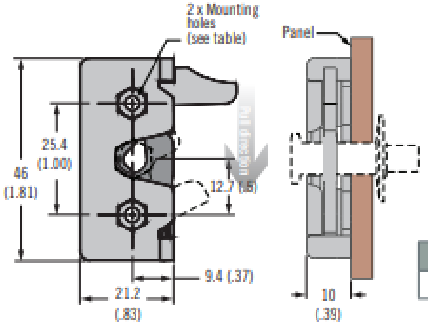
Accessories

Cables and retainer clips
see pages 272-275

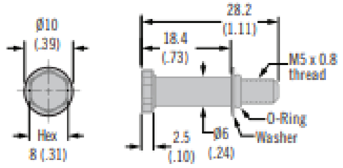
Notes

Electromechanical rotary latch
available see page 23

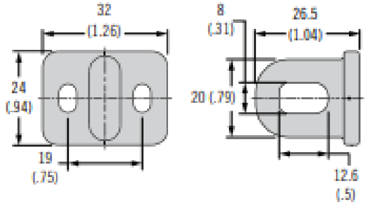
Single Stage - Hand Actuation, Integrated Bumper



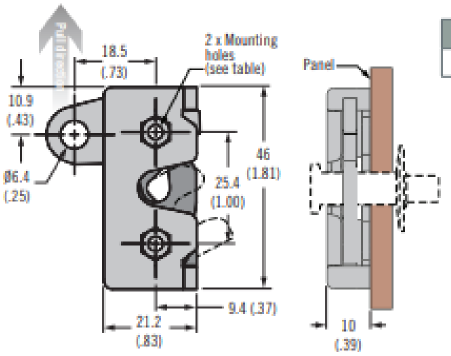
Part Number	
Striker bolt	R4-90-0521-10



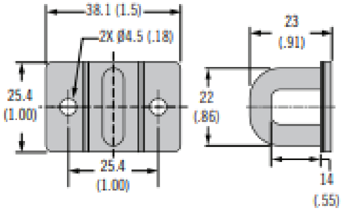
Part Number	
Molded striker	R4-0-61336



Two Stage - Bottom, Integrated Bumper



Part Number	
Wire form striker	R4-0-61352



Part Number Selection

R4 - 05 - S I - L 0 5 - M

S Stage & Actuation
2 Single stage
4 Two stage

I Mounting Style
0 4.5 (.177) thru
1 8-32 thread
2 M4 x 0.7 thread

L Lever Type
4 Hand Actuation
5 Bottom

M Material
10 Steel
20 Stainless Steel

Other options available. For complete details on variety, part numbers, installation and specification, go to

INFO CLIC *www.southco.com/R4*

Dimensions in millimeters (inch) unless otherwise stated

southco
CONNECT · CREATE · INNOVATE

Appendix AI: System Team Design Verification Plan

DVP&R - Design Verification Plan (& Report)											
Project:	F72 Configurable Seat		Sponsor:	Ritch Hollingsworth and Dr Mello						Edit Date:	2/10/2021
TEST PLAN										**TEST RESULTS**	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING		Numerical Results	Notes on Testing
								Start date	Finish date		
1	Nesting Efficiency	Measure how much floor space is saved by nesting the seats	Measure the saved foor space from seated to nested configuraitons	70% Open Floor Space	N/A	3D Printed Prototype or Renderings	Daniel	2/4/2021			
2	Seatbelt Safety Standards	Test seatbelt assembly under 5000 lb of force	Check for permanent deformation	Pass FMVSS 209/210	N/A	Full Scale System	Phoebe	2/4/2021			
3	Customer Ergonomic/Aesthetic Survey	Give survey to users of seat to gage ergonomic and aesthetic satisfcation	Measure satisfaction averages	80% satisfaction	N/A	3D Printed Prototype or Renderings	Steven	2/4/2021			
4	Transit Company Satisfaction Survey	Give survey to transportation companies to get feedback and gage satisfaction of possible buyers	Measure satisfaction averages	60% satisfaction	N/A	3D Printed Prototype or Renderings	Daniel	2/4/2021			

No Tests Performed

DVP&R - Design Verification Plan (& Report)

Project:	F72 Configurable Seat	Sponsor:	Ritch Hollingsworth and Dr Mello		Edit Date:	2/10/2021

TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING		Numerical Results	Notes on Testing
								Start date	Finish date		
5	Intuitive Design Survey	Give a person the 3D printed model with seats in seated position and time how long it takes them to articulate seat and translate on tracks with no instruction. Repeated 50 times.	Measure time	20 sec average	N/A	3D Printed Prototype or Renderings	Audrey	2/4/2021			
6	Manufacturing Cost Analysis	Use DFM software to test cost of the seat based on the mass manufacturing plan.	Measure cost per unit	$1000/seat	DFM software	CAD Model	Steven	2/4/2021			
7											

Appendix AJ: Track and Latch Team Design Verification Plan

DVP&R - Design Verification Plan (& Report)

Project: F73 Reconfigurable Seat Track and Latch
Sponsor: Mr. Ritch Hollingsworth and Dr. Joseph Mello
Edit Date: 5/17/21

TEST PLAN										TEST RESULTS				
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING		Numerical Results	Pass/Fail	Notes on Testing	Method of Failure	Design Recommendations
								Start date	Finish date					
1	1	Weigh the entire system on a scale	lb	weigh less than 70 lb	Scale	All components except for the track	Nicholas	4/21/21	5/17/21	46 lbf	Pass	N/A	N/A	N/A
2	2	Acuate the bar from locked to unlocked and unlocked to locked in clean conditions	lb	Takes less then 5 lb to actuate	Force Gage	Actuation system and locking pin	Alex	4/28/21	5/17/21	9.26 lbf	Fail	Data was skewed since the cam lever system was not functional	Cam System Not Functional	Redesign Cam Lever
3	3	Acuate the bar from locked to unlocked and unlocked and lock in dirty conditions	lb	Takes less then 5 lb to actuate	Force Gage	Actuation system and locking pin	Alex	4/28/21	5/17/21	11.87 lbf	Fail	Data was skewed since the cam lever system was not functional	Cam System Not Functional	Redesign Cam Lever
4	6	Push the seat system when the lock is disengaged under clean conditions	lb	Takes less then 10 lbs to push	Force Gage	Entire complete system	Kai	4/23/21	5/17/21	15.74 lbf	Fail	Data may be inconsistent due to uneven sliding of both sides of the seat	Insufficient Clearance in Mating Profile, lateral and vertical system binding	Larger track-to-latch profile clearance, attach a rigid support structure at the bottom of the seat between the two mounting plates (ie. Weld a plate)
5	7	Push the seat system when the lock is disengaged under dirty conditions	lb	Takes less then 10 lbs to push	Force Gage	Entire complete system	Kai	4/23/21	5/17/21	18.44 lbf	Fail but it was Nico's Fault	Data may be inconsistent due to uneven sliding of both sides of the seat	Insufficient Clearance in Mating Profile, lateral and vertical system binding	Larger track-to-latch profile clearance, attach a rigid support structure at the bottom of the seat between the two mounting plates (ie. Weld a plate)

Team F73 Reconfigurable Seat Track and Latch: Test 2 Procedure

Test Name: Actuation Force Test – Clean Conditions

Purpose:

The purpose of this test is to determine the force required to actuate our system from the locked to unlocked position for an ideal system under new/clean conditions.

