Safran Seat Attachment System
Final Design Review (FDR) Report
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Safran Seats
Santa Maria, CA
Statement of Disclaimer

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Glossary of Terms

1. **Seat Shell** – the part of a business class seat that surrounds the actual chair a passenger sits in. It contains the tray table, touchscreen, and other amenities.

2. **Harper Fitting** – the type of connector that attaches the seat to the floor tracks in Boeing airplanes. This part will be what connects to the part that is to be designed in this project.

3. **Herringbone Seat Arrangement** – Safran's proprietary business class seat arrangement. It involves having seats arranged at an angle instead of parallel with the plane’s length.

4. **NASA TRL Scale** – NASA's technology readiness level scale. This scale is broken down into numerical steps that range from a theoretical technology that has yet to be demonstrated to technologies that are well understood and used.

5. **Doubler** – the point on the seat shell that the part that will be designed in this project is connected. It is the attachment point of the part that connects the shell to the floor.

6. **SOR - Statement of Requirements.** It is a document created by Safran at the beginning of this project that outlined their overall goals for the team in terms of the final deliverable.

7. **QFD - Quality Function Deployment.** This is a process used to discover the main design points that will be important in the creation of a new part. Usually takes the form of a “house of quality” that outlines design characteristics and weighs them for multiple customers.

8. **Gantt Chart** – Chart used for project progress tracking. It consists of a series of horizontal bars that correspond to tasks that must be completed. They are clustered in groups for overall deliverables so that main milestone progress can be seen.
1. Abstract and Introduction

1.1. Abstract
This final design review (FDR) document outlines the senior design project being carried out by a team of mechanical engineering undergraduate students attending California Polytechnic State University, San Luis Obispo for Safran Seats in Santa Maria, CA. The project originally was to design, build, and test a universal attachment to secure a widebody business class seat to seven aircraft models with different seat track geometry. The goal was to design, document, and create a finished product that fits design, weight, and manufacturing requirements, as well as passes static 9G FWD testing. Structural analysis, manufacturing analysis, FEA, and CAD assemblies will also be handed over to Safran as the last step in the delivery of the final prototype. Additionally, any necessary bending, torsion, and stress concentration analysis will be completed and summarized for structural parts. Due to the COVID-19 outbreak in the state of California, deliverables had to be modified as the team was no longer allowed to finish the physical prototype and perform the final 9G test within the Safran facilities. This document describes the full timeline of the project, including background research, project requirements, expected final deliverables, concept ideation and preliminary concept design, final design and supporting analysis, the manufacturing plan for all components, the planned tests for design verification, and next steps for the project. Additionally, it outlines progress since the Critical Design Review (CDR) document was released with the modified deliverables due to the COVID-19 outbreak and shelter in place orders.

1.2. Introduction

1.2.1. Final Design Review Document Overview
This document outlines the overall design process for the project, from product specification development and background research, to project objectives, timeline, concept design, final design and analysis, manufacturing plan, design verification plan, and project management. It is an update since the CDR report, restating the problem and providing information on the development of the final prototype. As was previously stated, this prototype was never able to be physically created in its entirety as a result of the university-wide closure due to COVID-19.

1.2.2. Problem Statement
It is a goal of Safran seats to design the product platform of a widebody business class seat to allow the single product to fit across multiple aircrafts. Aircraft furniture is mounted to floors using predefined seat tracks that run the length of the airplane, and each aircraft model has unique seat track spacing that require variations in attachment configurations. It is beneficial to have a universal attachment method for passenger seating in order to sell to a wider range of customers and reduce development time and cost of producing the seat.

A seat designed for an Airbus A330 will not fit onto an Airbus A380 without a custom designed attachment method. This custom attachment causes many issues when designing seating platforms. The challenge is to design and analyze a product that allows a given seat shell to be installed onto the following aircraft seat tracks:

- Airbus: A320, A330, A350, A380
- Boeing: B747, B777, B787

A structural analysis will need to be performed for a 9G FWD dynamic case using given seat loads and center of gravity. Component weight is critical, and the final assembly should not weigh more than the current 15 lb. solution. Manufacturing methods are restricted to certified processes, which include
machining, composite layup and hot press, plastic injection molding and forming, extruding, and additive manufacturing (thermoplastic and metal). Casting and welding are prohibited. A full-scale seat shell was given to the team to produce a functional test part for structural testing at the SCC facility. The assembly was to then be tested on-site with the team to observe the test from behind a blast shield. With the outbreak of COVID-19 and new regulations from Cal Poly and the state of California during the shelter in place orders the team no longer was able to meet the requirements of delivery of a final physical prototype and performing the 9G testing on the prototype. Instead the team, with approval from their senior project advisor and company sponsor, altered the deliverables. In the added deliverables the team would be providing instructions for testing any uncertified equipment used in the prototype design, as well as a more complete manufacturing plan for making the parts using machines available to Safran Seats. All other documents specified by the SOR were still created and delivered to Safran. Furthermore, the group assisted Safran with all necessary aspects for the procurement of a patent on the solution developed.

1.2.3. Safran Group Introduction

Safran is the world leader in the commercial aircraft seats segment (economy class seats for twin-aisle jets). The Group designs, certifies, and assembles aircraft seats for crews and passengers, that combine ergonomics, comfort, design and space optimization. The continuous improvement of seat comfort and ergonomics is at the heart of Safran’s development strategy in this field. Today, one million Safran seats are in service in fleets all over the world. The Group offers a complete range of products, including passenger seats for economy, premium economy, business and first class, crew seats (pilots, hostesses, stewards’ seats) and helicopter seats. The Group also provides technical and commercial support to its customers worldwide throughout the product’s lifetime. [1]

The senior project team will be working primarily with Ian Bohannon, graduate of Purdue University, who is a lead design engineer for Safran Seats and the main contact for the team. Additionally, the team may work with Lucas Centeio, another Safran lead design engineer and Cal Poly graduate. Finally, significant work was James Voyles, the senior lead engineering manager at Safran.

The team working on the project consists of 3 students: Tyler Bragg, Craig Kimball, and Lynette Cox. Tyler is a 4th year mechanical engineer with a concentration in manufacturing. He will be graduating in the spring and plans on going into continuous improvement, operations, quality or manufacturing engineering after this year. Thus far, he has had three internships (for Oakley, Callaway Golf, and Full Swing Golf). Craig is a 4th year mechanical engineer in the general concentration. He has automation, manufacturing, and R&D experience from internships with Ernie Ball Music Man a guitar company, and undergraduate research in shape memory polymers his freshman year. Lynette is a fourth-year mechanical engineering major concentrating in mechatronics. She has teamwork, design, composites, and manufacturing experience through the Cal Poly Racing Formula SAE team, as well as R&D and design experience from an internship with the Volkswagen Innovation & Engineering Center of California.
2. Background Research

Initial background research was focused on four topics: customer research, product research with a focus on existing patents, and technical research. Customer research included meeting with the sponsor to gain a better understanding of the expected deliverables of the project and the sponsor’s expectations of the final design. Product research involved finding patents for existing seat track mount designs and any competitor products. Technical research was comprised of finding documentation regarding the general method for seat installation and general composites manufacturing and design methods.

2.1. Discussion of Existing Products & Patents

See Appendix A for a complete table of patents explored within the research of this project.

Patent 1: US 524154B2

[Diagram of Harper seat rail Connector]

This patent, filed by the Boeing corporation, exhibits a fastening device system used on Boeing planes to mount a seat attachment system to the seat rails. The connector is attached by sliding it into the seat rail, then two insert pins (4A) and (4B) are rotated, allowing the bottom rounded edge to become offset from the initial pin position in the seat rail slot, locking the connector into place. This device is one of the devices that Safran Seats will be providing the project team as an option for attaching the final solution to. Additionally, this patent gives the team a good idea of what the attachment points will look like for the design. The attachment point on this device is shown by (16) on the patent drawing. The patent also includes another configuration of the fastening device used for rear mounting points, meaning the front and rear of the seat are joined to the plane using different devices.

Patent 2: US6659402B

[Diagram of Boeing modular Seat connector]

The patent covers a device used to mount economy class seats inside an aircraft. The system is designed to be modular to fit to the various track widths within a plane cabin. Its assembly works by coupling the base to the seat rails using at least one attachment mechanism. The seat panel length is then adjusted, and the forward seat panel is installed. The entire system is locked into place on the seat rail tracks first from the rear attachment points and then the front attachment points.

Figure 2.1-3: Patent Photo of composite leg used to join economy seat to seat rail

The patent describes a method for manufacturing a composite leg to be used on an airplane seat structure. The patent goes into detail describing all of the doublers and fasteners used to join a composite leg of an airplane seat, to the seat structure and to the seat rails. The patent also describes the composite leg is made from “continuous compression molded composite extrusions.” This is then assembled with the core material to produce a foot end and seat end to be used in joining the seat to the aircraft. The method used for the forming of the composite leg is given in more detail within claim 1 of the patent.


Figure 2.1-4 Side view of Boeing composite Triangle for seat attachment

This patent shows a full composite assembly of a seat structure using similar manufacturing methods described in patent 3. The frame and mounting points are all designed as a composite and then joined to conserve weight of the overall assembly. Within its claims and associated images, the patent gives clear detail of the shape and design of each composite component. One of these pieces is a flexible composite arm, designed for dynamic load cases, that attaches to the rear mounting point of the seat. The arm is designed with a bowed curve to store energy under dynamic loading conditions and keep from transferring the load to critical joining areas of the structure.