Scope:

The scope of this test is to record the force required to fully actuate the foot pedal of the actuation system. The pedal will be fully moved from the locked to the unlocked position and the measured force will be recorded for multiple trials.

Equipment:

- Actuation system (Verification Prototype)
- Force Gauge

Hazards:

- A large load on the system could cause it to move fast, which could lead to injury if the operator has any limbs in the path of the lever arm.
- There is also a pinch point between the lever arm and the latch

PPE Requirements:

- Safety glasses
- Closed-toed shoes

Facility:

The testing should be done on a flat surface. To reduce the need to move/transport the seat and/or other heavy materials, the test (results below) will be performed in the senior project room of the track and latch team in the Bonderson Projects Center (at Cal Poly San Luis Obispo).

Procedure:

1. Set up the force gauge with the hook attachment.
2. Secure the actuation system to the testing surface.
3. Hook the attachment of the force gauge around the foot pedal.
4. Pull up on the foot pedal with the force gauge until the system fully actuates from the locked to unlocked position.
5. Record the maximum force applied during actuation.
6. Return foot bar to locked position.

7. Repeat steps 3-6 five times.
8. Average the applied force across all trials.
9. Clean up. (Don’t forget to sing the song)

Results:

Trial	Applied Force [N]	Applied Force [lbf]
1	40	8.99
2	42	9.44
3	40	8.99
4	38	8.54
5	46	10.34
Average Force:	41.2	9.26

Test Date(s):

5/17/2021

Performed By:

Kai Quizon, Jacob Winkler

Team F73 Reconfigurable Seat Track and Latch: Test 3 Procedure

Test Name: Actuation Force Test – Dirty Conditions

Purpose:

The purpose of this test is to determine the force required to actuate our system from the locked to unlocked position for an ideal system under dirty conditions.

Scope:

The scope of this test is to record the force required to fully actuate the foot pedal of the actuation system. Crushed leaves, dirt, and other particulates will be applied to the system to simulate a real use case of the system. The pedal will be fully moved from the locked to the unlocked position and the measured force will be recorded for multiple trials.

Equipment:

- Actuation system (Verification Prototype)
- Force Gauge

Hazards:

- A large load on the system could cause it to move fast, which could lead to injury if the operator has any limbs in the path of the lever arm.
- There is also a pinch point between the lever arm and the latch

PPE Requirements:

- Safety glasses
- Closed-toed shoes

Facility:

The testing should be done on a flat surface. To reduce the need to move/transport the seat and/or other heavy materials, the test (results below) will be performed in the senior project room of the track and latch team in the Bonderson Projects Center (at Cal Poly San Luis Obispo).

Procedure:

1. Set up the force gauge with the hook attachment.
2. Secure the actuation system to the testing surface.
3. Hook the attachment of the force gauge around the foot pedal.
4. Pull up on the foot pedal with the force gauge until the system fully actuates from the locked to unlocked position.
5. Record the maximum force applied during actuation.
6. Return foot bar to locked position.

7. Repeat steps 3-6 five times.
8. Average the applied force across all trials.
9. Clean up. (Don't forget to sing the song)

Results:

Trial	Applied Force [N]	Applied Force [lbf]
1	52	11.69
2	50	11.24
3	60	13.49
4	48	10.79
5	54	12.14
Average Force:	52.8	11.87

Test Date(s):

5/17/2021

Performed By:

Kai Quizon, Jacob Winkler

Team F73 Reconfigurable Seat Track and Latch: Test 4 Procedure

Test Name: Sliding Seat Motion Load Analysis and Friction Coefficient Determination

Purpose:

The purpose of this test is to find the force required to slide the entire seat along the track under ideal conditions (smooth track, no dirt or grime, etc.). Additionally, it determines whether the designed movement system meets our initial engineering specification for this criterion (<10 lbf to actuate)

Scope:

This experiment will analyze the force it takes to slide the entire latching system along the seat track between two different positions and use this data to estimate the functional frictional coefficient for the system slide. For this test, a system with the entire seat weight will be used. Force will be applied to the system through a force gauge (using a *push* not a *pull*). The user will apply force between 0 N and 120 N. The displacement of the system will be measured at each of these data points to visually demonstrate the minimum required force for movement. From this minimum force, the maximum static friction coefficient will be determined. Uncertainty from the force measurement will be carried through calculation to the static friction coefficient.

Equipment:

- Assembled seat system attached to stationary track (Verification Prototype)
- Flat cross board to attach to force gauge

Hazards:

- Potential Pinch points (between track and sliding latch, double pin mechanism)
- Moving/orienting heavy material

PPE Requirements:

- Closed-toed shoes (reduces risk of injury if heavy material is dropped)

Facility:

The test needs to occur on flat ground. To reduce the need to move/transport the seat and/or other heavy materials, the test (results below) will be performed in the senior project room of the track and latch team in the Bonderson Projects Center (at Cal Poly San Luis Obispo).

Procedure:

1. Ensure system is placed on level ground.
2. Calibrate force gauge or observe force gauge's calibration certificate.
3. Zero gauge by spinning indicator dial to zero position.
4. Prepare to push seat through actuator by tightly grasping actuator, placing actuator *push* head against a cross beam connecting the latch system, and bracing self.

5. Using the dial indicator, apply force at 10 N intervals from 0 N until system first gives way to movement.
6. Record force that causes initial movment.
7. Zero gauge.
8. Mark the initial position of the chair with ink at the backmost location of the latch track interface.
9. Collect data at 10 N intervals from 0 N to a force that is 120 N.
10. When the seat moves, measure the distance it moves and repeat step 8 before continuing to the next force interval.
11. Clean up. (Don't forget to sing the song)

Results:

Table 1. System Displacement at Varying Input Forces

Input Force [N]	Input Force [lbf]	System Displacement [in]
0	0.00	0
10	2.25	0
20	4.50	0
30	6.74	0
40	8.99	0
50	11.24	0
60	13.49	0
68*	15.29	0.125
80	17.99	0.5
90	20.23	1**
100	22.48	1
110	24.73	1
120	26.98	1

** The minimum force required to move the seat is 68.5 N (15.74 lbf), highlighted above*

*** A System Displacement of 1 inch indicates that the system will continue to slide when that amount of force is applied.F*

Table 2. Uncertainty Analysis for Minimum Movement Force

Force (N)	U_f	$C=f(x_m)$	$F(F+U_f)$	$F(F-U_f)$	S_1	S_2	U_μ
68	1	1.478	69	67	1.5	1.456	0.0435

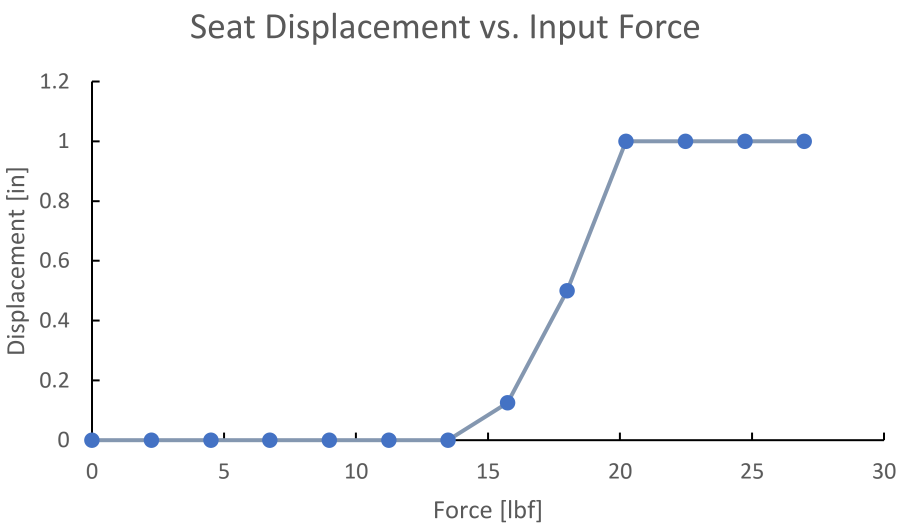


Figure 1. Seat Displacement at Varying Input Forces under Clean Track Conditions

Test Date(s):

5/17/2021

Performed By:

Kai Quizon, Jacob Winkler

Team F73 Reconfigurable Seat Track and Latch: Test 5 Procedure

Test Name: Sliding Seat Motion Load Analysis - Dirty Conditions

Purpose:

The purpose of this test is to verify that the seats will still be able to be repositioned when the track is compromised with normal operating levels of contaminants and measure the required force for movement.

Scope:

The scope of this test is to subject the model of our system to increasing load until the system begins to slide along the track.

Equipment:

- System Prototype
- Dirt and debris
- Force Gauge
- Cross Member for Force Application (Wooden 2x4 acceptable)

Hazards:

- Caution should be exercised, along with proper lifting technique when lifting heavy weights.
- Potential pinch points between moving parts

PPE Requirements:

- Closed-toed shoes

Facility:

The test needs to occur on flat ground. To reduce the need to move/transport the seat and/or other heavy materials, the test (results below) will be performed in the senior project room of the track and latch team in the Bonderson Projects Center (at Cal Poly San Luis Obispo).

Procedure:

1. Review the calibration certificate of the force gauge and zero by spinning the dial.
2. Place the system (verification prototype) on flat ground and ensure the system has no tendency to slide on the floor.
3. Sprinkle dirt and debris over the track. Grind with regular walking motions to simulate guest usage.
4. Place the tip of the force gauge at the center of the cross member. The cross member should be in contact with the back of both latch assemblies.
5. Apply a slowly increasing force to the system until the system first moves.

6. Record the minimum force for system movement.
7. Mark the backmost point of the latch assembly on the floor.
8. Apply forces in 10 N intervals from 0 N to 120 N
9. Measure the displacement of each force application, being sure to re-record the zero point after the seat has moved.
10. Clean up (don't forget to sing the song)

Results:

Table 1. System Displacement at Varying Input Forces

Input Force [N]	Input Force [lbf]	System Displacement [in]
0	0.00	0
10	2.25	0
20	4.50	0
30	6.74	0
40	8.99	0
50	11.24	0
60	13.49	0
70	15.74	0
82	18.44	0.125
90	20.23	0.125
100	22.48	0.5
110	24.73	1
120	26.98	1

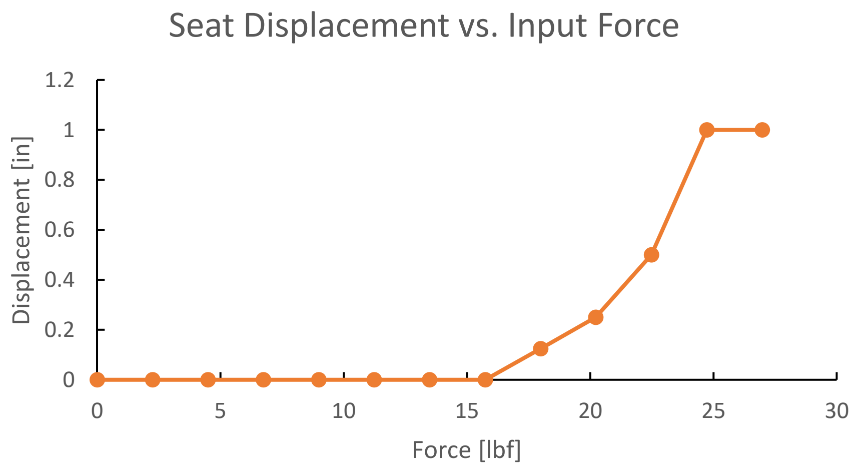


Figure 1. Seat Displacement at Varying Input Forces under Dirty Track Conditions

Test Date(s):

5/17/2021

Performed By:

Kai Quizon, Jacob Winkler

G3 Engineering

Appendix AK. Articulation Design Verification Plan & Report

DVP&R - Design Verification Plan (& Report)											
Project:	F74 - Configurable Seat Team - Articulation		Sponsor:	Dr. Joseph Mello and Mr. Ritch Hollingsworth						Edit Date:	5/20/2021
TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING		Numerical Results	Notes on Testing
								Start date	Finish date		
1	2: Strength	Seat will be loaded to a minimum of the expected static load case, additional load may be applied to verify safety factors.	Pass/Fail	Sustain Expected Load (Value TBD)	Force Meter	VP (x1)	Rick	5/11/2021	5/18/2021	N/A Supported loads of up to 175 lb applied at the seat support point with no qualitative signs of failure.	Combined with test #2 as both tests have the same basic procedure and data collection method (further explanation below). Due to difficulty of fixturing the seat, only one data point was collected that exceeds the expected static load case. Additional, unrecorded testing was conducted that supports this conclusion.
2	3: Stiffness	Under expected static load condition, during strength test, various deflection cases will be measured using a dial caliper	Distance	1/4" Max Deflection under Expected Load Case (appx 150 lbf)	Force Meter, dial caliper	VP (x1)	Rick	5/11/2021	5/18/2021	For Primary Load Case (Vertical): 0.38 in (projected for 150lb load) 0.43 in (measured for 179 lb load)	Under the load cases that could be tested, the seat did not meet the desired stiffness criteria. It should be noted, however, that the deflection was not significant enough to be noticed during user testing.
3	4: Operation Effort	Use force meter to measure required upward force applied by user to articulate.	Force	5 lbf	Force Meter	VP (x1)	Anil	5/11/2021	5/14/2021	67 lbf / 17 lbf Deploy Against / Stow Without Gas Spring	Due to incorrect gas spring sizing, the load required to deploy the seat significantly exceeded the target value. Without the gas spring the seat cannot automatically stow itself, but the required force input is significantly reduced.
4	5: Operation Time	Time how long it takes for a user to fully articulate/unarticulate the seat	Time	5 sec	Timer	VP (x1)	Emily	5/11/2021	5/14/2021	3.6 Seconds 1.3 Sec to Deploy, 2.3 Sec to Stow (Stow limited by gas spring)	The simplicity of the overal design combined with testers capable of counteracting the excess force of the gas spring resulted in an operation time well within the target value.

[F74 Configurable Seat Articulation] Test Procedure: Operation Effort

Test Name: Operation Effort Test

Purpose: The purpose of this test is to verify that the user can operate the device with a minimal amount of effort.

Scope: The measured quantity in this test will be the force required to articulate the seat out of a stowed configuration.