Figure 2.1-5 Patent photo of a Herringbone arrangement of Safran Seats

This patent, filed by Safran seats, covers the design of their seat layout called the “Herringbone”. The Herringbone design angles passenger airline seats at an inward or outward angle depending on the location within the aircraft. This design allows for an increase of seat density within the plane. The patent shows that the frame for which the designed attachment system is mounted to is offset from the seat rails, which run along the length of the plane, giving a visual for where the attachment design would sit within the seat shell assembly.
2.2. Summary of Relevant Technical Literature

The goal of the initial technical research was to find documentation on topics that may be applied to the project, including general practices Safran uses to choose components for their designs, general methods and practices for airplane seat installation, and composites manufacturing and design methods. The findings of the technical research are summarized below in Table 2.2-1.

<table>
<thead>
<tr>
<th>Document 1: Hardware Decision Tree [5]</th>
<th>This document from Zodiac lays out the order in which fasteners and hardware should be chosen when creating a design. The document includes recommendations for screws, inserts, rivets, washers, nuts, riv nuts, pins, spacers, and snaps.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Document 2: Ergonomic and Human Factors Design Criteria for Producibility and Maintainability of Commercial Aerospace Products [6]</td>
<td>This document goes into specific detail of all human factors and design considerations for Boeing aerospace products. This includes design for maintainer, control-display integration, visual displays, controls, labeling, physical accommodation, ergonomics, and user-computer interface.</td>
</tr>
<tr>
<td>Document 3: Potting of Mechanical Inserts in Sandwich Panels [7]</td>
<td>This document details the process specification for the wet potting of inserts in composite sandwich panels. The document includes definitions of installation methods for thru or blind inserts, quality assurance inspection requirements, potted insert testing procedures, details on mixing adhesive, and use of inserts in materials other than composite panels.</td>
</tr>
<tr>
<td>Document 4: Shell Installation [8]</td>
<td>This document from Zodiac details the specific shell installation procedure for the Skylounge III seat shells. The document describes the three install stages with detailed and labeled drawings per each step. The three stages include seat shell disassembly, track fitting install, and seat shell assembly.</td>
</tr>
<tr>
<td>Document 6: Beginner’s Guide to Out-of-Autoclave Prepreg Carbon Fiber [10]</td>
<td>This document introduces the manufacturing process, tools, and basics of creating composite components with prepreg (process of making composites where it has resin pre-inserted in the fiber that is activated by heat later on) materials.</td>
</tr>
<tr>
<td>Document 7: NASA TRL Definitions [11]</td>
<td>This NASA document gives specific definitions for the technology readiness levels 1 to 10, and additionally contains descriptions for hardware, software, and exit criteria for that level.</td>
</tr>
<tr>
<td>Document 8: Aircraft Materials and Processes [12]</td>
<td>This book illustrates the mechanics of materials for various aircraft materials, testing results from various testing procedures, and the resulting material properties of common aerospace materials. The book also describes the common uses for each of these materials for the aerospace industry.</td>
</tr>
<tr>
<td>Document 9: The Robustness of Carbon Members Bonded to Aluminum Connectors [13]</td>
<td>This article models and investigates how to automate the joining of composite materials to aluminum components. The authors use FEA to conceptually analyze the adhesives used to attach carbon tubes to aluminum connectors.</td>
</tr>
</tbody>
</table>
2.3. **Applicable Industry Codes, Standards, & Regulations**

As specified by Safran Seats, the design of the seat attachment structure cannot utilize any parts that have been cast or welded. The design must interface with the seat using #10-32 fasteners when possible. When not possible, hardware from the provided hardware decision tree should be prioritized before choosing other types. The seat attachment structure must not protrude beyond the front, aft, left, and right sides of the seat frame. Additionally, the team has the option of using a pre-defined and approved seat rail fastener to attach the final seat attachment structure to the seat rails. These seat track fittings must be located at least 4” apart, bolt to bolt.
3. **Objectives**

3.1. **Problem Statement**
The seat mount structure needs to be custom fitted to every airframe and seat structure. Airline seat manufacturers need a single seat mounting solution that interfaces with many different seat track designs. Additionally, the structure needs to interface with preexisting seat mounting points and withstand FAA-required 9G testing. The team will supply analysis to back up all design decisions for the final prototype.

3.2. **Boundary Diagram**

![Boundary Diagram](image)

Figure 3.2-1: Boundary diagram detailing the scope of work of the problem statement.

Figure 3.2-1 displays a picture of the boundary diagram that defines the scope of work of the project. The design will encompass a frame that interfaces to the seat rails on a plane and to existing doublers on a supplied seat shell. Within the boundaries of the design are the fasteners used to secure the design to the doublers and to the track rail connectors. The design will consist of a frame or system of frames that join the seat to the existing seat rails. The seat rail connectors will be specified by the design team, but these do not necessarily have to be designed by the team.

3.3. **Customer Wants & Needs**
For the seat attachment design the Customer (Safran Seats) provided a Scope of Requirements Document (SOR). The SOR outlines the specifications needed by Safran Seats for the design and can be classified as customer needs. Other criteria from Safran discussed within the SOR but are not directly associated with the deliverable prototype are discussed under customer wants. The list below outlines these needs and wants.
3.4. QFD Process

Reference Appendix B, QFD House of Quality, to view the deliverable from this process. The house of quality was the product of group brainstorming to define the project needs. First, the team spoke with the sponsor to determine what they viewed as the most important aspects of the project. This led to a discussion regarding the possible groups that would be impacted by the prototype design. Further requirements were developed with these specific groups in mind.

After the wants of the project were developed, attention shifted to developing numerical tests to measure whether these wants have been met. Upon completion of this brainstorming, markers were placed to display how each test relates to each want. Overly redundant tests were then removed as appropriate.

Following test development and comparison, the group assessed what direction would be considered progress for the test (up or down). This marker was added above the test. In the “roof” of the house of quality, each test was then compared in terms of whether they had positive, negative, or no interaction.

After all relations were settled, research was then conducted into competitor products. Several were chosen and assessed on how well they fit the wants from the beginning of this process on a scale of 1 to 10. To do this, the group followed a process similar to that of creating an impact/difficulty matrix taught in Lean/Six Sigma training. One group member would first choose the number they felt fit for each product in each want. Then another member would get to go through that list of numbers and change any they disagreed with and state why. The last member would then do the same and then it would return to the first person. The group went around in this way until an equilibrium was reached and everyone agreed with the numbering. Ultimately, this indicated that their product did not fit the requirements well and that it would be best to develop a new one.
Lastly, the group followed the same numbering method from the assessment of competitor products to determine the importance of each want to every identified customer. The results of these decisions provided a relative weighting of the importance of each want. The QFD was then sent to the project sponsor and any input they provided was implemented.

3.5. Engineering Specifications

<table>
<thead>
<tr>
<th>#</th>
<th>Spec. Description</th>
<th>Requirement or Target (units)</th>
<th>Tolerance</th>
<th>Risk</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Weight</td>
<td>15 lb.</td>
<td>Max</td>
<td>M</td>
<td>Measured</td>
</tr>
<tr>
<td>2</td>
<td>Size</td>
<td>Fits within a 1” height below seat</td>
<td>Max</td>
<td>L</td>
<td>Tested</td>
</tr>
<tr>
<td>3</td>
<td>Materials</td>
<td>No cast or weld</td>
<td>-</td>
<td>M</td>
<td>Designed</td>
</tr>
<tr>
<td>4</td>
<td>Standards</td>
<td>9G FWD testing</td>
<td>Must Pass</td>
<td>H</td>
<td>Tested</td>
</tr>
<tr>
<td>5</td>
<td>Modular</td>
<td>Must fit seat rails in the following : A320, A330, A350, A380, B747, B777, B787</td>
<td>Min</td>
<td>M</td>
<td>Tested</td>
</tr>
</tbody>
</table>

3.6. Specification Measurement Plan

<table>
<thead>
<tr>
<th>Specification</th>
<th>Measurement Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyze manufacturing process</td>
<td>Manufacturing process must be able to be completed in house and finished by May, 2020 (Requirement cancelled due to COVID-19)</td>
</tr>
<tr>
<td>Comparison to original design by Safran Seats</td>
<td>Design must be unique and different than the current design solution</td>
</tr>
<tr>
<td>Withstand 9G FWD impact test</td>
<td>Design will be tested using certified 9G FWD static testing equipment in Santa Maria test facility (Requirement cancelled due to COVID-19)</td>
</tr>
<tr>
<td>Installation time test (less than 4 min)</td>
<td>Team will run time-to-assemble studies on final physical prototype assembly</td>
</tr>
<tr>
<td>Interface with desired Seat Shell</td>
<td>The interface point on the design fits to all mating points using 10-32 fasteners</td>
</tr>
<tr>
<td>Must weigh less than 15 lb.</td>
<td>The full physical prototype will be weighed using a scale (projected from finished parts due to inability to complete manufacturing)</td>
</tr>
<tr>
<td>Fits all desired seat track standards (7)</td>
<td>A fixture will be made that can simulate all track lengths required, and the design will interface with the fixture in all 7 configurations</td>
</tr>
<tr>
<td>Zero infringed patents</td>
<td>Patent searches will continue to be conducted and designs will be reviewed for any potential copying of patented processes or technology</td>
</tr>
</tbody>
</table>