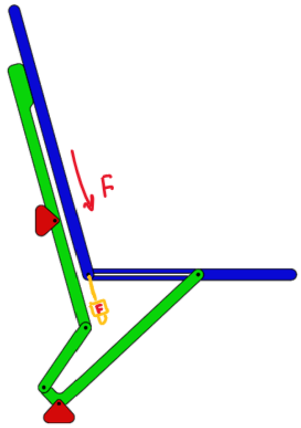
Equipment:

- Force Gauge – Contact Ben Carr (bwcarr@calpoly.edu) for *Equipment Loan Agreement*
- Verification prototype

Hazards: Pinch points, Heavy Weight

PPE Requirements: Closed-Toed Shoes, Safety Glasses

Facility: Mustang 60 – Bonderson Project Center: Contains sufficient space and a stable environment to house and actuate the seat



Procedure:

1. Set up verification prototype in stowed configuration.
   a) Attach Force Gauge at hinge point between seat bottom and seat back
2. Articulate seat into deployed configuration by moving the seat back down.
   a) Measure the force required to pull the seat down against the gas spring using the Force Gauge.
3. Record values and repeat for 2 trials across 3 team members

Results:

Target: Less than 5 lbf to deploy the seat (Stowed configuration -> Seated configuration)

Test Date(s): 5/13/2021

Test Results:

Team Member	Stowed -> Seated (lbf)	Seated -> Stowed (lbf)
Anil		
Rick		
Emily		
Average:		

Performed By: Anil Singh

Results:

<table>
<tr><th colspan="9">Articulation Load Data</th></tr>
<tr><th colspan="4">Deploying - Gas Spring Engaged</th><th></th><th colspan="4">Stowing - Gas Spring Disengaged</th></tr>
<tr><td rowspan="2">Trial</td><td>Hold</td><td>Move</td><td rowspan="5">Compression Test</td><td rowspan="5"></td><td rowspan="2">Trial</td><td>Hold</td><td>Move</td><td rowspan="5">Tensile Test</td></tr>
<tr><td>[lb$_f$]</td><td>[lb$_f$]</td><td>[lb$_f$]</td><td>[lb$_f$]</td></tr>
<tr><td>1</td><td>45</td><td>68</td><td>4</td><td>15</td><td>18</td></tr>
<tr><td>2</td><td>48</td><td>69</td><td>5</td><td>10</td><td>17</td></tr>
<tr><td>3</td><td>50</td><td>63</td><td>6</td><td>12</td><td>15</td></tr>
<tr><td>Average:</td><td>48</td><td>67</td><td></td><td></td><td>Average:</td><td>12</td><td>17</td><td></td></tr>
</table>

<table>
<tr><th colspan="5">Average Operation Effort</th></tr>
<tr><th colspan="2">Deploying - Gas Spring Engaged</th><th></th><th colspan="2">Stowing - Gas Spring Disengaged</th></tr>
<tr><td>Hold</td><td>Move</td><td rowspan="3"></td><td>Hold</td><td>Move</td></tr>
<tr><td>[lb$_f$]</td><td>[lb$_f$]</td><td>[lb$_f$]</td><td>[lb$_f$]</td></tr>
<tr><td>48</td><td>67</td><td>12</td><td>17</td></tr>
</table>

[F74 Configurable Seat Articulation] Test Procedure: Operation Time Verification

Test Name: Operation Time Test

Purpose: Verify operation time, Ensure the design is intuitive and easy to use

Scope: Time it takes to articulate and unarticulate the seat

Equipment:

- Timer
- Verification prototype
- Test Participants

Hazards: Pinch points

PPE Requirements: N/A

Facility: Bonderson (Area with open space)

Procedure:

4. Gather test participants (6), preferably those who have never seen the design beforehand
5. Set up the verification prototype in either the seated or stowed configuration. Make sure participants cannot see the seat before their individual test run
6. Allow a single participant to attempt to either stow the seat or deploy the seat. Time how long it takes them to complete this task. Record this value in the Data collection table
7. Ask the same participant to either re-stow or re-deploy the seat. Time how long it takes them to complete this task. Record this value in the Data collection table
8. Repeat for all participants
9. Verify that all data has been collected. Dismiss participants and store verification prototype.

Target Results:
Less than 5 seconds to deploy the seat (Stowed configuration -> Seated configuration)
Less than 5 seconds to stow the seat (Seated configuration -> Stowed configuration)

Test Date(s): 5/13/2021

Test Results:

Participant	Stowed -> Seated (sec)	Seated -> Stowed (sec)
1		
2		
3		
Average:		
Participant	**Seated -> Stowed (sec)**	**Stowed -> Seated (sec)**
4		
5		
6		
Average:		

Performed By: Emily Sun

Potential Safety Risks

Safety Risk	Response
Pinch points	Participants will be informed of all possible pinch points before testing
Heavy Weight	Test Moderator will be on stand-by

Results:

Articulation Time				
Tester	Trial	Stow	Deploy	
		[s]	[s]	
Anil	1	0.99	2.2	
	2	0.99	2	
Jacob	3	1.96	2.88	
	4	2.17	2.17	
Rick	5	0.66	2.24	
	6	0.85	2.35	Total Time:
Average:		1.27	2.31	3.58 Seconds

Average Operation Time		
Stow	Deploy	
[s]	[s]	Total:
1.27	2.31	3.58 Seconds

[F74 Configurable Seat Articulation] Test Procedure: Stiffness Verification

Test Name: Stiffness Test

Purpose: Verify stiffness calculations, determine deflections corresponding to different applied loads, determine the amount of static loading that can be applied before excessive deflection occurs

Scope: Stiffness of structural linkages – seat bottom, seat back, side frame, diagonal brace

Equipment:

- Verification Prototype
- Scale
- Bucket
- Water
- Ratchet Straps
- Dial Indicator
- Force Meter

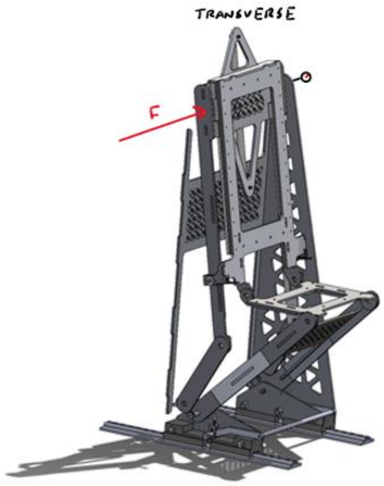
Hazards: heavy weight

PPE Requirements:

Facility: Any location with sufficient space to house the seat in a stable environment will be sufficient. This test was conducted at Cal Poly in the Mustang 60 – Bonderson Project Center

Procedure:

10. Set up baseline measurements via FEA
    a) Project failure load to verify experiment safety
11. Set up verification prototype for experiment
    a) Secure to a sturdy base
12. Touch off dial indicator at desired location and zero
13. Quantify load and record
    a) Weigh bucket & water with scale
14. Load seat with static load
    a) Apply load using ratchet straps in specified configurations
15. Record the amount of displacement seen on dial indicator
16. Compare measured displacement to baseline for verification of reasonability
17. Apply manual load for optimal comparison to typical use
18. Repeat steps 1-7 for different configurations and loading cases



Results:

Desired results for in plane: 0" +/- 0.25 " (1/4" or less of deflection)

Desired results for out of plane: 0" +/- 0.0625" (1/16" or less of deflection)

Test Date(s): 5/13/2021

Test Results:

Loading	**Vertical**	**Axial**	**Transverse**
50lbs			
Average:			
100lbs			
Average:			
150lbs			
Manual:			

Performed By: Rick Hall

Results:

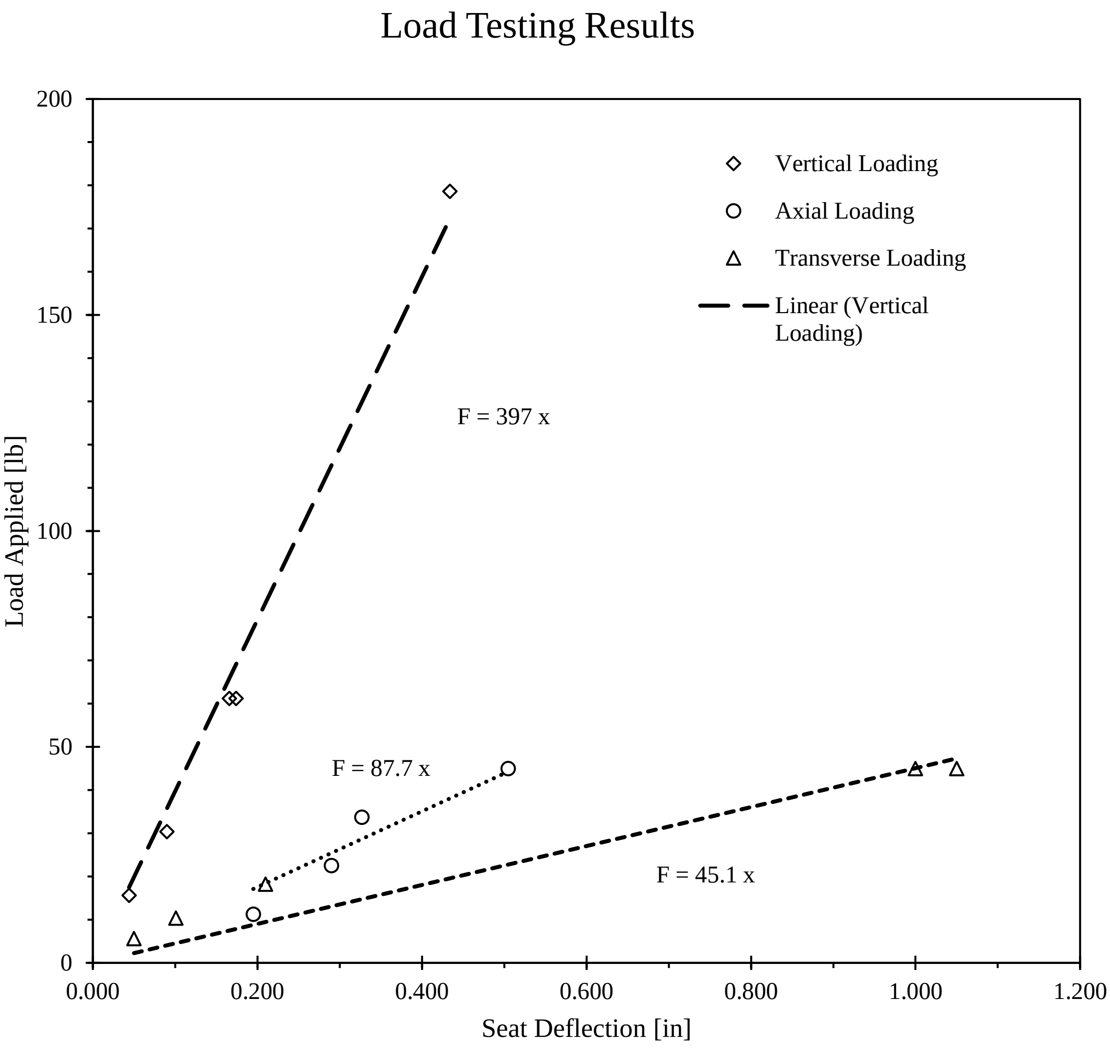
Stiffness Testing Raw Data													
Vertical Loading (Case 1)					Axial Loading (Case 2)					Transverse Loading (Case 3)			
Trial	Load	Tare	Deflection		Trial	Load	Tare	Deflection		Trial	Load	Tare	Deflection
	[lb$_f$]	[in]	[in]			[N]	[in]	[in]			[N]	[in]	[in]
1	15.6	0	0.044		1	200	0	0.505		1	46	0	0.101
2	30.4	0	0.090		2	150	0	0.327		2	25	0	0.050
3	61.2	0	0.166		3	100	0	0.290		3	81	0	0.210
4	61.2	0	0.174		4	50	0	0.195		4	200	0	1.000
5	178.6	0	0.434							5	200	0	1.050

Stiffness Testing Refined Data										
Vertical Loading (Case 1)				Axial Loading (Case 2)				Transverse Loading (Case 3)		
Trial	Load	Deflection		Trial	Load	Deflection		Trial	Load	Deflection
	[lb$_f$]	[in]			[lb$_f$]	[in]			[lb$_f$]	[in]
1	15.6	0.044		1	45.0	0.505		1	10.3	0.101
2	30.4	0.090		2	33.7	0.327		2	5.6	0.050
3	61.2	0.166		3	22.5	0.290		3	18.2	0.210
4	61.2	0.174		4	11.2	0.195		4	45.0	1.000
5	178.6	0.434						5	45.0	1.050

Equivalent Stiffness		
Vertical	397	lb/in
Axial	87.7	lb/in
Normal	45.1	lb/in

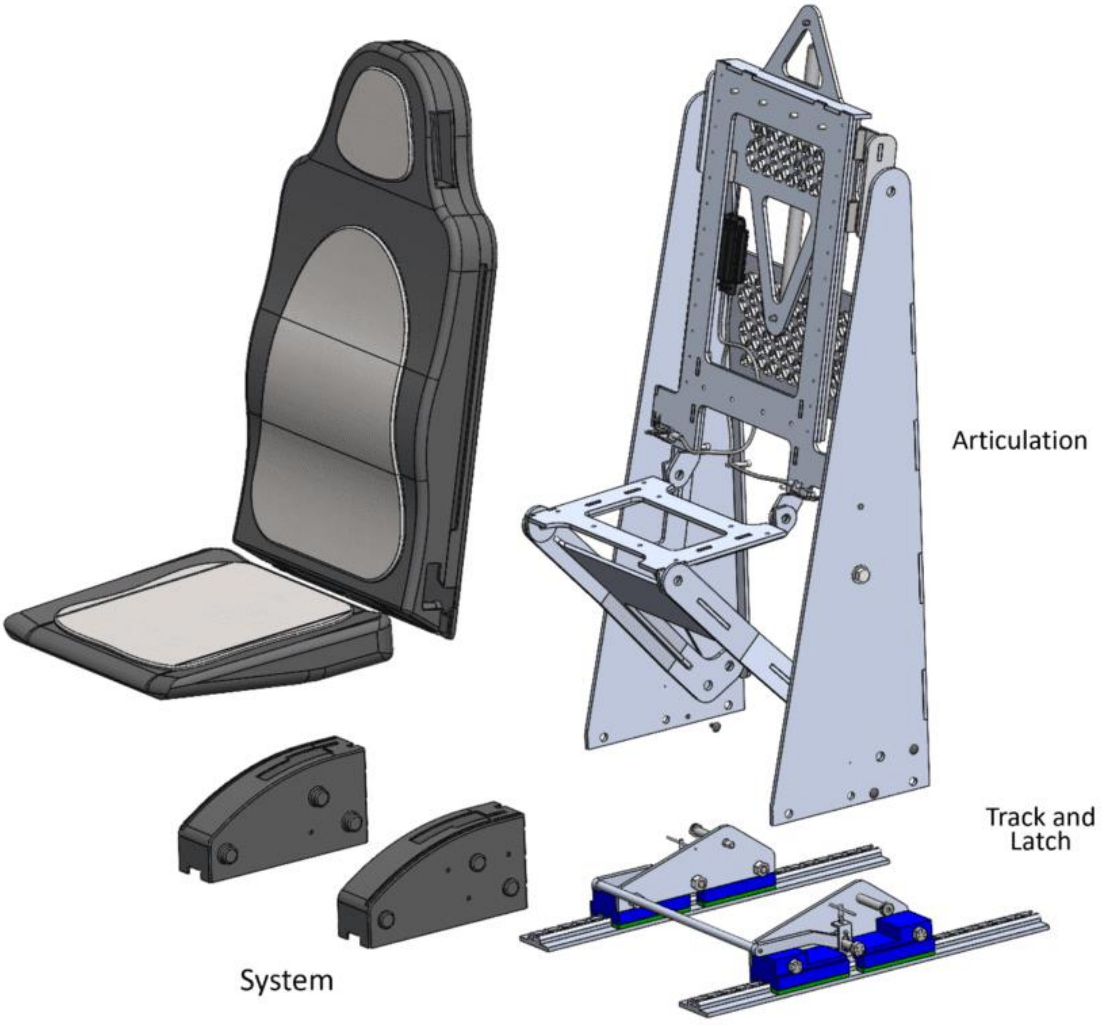
Load for 1/4" Displacement		
Vertical	99.25	lb
Axial	21.925	lb
Normal	11.275	lb