3.7. High Risk Specifications

From the specifications listed in the QFD and in the specification measurement plan, the only high-risk specification is the 9G FWD impact test. The design must pass the 9G FWD test regardless of other criterion to be certified to fit onto a plane, and thus will be the major driving factor of the design. Structural Analysis and FEA will be done in advance to verify that the design should pass the testing before physical testing is performed. The 9G FWD test uses a static loading to simulate a 9G dynamic crash on the structural
components of the system [14]. The test is conducted by using a jig that attaches a fully assembled seat assembly and begins to load the part at fixture points until 9G is achieved and sustained. The static loading is applied gradually, not immediately [15].
4. Concept Design

4.1. Brainstorming
When coming up with the selected design of this project the first thing that occurred was a brainstorming session. Each member of the team was given a large stack of sticky notes and, after a quick warm-up, were tasked with rapidly writing down any ideas they came up with pertaining to meeting all, or some of the requirements of the project. Once the allotted 5 minutes were over, the ideas were then organized into categories based on what the group members felt was the best fit. These categories were defined as components, fasteners, materials, full system, or misc. structures. Figure 4.1.1 below shows a picture of the brainstorming session, with all the sticky notes laid out, as well as the final lists of all of the resulting ideas. Refer to Appendix D to see the list of ideas categorized.

4.2. Concept Prototyping
After brainstorming, the team took some of the realistic achievable concepts and began to look into making physical prototypes to assess their function as well as how to incorporate the attachment system geometry into the overall seat. Each team member made drawings and physical models of various functional prototypes of one of two categories: modularity or frame shape. These two categories were decided as the team felt that they were two of the most critical functions of the design. The frame controlled the shape and weight of the design, whereas modularity focused on the mechanisms and techniques that could be used to allow the design to accommodate multiple seat rail widths. These ideas were then used to create the initial Pugh matrices for the decision selection process, which are further described in the next section.

4.3. Pugh Matrices
Before matrices were created, specific criteria were determined in order to rate each design idea. These were selected by reviewing the quality function deployment (QFD) and by revisiting the statement of requirements (SOR) provided by Safran. A list of the selected criteria is given below, as well as what questions were used to analyze the effectiveness of a potential design.
Design Criteria

1. **Weight**
   a. How much would the design weigh?
   b. Is it bulky?
   c. Will it need a device to carry it?

2. **Ease of Manufacturing**
   a. Does this require intricate parts?
   b. Are there areas where high levels of precision are necessary?

3. **Ease of Installation**
   a. Does it fit through an airplane door?
   b. Are there connection points that are hard to reach?
   c. How do components mate together?

4. **Novel Design**

5. **Number of Total Components**

6. **Cost**

It is worth noting that material was not used as a judging criterion. The team felt that without doing more in-depth analysis, or having a selected design, it would be difficult to fully weight the pros and cons of a material for this project. This decision will likely be made during the analysis soon after PDR. One of the Pugh matrices during this step can be seen in Table 4.3-1 below. Refer to Appendix E for all Pugh matrices.

---

### Table 4.3-1 Pugh Matrix

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>Concept 1: use of seatbelt harness hardware to quickly attach frame to seat track</th>
<th>Concept 2: rail fitting to attach frame pieces to seat track (single pin adjustable on seat track end of frame rail, pin goes in horizontally)</th>
<th>Concept 3: rail fitting for adjustability on different seat track widths, pin goes in vertically</th>
<th>Concept 4: rail fitting with pins on both the seat frame and seat track ends of the frame for quick adjustment to different seat track widths, pins go in horizontally</th>
<th>Concept 5: rail fitting with pins on both the seat frame and seat track ends of the frame for quick adjustment to different seat track widths, pins go in vertically</th>
<th>Concept 6: Use of carbon fiber tubes as a direct press from frame seat frame to seat track</th>
<th>Current Solution: Aluminum Frame, 2 Pieces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cost</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ease of Manufacturing</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Ease of Installation</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Number of total components</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Novel Design</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ease of Distinct/Unique Appearance</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
</tr>
</tbody>
</table>

*A larger version of this Pugh Matrix can be found in Appendix E*

---

### 4.4. **Weighted Decision Matrix**

After Pugh matrices were completed and reviewed by the team, designs that scored well were identified and concepts were taken from each to create 5-6 more complete concept designs for the weighted decision matrix. Once the designs were inserted into the matrix, weighting was then discussed and assigned. For weighting the team felt that the top 3 important criteria in the design were weight, ease of installation, and ease of manufacturing. Each of these was given a weight of 0.25 or 25%. Weight was rated highly because the design cannot exceed 15lbs, and the lighter the solution is, the lighter the entire seating package becomes. Installation and manufacturability were also rated highly as Safran has time constraints on how long one of their seats should take to install, and the team felt that whatever solution is selected should be
one that the team is capable of creating on campus, and possibly with additional support from Safran. The next highest rated criterion was “novel design,” which was given a weight of 0.15. In discussions with Safran it was determined that it is important that the design be unique from the current design used, and as a result the criteria was rated highly. Lowest in weighting is cost and number of components, as neither criteria was directly mentioned in the SOR document, but still have some impact on design choice. Below in Table 4.4-1 is the final weighted decision matrix.

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>Weight</th>
<th>Concept 1: Carbon tubing attached to a fixed mounting point on a sliding modular frame</th>
<th>Concept 2: A triangle and square frame (metal?) attached to a split ski modularity system</th>
<th>Concept 3: A frame made from metal cable (ski cable) in a taught webbing form secured to a modular base frame</th>
<th>Concept 4: An inverted I spider frame (Al) that adjusts size through the middle beam using a ball-lock</th>
<th>Concept 5: Two opposing triangles with holes, or t-slots to mount to for modularity made of metal</th>
<th>Current Solution: Aluminum Frame, 2 Pieces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>0.25</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Ease of Manufacturing</td>
<td>0.25</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Ease of Installation</td>
<td>0.25</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Novel Design</td>
<td>0.15</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Number of total components</td>
<td>0.05</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Cost</td>
<td>0.05</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Totals</td>
<td>2.35</td>
<td>2.6</td>
<td>2.5</td>
<td>3.3</td>
<td>3.45</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The team discussed the results from the decision matrix and how the highest scoring concept design could be modified or further improved upon to create a design the team is satisfied with. The team used a brainstorming technique to come up with similar designs to the highest-ranking concept from the weighted decision matrix, “opposing triangles”, by drawing a top down view of the locations of all doublers on the seat shell and connecting them using lines to come up with different frame geometry. Examples of this can be seen below in Figure 4.4.1.
4.5. Selected Design Concept

The selected preliminary seat frame geometry consists of two triangular frame pieces that both attach to an I-shaped frame. Each of the triangular pieces join to 3 doublers each on the left and right sides of the seat. One triangle sits below where the seat will be attached to the shell and the other triangle sits below the part of the shell that has the desk and any other seat accessories. These triangles are mounted to the I-frame that sits below the triangles, which connects to 2 seat tracks via Safran-provided floor fittings. The triangles are meant to have set dimensions and geometry that does not change from airplane to airplane.

In order to add modularity to the design and allow for variable distances between the tracks, the I-frame is adjustable in length in its center section and is meant to lock into specific positions using a fastener or Balllok connector. The seat rail mounts sit on the end pieces of the I and give the seat ability to accommodate the various seat track widths of the 7 aircraft. Each aircraft has between 1 to 3 different seat track widths, with the smallest distance spanning 17” and the largest spanning 36.5”. To put this range into perspective,
the seat frame is 42” total in width, meaning the I-beam would have to be able to change length by 19.5”. The team notes that this is a large amount of material that may not be put to use with the smaller seat track widths, and this design may need to be reconsidered to reduce weight and wasted material.

![Figure 4.5-2 Preliminary physical concept model of basic frame geometry.](image)

4.6. Preliminary Analysis

In order to perform any preliminary calculations on the selected attachment system design, some assumptions had to be made. The main test that the team is designing for is a static 9G FWD loading test, and the details and assumptions of which were provided by Safran Seats via their Scope of Requirements document and during discussions about the allowable assumptions that can be made about the test procedure. It can be assumed that the loading from the 9G FWD test is applied to the center of gravity (CG) of the entire seat package, and that the seat shell structure can be treated as a single structural component. In the case of the preliminary selected design made by the team, the load from the seat would first be transferred from the seat to the two structural triangle frames that attaches to the six doublers of the frame.

The other major assumption that the team made for this preliminary analysis is the 4 seat rail attachment points are placed symmetrically around the seat frame CG, and that the loading being transferred to each mount is therefore equal. Figure 4.6-1 shows some sample calculations for the forces each rail attachment point would experience using these assumptions.
Hand calculations for the moments experienced at each mounting point were also performed, and can be found in Appendix F. A rough shear moment diagram was drawn for the triangle frame to see which sections of the frame would experience the most loading. The results from this can also be seen in Appendix F. From this basic analysis it seems to be the critical areas of the design are going to be the points where fasteners join the triangles to the I frame, and the points near the center line of the structure. Next analysis will need to be done to look at the change in stresses of the frame with varying wall thicknesses and material densities. At this point the team will have enough information to revisit material choice and see if the initial choice of extruded metals is still the best choice.

4.7. Design Challenges & Safety Risks

One of the most critical decisions that still needs to be made for the project is the material that the triangular frame will be manufactured from. The team is currently considering either an entire extruded and machined metal frame, or a hybrid frame that consists of both composite parts and extruded metal. This decision has major effects on the overall weight, complexity, and manufacturability of the design. More calculations need to be performed before the team can make a supported decision about what materials will work best for the frame. The team needs to look further into the magnitudes of stresses in the frame. Additionally, during preliminary analysis it was discovered that the doublers are not all at equal heights, which creates
more complexity regarding the direction of forces and additional moments that were not previously forecasted that will possibly be seen by the frame.

Other challenges moving forward include making the modularity design as robust as possible while still fitting the wide span of track widths required by the SOR. While building the concept model, the team discovered that the seat frame needs to have a lot more modularity than initially expected. Different aircraft each have between 1 and 3 different seat track widths per plane, ranging from 17” to 36.5” in width, which requires the team to find a way to make the frame adjustable up to a 19.5” span. This could possibly add a lot of excess, unnecessary weight to a frame that only needs to span the 17” yet has the ability to expand to 36.5”. Additionally, the seat rails are offset from the seat frame centerline in certain aircraft, therefore it will be a challenge to either make sure that the seat can be mounted at different offsets on the seat frame design, or give the modularity system the ability to adjust its centerline to accommodate these various offsets on certain aircraft.

Regarding the possible safety risks that the team may encounter for the rest of the duration of this design process, the team created a Design Hazard Checklist to demonstrate all safety considerations regarding the scope of the project. For a full analysis of the risks involved with the design, build, and testing of this project, see Appendix G.
5. Final Design

5.1. Assembly Overview

The final assembly is designed to meet all of the requirements specified by Safran Seats: The design fits within the current shell design, weighs less than the 15 lb. maximum, is modular and therefore installable in any aircraft, does not interfere with the current seat frame design, and attaches to two seat tracks with a minimum 4” center-to-center gap between any floor fitting. The final design consists of 4 sub-assemblies: (A) Support Beams, (B) Doubler Connectors, (C) Mid-Frame Supports, and (D) Beam to Connector Fittings.

Sub-assembly A, Support Beams, consists of one front and one rear beam that span lengthwise across the inner bottom of the seat frame shell. These beams are the foundation of the assembly that connects all other sub-assemblies with one-another.

Sub-assembly B, Doubler Connectors, consists of 4 plates that have 1 or 2 tabs each. The doubler connectors interface between the Support Beams sub-assembly and the seat frame doublers on the seat shell.

Sub-assembly C, Mid-Frame Supports, consists of 2 parts that act as doubler connectors near the centerline of the seat shell, and 2 parts that connect between the doubler connectors and the Support Beams sub-assembly.

Sub-assembly D, Beam to Connector Fittings, consists of 4 parts that interface between the Support Beams sub-assembly and the provided seat track fittings of the airplane. It is this component that allows the final design to be modular and installable in any aircraft.

The final design is meant to be assembled almost exclusively with NAS 1801 #10-32 fasteners. NAS 1801 #10-32, 5/8” length fasteners are used to attach sub-assembly B, doubler connectors, to the seat frame. NAS 1801 #10-32, 1” and 1.5” length fasteners are used to attach sub-assembly A, support beams, to sub-assembly B, doubler connectors. NAS 1801 #10-32, 1.25” length fasteners are used to attach sub-assembly A, support beams, to sub-assembly C, mid-frame supports.

Additionally, the final assembly requires #10 helical inserts, #6 helical inserts, #6-32 flat head machine screws, #10 washers, #10-32 self-locking nuts, and fasteners unique to the provided floor fitting hardware.

All components are to be made with a 6061-T6 aluminum alloy. 6061-AL has a yield strength of 40ksi, when given a T-6 temper, and is also an aerospace certified material. It is a commonly used alloy in many applications and is readily available in many different sizes of stock and extrusion patterns. It is easy to machine and has a density of 0.0975lb/in³, which helps achieve the weight requirement of the design.

5.2. Sub-Assembly A: Support Beams

Sub-assembly A, Support Beams, consists of one front and one rear beam that span lengthwise across the inner bottom of the seat frame shell. These beams are designed to sit perpendicular to the seat tracks of the airplane. The location of this sub-assembly is shown below in Figure 5.2-1.
These beams are the foundation of the assembly that connects all other sub-assemblies with one-another. The beams consist of 6061-T6 aluminum rectangular bar stock, with cross-sectional dimensions of 1” x 0.5” x 1/16” wall thickness. The front beam is 40.5” in length, and the rear is 39.5” in length due to differences in front and rear doubler placement. It is important to note that larger cross-sectional beam dimensions may result in interference with the existing seat shell and seat frame.

To determine beam specifications, first a load case scenario was set up such that each Beam to Connector component (sub-assembly D) is spaced symmetrically about the center support, and the test load was distributed evenly across the two components. A shear moment diagram was then used to find the critical locations on the beam.

Next, a stress equation was developed and organized such that area and moment of inertia were calculated based on beam length, width, and thickness. A MATLAB script was developed based on this equation to allow the team to iterate through and test various beam dimensions and expected loads to verify that the
final selected beam specifications would meet the load test requirements as specified by the sponsor. For documents related to beam analysis refer to Appendix J. For the MATLAB script refer to Appendix K.

![Stress Equations Used in MATLAB Script](image)

In the equations above, `Reaction_F` refers to the reaction force a doubler attachment sees during testing and `Applied_Load` is the test load divided in half for front and rear sections. `I` and `A` refer to moment of inertia and cross-sectional area, respectively.

### 5.3. Sub-Assembly B: Doubler Connectors

Sub-assembly B, Doubler Connectors, consists of 4 plates that each have 1 or 2 tabs each. The Doubler Connectors interface between the Support Beams sub-assembly and the seat frame doublers on the seat shell. The location of this sub-assembly is shown below in Figure 5.3-1.

![Figure 5.3-1: The doubler connections subassembly, highlighted in a yellow color within the total design assembly.](image)

These four Doubler Connectors are what attach the universal frame structure to the seat shell. The plates are made with 6061-T6 aluminum 0.19” plate stock, while the tabs are to be machined out of 0.375” aluminum plate stock. The Doubler Connectors connect to the doublers of the seat shell via pre-supplied composite inserts that already exist on the seat shell structure and NAS 1801 #10-32 bolts. The tabs connect to the support beams as described in sub-assembly A.

![Figure 5.3-2: From left to right: rear right doubler connector, rear left doubler connector, front right doubler connector, front left doubler connector.](image)
As shown above in Figure 5.3-2, each of the 4 Doubler Connectors are unique in geometry and hole placement. This is because they are designed to match the hole and doubler geometry that already exists on the seat shell. Figure 5.3-3 below, the rear left doubler, shows an example of the spatial limitations within the seat shell frame.

![Figure 5.3-3: A view of rear left doubler attached to the seat frame.](image)

Each Doubler Connector consists of two components: a flat plate and a separately machined tab that is connected to the plate via #6-32 flat head machine screws and adhesive film. This design decision was made to reduce material waste during the manufacturing process, as well as allow the senior project team to easily prototype these parts, however, will require the group to qualify the #6-32 screws as they are not on Safran’s preapproved hardware tree.

![Figure 5.3-4: Rear face view of a doubler connector showing the tab attachment via machine screws.](image)

The design concern regarding the doubler connectors was focused on the tab that mates with the support beam of the assembly A. To get accurate stress information at these points, FEMAP and FEA software were used to analyze each component. For each of the four doublers, the load was applied at a rigid node in the bolt hole to simulate the bolt that connects the tab to the support beam, which experiences shear forces during the 9G test.
Figure 5.3-5: FEA results of a doubler plate and tab

As shown in Figure 5.3-5 above, the areas of max stress occur at the base of the design, but below the yielding stress of 6061-T6 aluminum, proving the part meets the necessary design requirements. In Figure 5.3-5, it is assumed in the analysis that the doubler tab is glued to the doubler surface with an estimated 80% weld strength, allowing the full cross-sectional area to take load. In the final prototype this will be achieved with the two #6-32 screws holding the doubler tab against the plate, and an adhesive applied between the plate and tab. The reason for the addition of the adhesive is to help the #6-32 screws hold the load being applied to the tab. In Appendix J there are calculations showing the screw response if there were to be no adhesive applied between the tab and the doubler plate, resulting in the screws experiencing a load of 176ksi, which is 25ksi higher than their yield strength. By adding the adhesive between the two parts, it allows the entire cross-section at the connection to absorb the load rather than just the screws bringing the stress down below yield as seen in FEA.

As shown by the calculations, the screws experience substantial force in this scenario, meaning an adhesive will be applied between the tab and doubler as well to increase area transmitting load and reducing the shear stress experienced by the bolts.