Displacement for 150 lb Load		
Vertical	0.38	in
Axial	1.71	in
Normal	3.33	in


Load Testing Results
Load Applied [lb]
Seat Deflection [in]
0
50
100
150
200
0.000
0.200
0.400
0.600
0.800
1.000
1.200
Vertical Loading
Axial Loading
Transverse Loading
Linear (Vertical Loading)
F = 397 x
F = 87.7 x
F = 45.1 x

Appendix AL: User Manual

User Manual



This user’s manual includes instructions for product use and important safety information. Read this section entirely including all safety warnings and cautions before using the product. No user assembly is required.

⚠ **CAUTION: THIS SEAT IS DESIGNED FOR NORMAL, EVERYDAY USE IN TRANSIT VANS AND VEHICLES. DO NOT TAMPER WITH THE LINKAGES OR MECHANISMS AS THIS MAY LEAD TO BODILY HARM OR DEATH**

Contents

Track Installation

NOTE: PRIOR TO INSTALLATION, CONFIRM THAT TRACK SEGMENTS ARE OF APPROPRIATE LENGTH FOR VEHICLE. IF TRACKS ARE NOT CUT TO THE APPROPRIATE LENGTH, CONTACT MANUFACTURER.

1. Align bolt holes of the provided track (Component 1) and ¼” Aluminum Sheet (Component 2)
2. Install the track assembly directly to **vehicle structural components** by securing the provided bolts through the predrilled holes in Components 1 and 2.

IMPORTANT: TRACK SUBSYSTEM MUST BE SECURED TO VEHICLE STRUCTURAL COMPONENTS. DO NOT OPERATE WITH TRACK INSTALLED ONLY TO VEHICLE FLOOR.

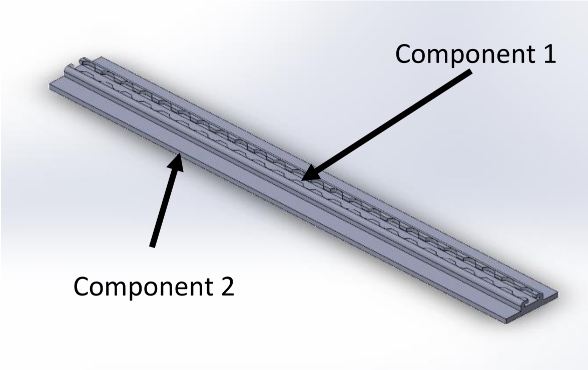


Figure 1. Track Subassembly

3. Confirm the installed track separation matches the provided specification sheet for the desired installed model.
4. Mate each individual Seating Assembly by aligning the profile in Component 3, shown highlighted in blue in Figure 2 with the track profile of Component 1.

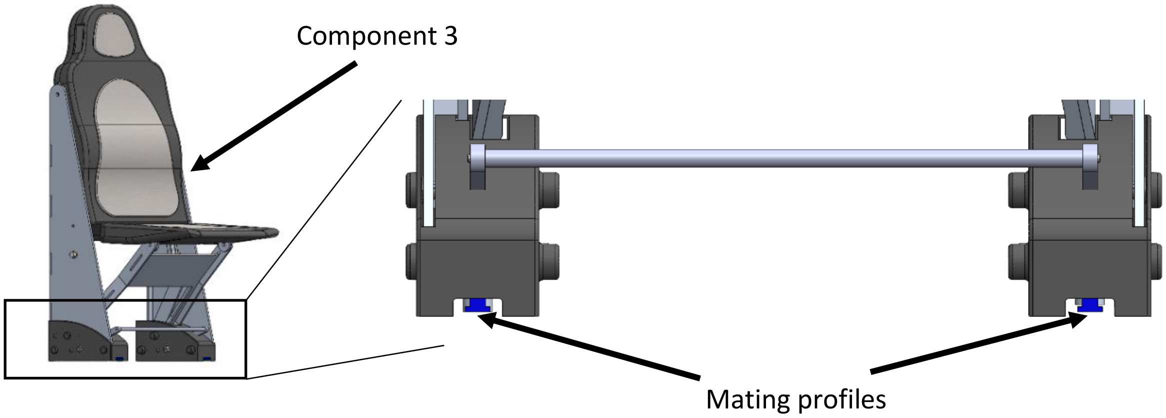


Figure 2. Full Seat Assembly with Latch T-profile

CAUTION: COMPONENT 3 (SEATING ASSEMBLY) REQUIRES TWO PERSON LIFT TECHNIQUES. DO NOT LIFT ALONE.

5. Confirm that each individual Seating Assembly (Component 3) is mated to both sides of Track Assembly and able to move freely along the track.

Normal Operation

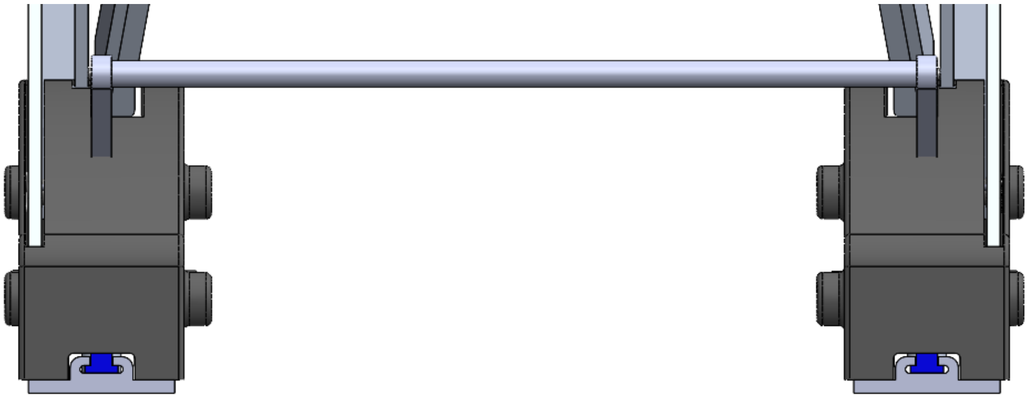


Figure 3. Unlocked (Top) Position

Figure 4. Locked (Bottom) Position

Locking the Seat

1. Press down on the front cross bar (Component 4) to move it from the top position (Figure 3) to the bottom position (Figure 4)

NOTE: YOU WILL HEAR AN AUDITORY *CLICK* WHEN THE SEAT SUCCESFULLY LOCKS WITH THE TRACK. SLIGHTLY MOVING THE SEAT MAY BE NECESSARY TO ENGAGE WITH TRACK.