5.4. Sub-Assembly C: Mid Support

Sub-assembly C, Mid-Frame Supports, consists of two parts that act as doubler connection plates near the centerline of the seat shell, and 2 parts that connect between the plates and the Support Beams sub-assembly. The location of this sub-assembly is shown below in Figure 5.4-1.
These Mid Supports help distribute loads more evenly throughout the seat shell and connect to the doublers at the center front and rear of the shell. Each component is made from 6061-T6 aluminum and connect to one another via #6-32 flat head machine screws, as shown below in Figure 5.4-2. The senior project team decided to split the front and rear mid-supports into two separate parts in order to make manufacturing easier, as both components are not perpendicular to the support beams and have complex angles.

It is important to note that the beam connectors (the parts that connect to sub-assembly A, Support Beams) connect directly to the support beams via thru bolts. This is because these parts do not need to move with respect to the seat shell frame in order to make the design universal.

Like the doubler Connectors from sub-assembly B, FEA for the mid support was done to verify that it would be able to withstand the load case from the 9G FWD testing.
From the results of FEA analysis done with the Middle Support connected to the Middle Doubler, it was found that the highest stress concentrations are located at the outer edges of the fillet near the bottom of the part. This can be seen above in Figure 5.4-3. These values are below the yield of the selected material, and the team thinks the part will be able to withstand the test loads. The high stress point near the connection of Doubler and support, on review, appears to be a singularity in the solution set of this model and can be neglected.

5.5. **Sub-Assembly D: Beam to Connector**

Sub-assembly D, Beam to Connector Fittings, consists of 4 parts that interface between the Support Beams (sub-assembly A) and the provided seat track fittings of the airplane. It is this component that allows the final design to be modular and installable in any aircraft. This is due to (1) the ability of all of these parts to slide along the length of the sub-assembly A (support beams) and clamp down at the desired seat track width and (2) the ability of these parts to attach to interface with the two types of floor fittings, stud and Harper.
The two front Beam to Connector components have the same geometry but are mirrored to place the connecting tab on the opposite side, and the same applies to the two rear components. These similarities in geometry are shown below in Figure 5.5-2.

Figure 5.5-2: From left to right: front left Beam to Connector with a front Harper fitting, front right Beam to Connector with a front stud fitting, rear left Beam to Connector with a rear Harper fitting, rear right Beam to Connector with a rear stud fitting.

These components attach the support bars to the seat rail connectors. These components act as sliding clamps allowing for modularity within the system, as the parts can be adjusted to any position and then clamped down using the bolts shown in the top of each part. The reason the tab comes off to the side on each is to accommodate the widest fitting required by this design, without interfering with other components.

Figure 5.5-3: FEA results of rear and front Beam to Connector component
The FEA for the beam to connector provided useful information in the iteration of this design. From the Results of the Front and Rear pieces high stress points appear at corners and fillets in the design, where there are changing cross sectional areas. For both cases FEA verifies that these regions are below yield values, however knowing that these are critical parts, the team may iterate the design to replace fillets with a chamfer increasing the cross-sectional area in those regions and decreasing stress.

5.6. Limitations of the Final Design
As described in the scope of work and project requirements for this design, the Universal Seat Attachment assembly should be able to fit all seat track distance configurations for all airplane seat tracks. A Seat Track Fitment Study, attached as Appendix S, was done using CAD to validate the ability of the design to fit most of the final standards, with an exception for seat widths that go beyond the maximum distance of the final design.

This study shows each possible seat track distance variation, and then examines the ability of the Universal Seat Attachment to meet these requirements without interfering with any of the pre-existing components of the seat. The study found that airplane seat tracks have a minimum distance requirement of 17” and a maximum distance requirement of 36.5”, while the Universal Seat Attachment has a minimum distance requirement of 17” (meeting the minimum distance goal) and a maximum distance of 35” (not meeting the maximum distance goal) before the assembly will interfere with the composite shell of the seat frame. The team suggests that the Universal Seat Attachment will be able to meet the maximum distance goal of 36.5” only if the current seat shell design can be modified with cutouts and covers in order to extend the seat track fitting attachment location beyond the boundaries of the seat shell. Table 5.6-1 models the results of the study. To review the full Seat Track Fitment Study document, see Appendix S.

<table>
<thead>
<tr>
<th>Distance Study Results</th>
<th>Required by Airplane Models</th>
<th>Attainable by Universal Seat Attachment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Distance</td>
<td>17”</td>
<td>17”</td>
</tr>
<tr>
<td>Maximum Distance</td>
<td>36.5”</td>
<td>35” (without modification to the shell)</td>
</tr>
</tbody>
</table>

*The team suggests that the Universal Seat Attachment will be able to meet the maximum distance goal of 36.5” only if the current seat shell design can be modified with cutouts and covers in order to extend the seat track fitting attachment location beyond the boundaries of the seat shell.
6. New Project Scope & Results

This section details the changes in the scope of this project due to the impact of the shelter-in-place order for San Luis Obispo county due to the COVID-19 outbreak.

6.1. New Problem Statement & Objectives

The shelter-at-home order for San Luis Obispo county was initiated on March 18, 2020, and the executive order to stay home except for essential needs was initiated on March 19, 2020 for the State of California. The intent of the order, slowing the spread of COVID-19 in California by ensuring that people are self-quarantining in their places of residence, caused California Polytechnic State University, San Luis Obispo to move all courses online and restrict students from stepping onto the campus in person. Additionally, the Mechanical Engineering department restricted all senior project students from utilizing the on-campus machine shops or personal power tools at home to carry out the manufacturing of their projects. This required the senior project team to re-evaluate and modify the scope of requirements for the project. The original problem statement of this FDR report was updated to reflect these changes, and the following section details the changes in final deliverables to be delivered to Safran Seats.

6.1.1. Updated Objectives & List of Final Deliverables for Safran

The original objective of this project was to design, build, and then perform a 9G FWD test on the completed assembly that fulfills the project requirements. The stay at home order was initiated during the manufacturing phase of the project, so the final assembly build was not completed. The team deliberated and produced the following new set of objectives and list of modified deliverables to complete the project.

Modified Project Objectives
1. Design a universal attachment method that satisfies the original universal attachment requirements
2. Complete additional analysis and FEA to show that the design passes the 9G FWD test case
3. Create documentation to assist Safran in completing the 9G FWD test on their own

Modified List of Deliverables
- Manufacturing Time Study
- Manufacturing Cost Analysis
- Detailed Part Drawings
- Final Design BOM with estimated final weights
- Structural Analysis FEA
- Final Design Fitment Study for all seat track combinations
- Assembly Installation Instructions with time estimate
- Detailed Testing Plan for doubler tab design verification

6.1.2. Documents Created to Assist Sponsor in Future Project Use

The following appendices are documents that were created to assist Safran Seats in completing the project and carrying out the original 9G FWD testing plan:
- Appendix M: Doubler Tab Design Verification Testing Instructions
- Appendix R: Instructions for Assembly
- Appendix N: Manufacturing Cost Analysis & Time Study
- Appendix S: Seat Track Fitment Study
6.2. Design Changes Due to Change in Manufacturing Ability

Most of the original design was intended to be manufactured using a waterjet. Since Safran most commonly manufactures their parts using CNCs, the team made small adjustments to the final design in order to make all the parts manufacturable with a 3-axis CNC. The primary challenge with manufacturing our parts on a 3-axis CNC came from the manufacturing of both the front and rear beam to connector components. In both cases, there is such a complex geometry that machining is only possible one of two ways: either use a fourth axis or use 3 separate CNC operations and setups. We were informed that it would be preferable to go with the latter option and thus did CAM using HSMworks to create G&M code for all three operations. Ultimately, we were successful in the creation of these codes with some modifications. First, on all components (not just beam to connector), internal corner radii were altered from 0.100” to the nearest fractional size due to the fact that a 0.100” radius is not a standard size end mill. Additionally, on the beam to connector components, the slot that the beam slides through had to be expanded as a result of the newly added internal fillets. This is because with the new fillets, the beam would no longer fit as planned. The expanded area allows the beam to slide through again. This does not adversely impact the overall effectiveness of the design as it increases the distance from the screw to the outside wall of the slot (thus increasing the bending moment and therefore clamping force). The clamping force calculations were re-verified and are shown in Section 6.3 Additional Analysis, Figure 6.3.2. In the generation of G&M code for the purposes of proving the manufacturability of our new design, standard sized end mills, drills, and taps were selected from the catalog on McMaster Carr.

![Figure 6.2-1 Beam to Connector Components (Left: Front BTC, Right: Rear BTC)](image)

6.3. Additional Analysis

The team completed additional analysis to verify the changes in the design, as well as further analyze the ability of the assembly to withstand the 9G FWD test case. Refer to Appendix M for a complete testing plan for the doubler tab design.

To ensure success during 9G testing the #6-32 screws specified in the BOM need to be tested as they are not part of the verified hardware spec list provided by Safran. The team determined that a pull using an Instron pull test device would be sufficient in simulating the 9G test for the screws and developed a fixturing device for the testing.
Figure 6.3-1 Doubler Tab Testing Fixture

Figure 6.3-1 above shows the fixturing used for securing the doubler tab fixturing. The fixture consists of three components. The middle component is an L-bracket made of steel with mounting holes for the doubler tab to be installed on as well as mounting holes for the bottom “pull beam to be mounted using #6-32 screws, the same spec used on the ones on doubler tabs. The “top pull” bar has a U channel cut in the top with holes on the sides acting as a clevis pin, allowing a #10-32 bolt to be secured through the top puller and the doubler tab. The fixture was chosen to be made of steel because steel has a much higher strength than the aluminum doubler and would make sure that no flexure occurred in the fixture causing error in the results from the test. The goal of the test is to prove that the screws can take their expected load during the 9G test as calculated by the team. For manufacturing drawings for the fixture and testing instructions refer to Appendix M.

With the updates in design for manufacturability analysis on the clamping force was recalculated to verify that the original torque spec called for tightening the #10-32 bolt was still sufficient. The hand calculations performed on the part can be viewed in Figure 6.3-2 below.
From calculations the clamping force was found to be 13% higher than in previous calculations, but still within the range of being “hand tight” while maintaining a factor of safety of 2. In the case of this new design the factor of safety is 2.1.

6.4. **Assembly Instructions**

Final assembly for the universal seat attachment will involve the attachment of subassembly A, B, C, and D to the provided seat shell in the configuration required for an A380 track. Assembly will consist of first running the support bars (group A) through all clamping components in groups B, C, and D. Next, all doubler connectors from groups B and C will be screwed hand-tight into the doublers on the provided seat shell. The beam will then be attached to the doubler connectors. Clamping components that interface with the floor tracks will then be set to the appropriate position. A screw will be inserted and screwed in hand-tight to provide clamping force on the bar and lock in their current position. Lastly, the clamps interfacing with the floor fittings will be attached to the floor fittings. For full assembly instructions refer to Appendix R.
7. Original Manufacturing Plan, Completed Manufacturing, & Testing Plan

7.1. Manufacturing Overview
The FAA requires that parts designed for airplanes not be cast, welded, brazed, or otherwise heated such that the material properties of the part change. The design of all components within the final design do not require welding, and all parts are connected via fasteners. Safran Seats most commonly uses a combination of custom metal cold forming, CNC machining, and composites to manufacture all seat parts. It is in the best interest of the senior project team to design parts to be manufactured at the Safran Seats facility such that the final design can be manufactured there.

The senior project team has limited access to machines including CNC mills and lathes, cold metal forming machines, and large-scale full-time manufacturing facilities. Due to this, the team has designed all parts to be manufacturable at a prototype scale on the Cal Poly campus, as well as at the Safran Seats manufacturing facility. The plan to manufacture most of the parts is to use a combination of waterjet-cut stock and CNC/manual milling.

7.2. Manufacturing Plan
The final design of the universal seat attachment involves the custom manufacturing of 15 distinct components. The geometry of the final design was ultimately required to be too specific for off the shelf parts to be used. As such, a major aspect of the design process was design for manufacturability. As a result, all of the custom fabricated parts employ the same manufacturing processes: water-jetting, milling, and basic metal shop operations (such as breaking sharp edges). To preserve the brevity of this document, the specific operations, cost breakdown, and stock details have been integrated into the bill of materials (Appendix H) by part. Furthermore, part drawings for each custom fabrication can be seen in Appendix O sorted by subassembly group and part number listed in the bill materials.

7.3. Completed Manufacturing
Once the Design presented at CDR was approved by the company sponsors and project advisors the team went forward with manufacturing. Due to the COVID-19 outbreak and the shelter in place order in California starting on March 22, 2020, completion of all manufacturing for a final prototype was impossible. Any manufacturing that was completed is shown below in this report.

End Plates
Line files for all the endplates were created for use with the school’s waterjet, a Flow 3020 Mach100 waterjet. The aluminum stock was ordered to thickness for the parts so only a single waterjet operation needed to be performed. A concern during the waterjet process was the severity of kerfing that occurred on the edges of the endplates. Kerf is a taper that occurs on the edge of lasered, or waterjet parts that is a result of the material being cut being thicker than the focal point of the cutter. Upon inspection the team found the kerfing on the end plates to be nominal on the edges. For the holes a post waterjet drilling operation was performed to ensure the holes had a tighter tolerance to their nominal size and to remove any kerfing that occurred from the waterjet operation.
The first operation performed was cutting the aluminum stock to size using a vertical bandsaw. Once the stock had been cut to size the team then worked on a method to fixture the cut stock to the waterjet, such that position could be preserved between the first and second operation. The team settled on using a thick piece of steel plate butted up against the front edge of the waterjet frame and clamped to the table to act as a horizontal reference as well as another longer plate along the side as a vertical reference. Significant time was spent on this fixturing as the part would not be manufactured correctly if the x-y positions of the stock were not preserved across the waterjet operations. The first operation cut the side profile of the rear beam to connector component. Due to the thickness of the stock the feed speeds of the waterjet were very slow averaging 0.27 in/min throughout the operation. Once completed the stock was rotated along the x axis and a second operation was performed to cut the top profile of the part. A hacksaw was then used to cut any tabs used to hold the part to the stock during waterjetting and the part was inspected for dimensional accuracy and kerfing.
The final operation performed on the part was done with HAAS VF2 3-axis CNC mill to mill out a recess in the part to allow for both connector types to interface with the part.

Doubler Tabs

Due to circumstances out of the team's control, the waterjet was unavailable for use when the team began manufacturing on the Doubler tabs. First, using a bandsaw, the team cut long lengths of aluminum stock to an oversized part width. Using a manual mill, the thickness and widths of the stock were brought down to the specifications called out in the Doubler tab drawings. Next, using a bandsaw, the stock was cut to an oversized length, and then machined to spec using a manual mill. The manual mill was then again used to drill the holes for both the #10-32 bolt and the #6-32 screws. A hand tap was used to cut threads into the two #6-32 holes. The top curves of the tabs specified by the drawing were unable to be completed before the shutdown occurred in California.
Figure 7.3-5 Using the horizontal bandsaw to cut stock to size.

Figure 7.3-6 Machining the doubler tabs on a manual mill.
7.4. Cost and Procurement
The final design of the universal seat attachment involves a total of 25 distinct components and a quantity of 133 parts. Of these distinct components, 15 are custom fabrications and 10 are off the shelf parts. All manufactured components will be made from stock metal sourced from onlinemetal.com, fasteners will be purchased from McMaster-Carr, adhesives will be from Amazon and Rockwest Composites, and remaining components will be supplied by Safran. As a result, the estimated net cost paid by the group for project manufacturing materials is $564.17.

A cost study for the final prototype. The team looked at the cost per minute of CNC operations on machines used, as well as conventional costs for machinists for any parts requiring manual manufacturing. Because not all manufacturing was completed by the time due to the COVID-19, some cost values were pulled from average machinist cost in the SLO area. Below is Table 7.4-1 showing the manufacturing cost for each component of the design. For a complete cost analysis of each manufacturing process refer to Appendix N.

Table 7.4-1 Cost Study

<table>
<thead>
<tr>
<th>Part</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rear Beam to Connector</td>
<td>211.1</td>
</tr>
<tr>
<td>Front Beam to Connector</td>
<td>238.1</td>
</tr>
<tr>
<td>End plates</td>
<td>50.25</td>
</tr>
<tr>
<td>Doubler tabs</td>
<td>95.7</td>
</tr>
<tr>
<td>Middle Plates</td>
<td>50.25</td>
</tr>
<tr>
<td>Middle Connectors</td>
<td>78.7</td>
</tr>
<tr>
<td>Front / Rear Beam</td>
<td>30.4</td>
</tr>
<tr>
<td>Total manufacturing</td>
<td>754.5</td>
</tr>
</tbody>
</table>
### 7.5. Time Study
The team recorded the time taken for all operations that were physically performed by team members in the manufacturing for the final prototype. Any operation that was unable to be completed was given estimated times based on information found from estimations made in CAM (HSMworks) where applicable or based on information given by machine shops in the area. Below is a table summarizing the total time for manufacturing a single final prototype unit. For a more complete table refer to Appendix N.

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Time (Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rear Beam to Connector</td>
<td>340</td>
</tr>
<tr>
<td>Front Beam to Connector</td>
<td>358</td>
</tr>
<tr>
<td>End plates</td>
<td>85</td>
</tr>
<tr>
<td>Doubler tabs</td>
<td>120</td>
</tr>
<tr>
<td>Middle Plates</td>
<td>85</td>
</tr>
<tr>
<td>Middle Connectors</td>
<td>125</td>
</tr>
<tr>
<td>Front / Rear Beam</td>
<td>40</td>
</tr>
<tr>
<td>Total manufacturing</td>
<td>1153</td>
</tr>
</tbody>
</table>

Table 7.5-1 shows that the two components that take the most amount of time to manufacture are the Rear and Front Beam to Connector components. This is because the team chose to use a dual operation waterjet cutting procedure followed by CNC milling to manufacture these components. Referring to Appendix MN shows that the waterjet is what takes up most of the manufacturing time due to the slow feed rate as a function of the material thickness. The final drawing plans submitted updated corners and fillets in these components so that Safran could choose to CNC mill these components entirely, potentially saving manufacturing time and cost.

### 7.6. Design Verification Overview
See Appendix I, DVP&R, for an overview table of each specification and test plan to verify that the specification has been met. The following are all requirements set by Safran that must be met by the final design.