2. Push against the seat to confirm the seat is locked. The seat should *not* move or wiggle when it is in the locked position.

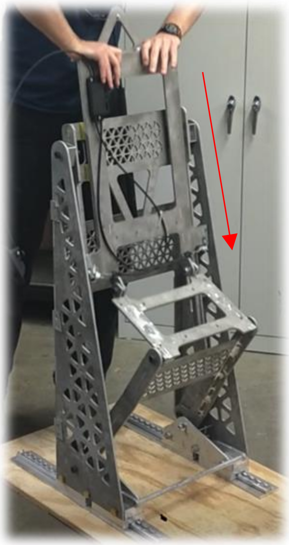
Unlocking the Seat

1. Pull up on the front bar by sliding your foot underneath the bar and pushing up
2. Seat can now freely move.

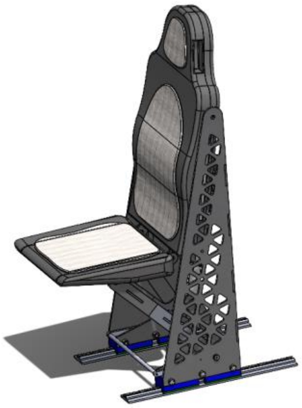
CAUTION: IF YOU ENCOUNTER SIGNIFICANT RESISTANCE IN MOVING THE CROSS BAR, STOP IMMEDIATELY AND CONSULT THE TROUBLESHOOTING SECTION OF THIS MANUAL.

Deploying the Seat

1. While standing behind the seat, use both hands to tilt the seat slightly



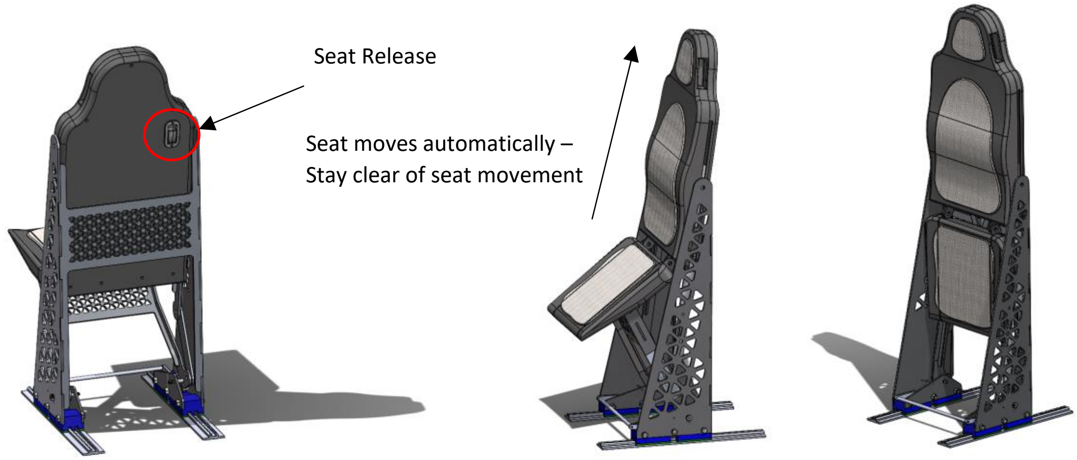
2. Keep pushing until latching system is activated. The user should hear an audible click when the seat is fully locked in a deployed position. Do not release the seat back until it has latched.



CAUTION: **BEWARE OF PINCH POINTS WHEN OPERATING THE SEAT. GAS SPRING APPLIES A CONTINUOUS UPWARD FORCE; DO NOT RELEASE SEAT BACK BEFORE AUDIBLE CONFIRMATION OF LATCH**

Storing the Seat

1. Lift Remote Actuation Latch, located on the back of the seat. The seat will actuate itself up and remain in a stored position.



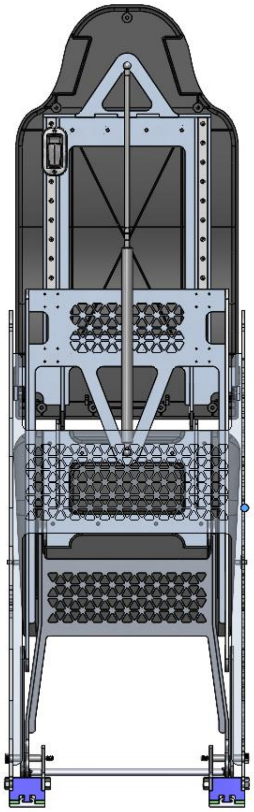
CAUTION: STAY CLEAR OF THE SEAT BACK AFTER THE LATCH HAS BEEN RELEASED. THE GAS SPRING WILL AUTOMATICALLY BEGIN ARTICULATING THE SEAT UP AND MAY IMPACT INTERFERING OBJECTS.

Maintenance

⚠ **CAUTION: DO NOT ATTEMPT TO PERFORM REPAIRS ON THE SEAT WHILE THE SEAT IS IN A DEPLOYED POSITION WITH THE GAS SPRING COMPRESSED. DOING SO MAY RESULT IN UNINTENDED OPERATION AND BODILY HARM.**

⚠ **CAUTION: BEWARE OF PINCH POINTS AND ACTUATION MECHANISMS WHEN PERFORMING MAINENANCE ON SEATING SYSTEM. ACCIDENTAL OPERATION CAN LEAD TO BODILY HARM.**

1. Periodically clean foreign debris from articulation points, seating locations, and internal components (At least one every 6 months).
    a. Use seat release latch to move seat into stowed position
        i. Do **NOT** attempt to remove gas spring if compressed
    b. Use a brush and receptacle to collect debris
    c. Disinfect with general purpose, nonabrasive cleaning solution
    d. For internal components:
        i. Remove seat back panel and/or latch cover to access internal components
        ii. Follow same cleaning and disinfecting guidelines as stated above



Troubleshooting

⚠ **IMPORTANT: DO NOT REMOVE PROTECTIVE COVERINGS UNLESS SPECIFICALLY INSTRUCTED TO BY A MAINTENANCE TECHNICIAN.**

1. If pushing up on the bar does not unlock the system, follow these troubleshooting steps:
   a. Check for binding with plastic covers. If plastic covers are interfering with arm movement, shift plastic covers.
   b. Push the seat along the track with slight force. Then retry moving cross bar.
   c. Using a can of pressurized air, blow into the plastic cover to dislodge any interfering debris. Then attempt to move cross bar again.
   d. If seat is still locked, contact manufacturer for further instruction.