- Weigh less than 15 lb.
- Fit to current shell design
  - No change to Seat Pitch (met by designing within seat shell)
  - No Change to Aisle Width (met by designing within seat shell)
- Withstand 9G FWD test
- Installable in any location on the following aircraft: **(met when designing modularity)**
  - A320, A330, A350, A380, B747, B777, B787
- Must be attached to two seat tracks, with provided floor fittings that have a minimum 4” gap center-to-center **(met by considering restraints in design)**
- Does not interfere with the current seat frame for the passenger seat (this provided seat frame must be physically separate from the design of the seat shell frame) **(met by designing components to deliberately avoid seat in assembly CAD)**
- Installable in under 15 minutes per seat shell
7.7.  9G FWD Static Test
The final test for the FP (Final Prototype) system, the 9G FWD static test will be conducted at Safran Seats testing facility. The purpose of this test is to certify the design for crash testing on a plane. For the component the team is designing the FP must sustain a 9G static load for 3 seconds without shearing. For the purposes of this test, yielding is considered passing (but it is preferred that it not). During the test, loading is applied at the center of gravity of the object to simulate emergency landing conditions. In the 9G FWD test, the method that will be used to test the FP currently, uses cords distributed around the Seat Shell system to pull on the part at the required 9G static load. To determine what the loading on the part the equation below is used:

\[ 160\text{lbs} \times 9 \times 1.33 \times 1.05 = 2010.96\text{lbs} \]

From the equation above 160lbs refers to the total certified weight of the seat shell package we are designing for. Nine is the multiplier for the 9G test. The 1.33 and the 1.05 are safety factors built into the calculation to accommodate for any error in weight and error in the load application respectively. All analysis was done using the 2010.96lbs load applied at the center of mass of the system.

7.8.  Installable in Under 15 Minutes
This requirement will be tested at the same time the 9G FWD static test is conducted. At this time, we will use a timer to record how long it takes to install our part into the overall seat shell assembly. The entire seat must be able to be installed in under 15 minutes. As such, our part will be considered to have passed this requirement if it can be installed in under 3.75 minutes. This allows the remainder of the seat shell to be easily installed using the remaining half of the 7.5 minutes allocated to the shell installation.

A time study was performed to supplement Appendix N, Installation Instructions in Appendix R, and it was estimated that a single person will most likely be unable to install the entire seat assembly within 15 minutes.

7.9.  Final Design Specifications
This section reviews all of the original requirements specified by Safran for the project, and compares these requirements with the specifications of the final design to show whether or not the final design was able to meet the end goal of the project. Table 7.9-1 summarizes these results.

<table>
<thead>
<tr>
<th>Project Requirement</th>
<th>Final Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weigh less than 15 lb.</td>
<td>Expected Final Assembly Weights (est. with CAD software):</td>
</tr>
<tr>
<td></td>
<td>With Harper Fittings: <strong>5.598 lb.</strong></td>
</tr>
<tr>
<td></td>
<td>With Stud Fittings: <strong>5.7242 lb.</strong></td>
</tr>
<tr>
<td>Fit to current shell design</td>
<td>Requirement met</td>
</tr>
<tr>
<td>No change to Seat Pitch or Aisle Width</td>
<td>Requirement most likely met, more analysis may be necessary to verify this.</td>
</tr>
<tr>
<td>Withstand 9G FWD test</td>
<td>Requirement not met</td>
</tr>
<tr>
<td>Installable in any location on the following aircraft:</td>
<td>Installable on the following aircraft:</td>
</tr>
<tr>
<td></td>
<td>Installable on the following aircraft with some modification:</td>
</tr>
<tr>
<td></td>
<td>B787</td>
</tr>
<tr>
<td>Requirement</td>
<td>Status</td>
</tr>
<tr>
<td>---------------------------------------------------------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>Must be attached to two seat tracks, with provided floor fittings that have a minimum 4” gap</td>
<td>Requirement met</td>
</tr>
<tr>
<td>Does not interfere with the current seat frame for the passenger seat (this provided seat frame must be physically separate from the design of the seat shell frame)</td>
<td>Requirement met.</td>
</tr>
<tr>
<td>No use of welding, casting, or other heat-based manufacturing processes</td>
<td>Requirement met.</td>
</tr>
<tr>
<td>Properly handles any possible contact of dissimilar metals</td>
<td>Requirement most likely met, more analysis may be necessary to verify this, specifically where the structure of the final design is attached to the seat track fittings, which are not made of 6061-T6 aluminum like the rest of the assembly.</td>
</tr>
</tbody>
</table>
8. Project Management

8.1. Overall Design Process

The goal of this project is to follow the full design process for the duration of three academic quarters. This includes a design phase with prototyping and design reviews, a build phase with detailed manufacturing plans and creation of a final prototype, and a testing phase to validate and test the decisions made in the design process.

The team performed its initial background research on the project, met with the sponsor to understand the scope of requirements, and received a tour of the Safran manufacturing facility. A scope of work (SOW) document was written to define the project scope and final deliverables.

The team has also performed concept ideation and deconstruction to initialize the project direction. These designs and design paths were presented in a PDR document. Once PDR was completed and feedback was reviewed, the team began analysis and development on the selected design. Solid models are used for more detailed analysis, and a final assembly has been documented and backed with detailed analysis and testing plans to validate the design decisions made by the team. This was culminated in the Critical Design Review (CDR) document, showcasing the design, manufacturing steps, and testing procedures.

After CDR, additional design changes were completed and manufacturing on the final design began. Ideally once manufacturing is completed, the team would have performed preliminary testing on all design criteria but the 9G FWD testing. Due to the impact of the COVID-19 stay-at-home order, the design direction had to be modified. The team was unable to finish the manufacturing of the final prototype, therefore they were also unable to complete the testing of any of the components. Instead, the team created documentation that further analyzes the design, and describes the rest of the procedure for completing the design process of the final prototype. All final materials are now being presented in this Final Design Review (FDR) document to be handed over to Ian Bohannon of Safran Seats.
9. Conclusion and Recommendations

9.1. Table of Key Deliverables & Project Timeline

The team plans on using and regularly updating a shared Gantt chart to track task progress throughout the design process. The initial team Gantt chart is attached as Appendix C of this document. Reference Appendix C, Initial Gantt Chart.

<table>
<thead>
<tr>
<th>Project Progress</th>
<th>Fall Quarter</th>
<th>Winter Quarter</th>
<th>Spring Quarter</th>
</tr>
</thead>
<tbody>
<tr>
<td>October</td>
<td>Sponsor Introduction</td>
<td>NDA Submittal</td>
<td>Sponsor Visit</td>
</tr>
<tr>
<td></td>
<td>Defining Scope of Work (SOW)</td>
<td>Customer Research</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SOW Submitted to Sponsor (Oct. 18)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>November</td>
<td>Develop Concept Models</td>
<td>Safety and FMEA Analysis</td>
<td>Preliminary Design Review (Nov. 12)</td>
</tr>
<tr>
<td>December</td>
<td>Design for Manufacturing Evaluation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter Quarter</td>
<td>Design Analysis</td>
<td>CAD Development</td>
<td>Bill of Materials Development</td>
</tr>
<tr>
<td></td>
<td>Critical Design Review (Feb. 6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>Manufacturing Plan Development</td>
<td>Part Drawings and GD&amp;T</td>
<td>Test Plan Development</td>
</tr>
<tr>
<td>February</td>
<td>Manufacturing &amp; Test Review (Mar. 12)</td>
<td>Part Manufacturing</td>
<td></td>
</tr>
<tr>
<td>March</td>
<td>Testing</td>
<td></td>
<td>Final Report</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Senior Project Expo (May 29)</td>
</tr>
</tbody>
</table>

9.2. Next Steps

Upon the submission of the FDR document the team is looking for approval on the handoff of the design and all deliverables outlined in the original and updated SOR. The next steps for the project recommended by the team are to first use the testing procedure outlined earlier in the report to prove the #6-32 screws will survive loads in 9G FWD testing. Once validated the team recommends building a testing prototype to use for 9G static FWD testing. For the front and rear beam to connector components the team recommends using the updated models and drawings, that have been made CNC-friendly for manufacturability, to CNC the components as opposed to manufacture by waterjet.

Following the approval of this FDR document, the group will hand off all materials to Ian Bohannon of Safran Seats. It is at this point that the project will be considered to be completed. For the foreseeable future, it may become necessary for members of the group to respond to messages from Ian regarding the pending patent application that has been filed on the beam to connector components of this design. The group will watch for these correspondences and reply with the appropriate information or actions as necessary. Furthermore, it has been specified by Ian that Safran no longer wishes that the group return any of the
project materials provided to the group throughout the year. This is as a result of the Santa Maria facility of Safran’s seats division being closed as a result of COVID-19. As such, the group will organize the timely disposal of these materials so as to make their project space available to a future group in time for next quarter’s starting class of senior project students. The group will then file for the publishing of this document with the Kennedy Library with the stipulation that it not be publicly available for a time of 2 years, or starting in June of 2022. This will allow all aspects of the patent to be settled before any proprietary information is revealed through this medium.