⚠ **IMPORTANT: FORCING THE BAR MAY RESULT IN PERMANENT SYSTEM DAMAGE AND COMPROMISED SAFETY. DO NOT USE EXCESSIVE FORCE TO ACTUATE CROSS BAR.**

2. If seat is not sliding when in the unlocked position, follow these troubleshooting steps:
   a. Ensure bar is in the fully unlocked position and cannot be pushed higher.
   b. Remove any debris from track that may be impairing movement.
   c. Using a can of pressurized air, blow into the plastic cover to dislodge any interfering debris. Then attempt to move seat again.
   d. If seat is still locked, contact manufacturer for further instruction.

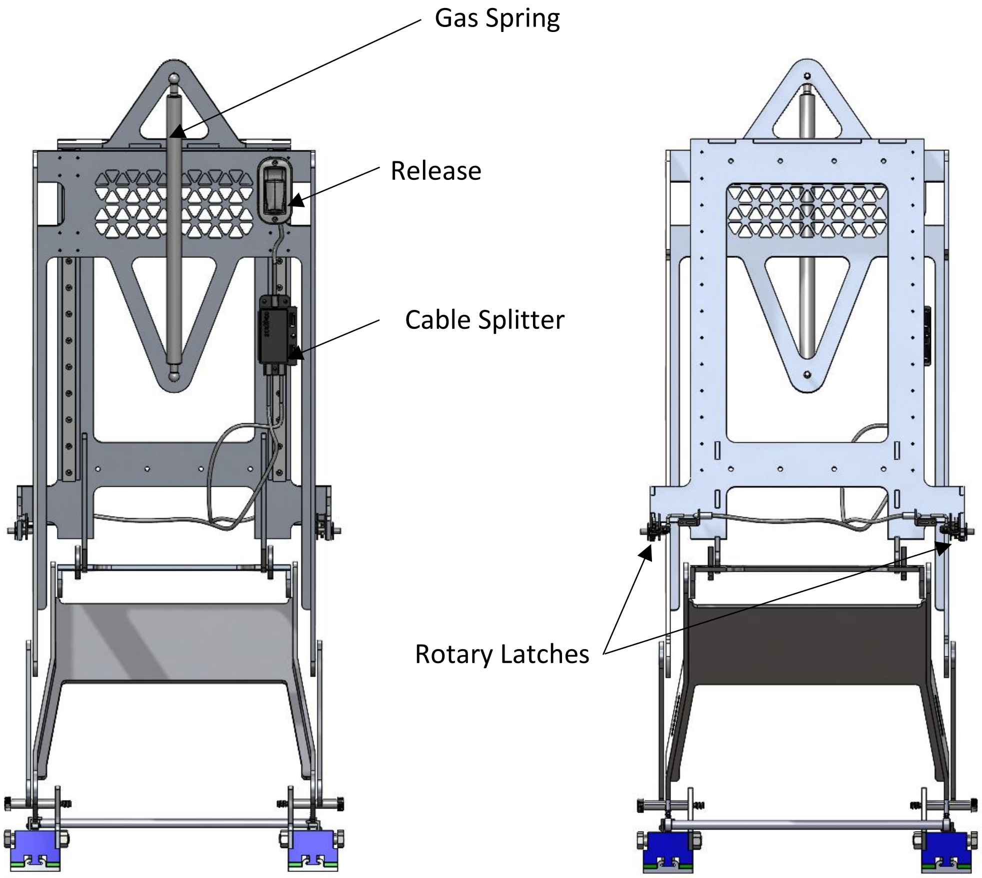
Repairs

CAUTION: DO NOT ATTEMPT TO PERFORM REPAIRS ON THE SEAT WHILE THE SEAT IS IN A DEPLOYED POSITION WITH THE GAS SPRING COMPRESSED. DOING SO MAY RESULT IN UNINTENDED OPERATION AND BODILY HARM.

1. If seat does not lift when latch is released, or the seat moves slowly, the gas spring may need replacement. The replacement procedure is as follows:
    a. Use seat release to move seat into stowed position
        i. Do **NOT** attempt to remove gas spring if compressed
    b. Remove back seat panel to access internal components
    c. Unscrew uncompressed gas spring from both threaded back frame points
    d. Discard worn gas spring and replace with McMaster item 4138T62 (Gas Spring) from parts list (See Table 1)
    e. Replace plastic seat back panel
    f. Ensure smooth operation before next use

2. If the latches are not releasing or engaging, one or more of the latch components may need replacement. Binding during actuation & uneven seat back movement may indicate the failure of one or both latches. Other signs include an inability for the seat to remain in a deployed position, or a lack of an audible click to indicate latch engagement. The replacement procedure is as follows:
    a. Use seat release to move seat into stowed position
        i. Do **NOT** attempt to perform maintenance if gas spring is compressed
    b. Remove back seat panel to access internal components
    c. Locate each latch component near the hinge point on either side of the seat, between the seat back and seat bottom frame. Check for damage or wear in each latch and identify any components that must be replaced.
    d. Unscrew the latch assembly from the seat frame at each of the threaded connection points to the frame.
    e. Remove the worn latch component and replace with Southco item R4-10-11-201-10 or R4-10-21-201-10 (See Table 1) depending on if left or right latch must be replaced.
        i. **NOTE** side of which latch is located. Right and left latches differ.
    f. Replace back seat panel
    g. Ensure smooth operation before next use.

3. If seat release shows signs of wear or breaks, it must be replaced. The replacement procedure is as follows:
    a. Remove back seat panel to access internal components. Allow worn latch to remain connected via the actuation cables to the seat. Set aside.
    b. If not already in stowed position, locate each latch component near the hinge point on either side of the seat, between the seat back and seat bottom frame. Manually disengage each latch from the striker pin so that the seat moves up into a stowed position.
        i. Keep extremities and loose objects, clothing, or hair clear of moving parts while manually disengaging latches
        ii. Do **NOT** attempt to replace seat release latch if gas spring is compressed
    c. Unscrew seat release latch from back seat panel. Remove the cable connection from the seat release latch and discard worn seat release latch.
    d. Replace with Southco item AC-70-101-11 (Rotary Paddle Latch) from parts list (See Table 1)
    e. Replace plastic seat back panel
    f. Ensure smooth operation before next use



Back View

Front View

Table 1. Parts List

PART DESCRIPTION	VENDOR	ITEM ID
Latching System		
Left Latch	Southco	R4-10-11-201-10
Right Latch	Southco	R4-10-21-201-10
Rotary Paddle Latch	Southco	AC-70-101-11
Cable - Latch to Splitter	Southco	AC-CHB0-7-0750-079
Cable - Splitter to Release	Southco	AC-CAH0-7-0750-034
Cable Splitter	Southco	AC-05-301-11
Cable Mounting Bracket	Southco	R4-0-50253-3
Latch Striker	Southco	R4-90-0521-10
Miscellaneous		
Short Alloy Steel Shoulder Screw	McMaster	item 91259A722
Long Alloy Steel Shoulder Screw	McMaster	item 91259A723
Ultra-Low-Profile Shoulder Screw (1/2" Ø)	McMaster	item 90969A410
Nylon Sleeve Bearing (5/8" Housing)	McMaster	item 6389K355
Thin Nylon-Insert Locknuts	McMaster	item 94627A180
Nylon Flat Washer	McMaster	item 90295A492
Gas Spring		
Gas Spring	McMaster	item 4138T62
Rail System		
Linear Slider Carriage	McMaster	item 9728K41
Linear Slider Rail	McMaster	item 9728K7