Presently, it is believed by the group that Ian and Safran should have no significant issue with the eventual manufacturing and testing of the Universal Seat Attachment. We believe that as long as the 6-32 screws pass the tensile test, no further modification should be necessary for our design to face the 9G FWD static test. It is also the belief of the group that the seat attachment will be able to withstand this test with minimal damage to the structure as a whole. This in combination with our belief that we have satisfied all other design goals for the project lead us and our advisor to the conclusion that this project has been a success. All findings have been summarized in this report and in our Final Design Expo webpage, which can be found under the Mechanical Engineering projects at http://projectexpo.wpengine.com. All CAD and other documentation will be electronically sent to Ian as soon as this final design is approved.
10. Conclusion

To reiterate, this document has the purpose of describing the team’s detailed design, decision making process, and findings-to-date, with the overall goal of providing context for what the team views as the final design direction it should take for the project. Thus far, the group has determined the needs of this project based on information gained directly from the sponsor and considering the other groups who could be stakeholders in the final product. While considering these needs, it was found that there are very little, if any, competitor products that fit the requirements to a satisfactory level. As such, the group agreed that the best course of action is to design a new part with the specific purpose of fulfilling these needs.

Upon determining that a new prototype must be developed, a general patent search in the area specified by these needs was launched. This search confirmed the previous conclusion that there are not many applicable designs. However, it did provide insight into several similar solutions. This information was crucial in the design process moving forward. Ultimately, it led the group to a final design backed with the necessary theoretical modeling and analysis. Next, manufacturing and delivery of a final prototype was anticipated.

Following the patent search, the group went through an ideation phase in which many concept models were created to explore potential solutions to the problem posed. The benefits and drawbacks of each concept model was explored, allowing the group to determine what are the best design characteristics to take forward to a conceptual prototype. The relative importance of each characteristic was assessed using Pugh matrices and ultimately, a weighted decision matrix. Next, a new design was developed keeping these design characteristics in mind. Ultimately, this conceptual prototype was meant to represent the design direction that the group believed to be the best for solving the problem defined in the SOW document. Ultimately, however, new information showed that the conceptual prototype would interfere with current seat geometry. As such, old ideas were explored and iteration lead to the current detailed design.

Originally, it was planned that after the design was approved by Ian Bohannon, the component manufacturing phase would begin. A mandated stay-at-home order issued in San Luis Obispo County due to the COVID-19 pandemic during the timeline of this project caused the team to be unable to finish the manufacturing of the final prototype. In its place, further manufacturing and FEA analysis was conducted and detailed manufacturing and installation instructions were generated. Using these pieces of information, the team has confidence that Safran should have no issue manufacturing the final prototype components in the future, carrying out the #6-32 screw test, and completing the 9G FWD load test as originally planned. Additionally, the team assisted Safran with the procurement of a patent on the idea of the “sliding adjustment” feature of the beam to connector components of the design and believe that this will be approved and put into place soon. It is requested that Ian Bohannon respond as soon as possible so that we can provide any final information, documents, and files necessary to consider this project complete.

The group would like to extend a special thanks to Ian Bohannon, James Voyles, Scot Scarborough, and Safran Seats for sponsoring this project as well as their guidance along the way. We believe that we would have never been able to successfully complete this had it not been for their unending support. We look forward to hearing about the results of the 9G FWD static test when the day ultimately comes that our design faces it and hopefully for the news that our patent has been approved. Working with you has been a pleasure.

Furthermore, we would like to thank Dr. Elghandour for his support throughout this project. His expertise and especially his knowledge of Safran, composite manufacturing, and FEA have proven to be an integral part of our success and we are very thankful for his support throughout the duration of the project.
Lastly, we would like to thank the faculty of the College of Engineering, the Department of Mechanical Engineering, and the Mechanical Engineering machine shops and shop technicians for providing us with the necessary tools for to complete this project. We look forward to putting our new skills to use in industry post-graduation.
11. References


## 1.0 Appendix A

### Initial Patent Search Findings

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Patent Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>US6659402B1</td>
<td>MODULAR AIRCRAFT SEAT SYSTEM</td>
<td>This is a patent that shows a modular rail attachment system for a set economy seat design</td>
</tr>
<tr>
<td>US4771969A</td>
<td>LEG SEAT TRACK FITTING</td>
<td>Shows a method for attaching a fixture to the seat rail attachment. Low profile design compared to other patents.</td>
</tr>
<tr>
<td>US20090243352A1</td>
<td>SECURE HERRINGBONE ARRANGEMENT FOR THE ARMREST OF A SEAT, SEAT AND TWO SEAT ASSEMBLY PROVIDED WITH SUCH AN ARRANGEMENT</td>
<td>Shows Herringbone design of Safran Seats.</td>
</tr>
<tr>
<td>EP1957807B1</td>
<td>ECCENTRIC FASTENING DEVICE</td>
<td>A fastening device used by Boeing to connect their mounting fixture for international flight chairs. Patent was recommended by Safran for inspiration.</td>
</tr>
<tr>
<td>Patent Number</td>
<td>Patent Title</td>
<td>Description</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>US20050211836A1</td>
<td>PAYLOAD TO SUPPORT TRACK INTERFACE AND FITTING APPARATUS AND METHODS</td>
<td>A patent form Boeing that shows an interfacing device for seat rails on Boeing aircraft. The patent also describes the methods in which the device installs into Boeing planes and how it is assembled.</td>
</tr>
<tr>
<td>US8590126B2</td>
<td>METHOD OF MANUFACTURING A COMPOSITE LEG STRUCTURE FOR A LIGHTWEIGHT AIRCRAFT SEAT ASSEMBLY</td>
<td>A method for laying up composite material into the shape of a seat attachment system for Boeing economy seats and showing the attachment locations on a seat frame to specified composite piece.</td>
</tr>
<tr>
<td>US20080282523A1</td>
<td>COMPOSITE SEAT PAN STRUCTURE FOR A LIGHTWEIGHT AIRCRAFT SEAT ASSEMBLY</td>
<td>Shows full assembly of a Boeing economy seat and how their composite seat attachment arms join to the seat structure. Also shows a design for a full composite seat frame.</td>
</tr>
</tbody>
</table>
### 2.0 Appendix B

**QFD House of Quality**

#### QFD House of Quality

**Project:** Universal Seat Attachment  
**Revision Date:** 10/01/94

#### Relationships

<table>
<thead>
<tr>
<th>Positive ‏</th>
<th>Negative ‏</th>
<th>No Correlation ‏</th>
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</thead>
<tbody>
<tr>
<td>Strong ‏</td>
<td>Moderate ‏</td>
<td>Weak ‏</td>
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#### Direction of Improvement

<table>
<thead>
<tr>
<th>Moderate ‏</th>
<th>Target ‏</th>
<th>Minimum ‏</th>
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</thead>
</table>

#### Correlations

- 1: Weak  
- 2: Moderate  
- 3: Strong

#### HOW MUCH: Target Values

<table>
<thead>
<tr>
<th>HOW MUCH: Target Values</th>
<th>Input Values</th>
</tr>
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</table>
| Max Relationship | 5  
| Technical Importance Rating | 4.44  
| Average Value | 3.80  
| Max Value | 5  
| Min Value | 1  
| Average Value | 3.86  
| Target Value | 3.50  
| Max Value | 5  
| Min Value | 1  
| Average Value | 3.86  

#### Column # 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

**Customer Requirements**

1. No Casting/Welding
2. Novel Design (not like old design)
3. Meets FAA requirements for 9G Impact
4. Easy to Install
5. Lightweight (less than 1 lb)
6. Minimized interference with existing components
7. Final design is at least 4' or 5' on the NACA 105 airfoil
8. No interference with existing components
9. Ease of use

#### Project Attributes

1. Compare to seat
2. Weight
3. Life Expectancy
4. Cost
5. Number of parts
6. Number of defect parts
7. Number of scrap parts

#### Competition Attributes

1. Competitor #1: Boeing
2. Competitor #2: Boeing
3. Competitor #3: Boeing

---

**B-1**
## 4.0 Appendix D

### Brainstorming Results

**Components**
- Springs
- Airbags
- Suspension cables
- In-ear headsets
- Stereo
- Stocks
- Stockbrokers
- Laser cutting
- Giant hooks
- Clamps
- Belt
- Hydraulic
- Levitation
- Threaded rod
- Rivet pieces
- Interlocking modules
- Vacuum forming
- Cross struts
- Linear rail
- Locking cam
- Antennas
- Buffers/cushion
- Cellular/square tubing
- Clamps
- Legos
- Gears
- Composite rail

**Fasteners**
- Hot glue
- Effort
- Chemical bonds
- Rivets
- Adhesive
- Non-permanent
- Velcro
- Super glue
- Semi-permanent
- Nails
- Quick release
- Corner pins
- Bax lock pins
- Body panel fasteners
- Grommets
- Shut safety
- Screws
- Truck latches
- 1/4 turn fasteners
- Composite mortar
- Basic bolts/nuts
- Non-traditional
- Magnets
- Rod ends

**Materials**
- Teeth (glaze)
- Composite
- Composites
- Super glue
- Wood
- Polymer
- Aluminum
- Steel
- Sandwich
- Epoxy
- Foam
- Urethane
- Epoxy
- Coating
- Concrete
- High density
- Thermo-set
- Glass
- Acrylic
- Misc structure
- Cables
- Kynar
- Lots of glue
- Spider tape
- Interior wall
- Extension
- 3D printed
- Hexagon jounce
- Giant hooks
- Two composite
- Lattice wall
- Sheet

**Full System**
- Later bed (??)
- Twin O lux
- (3 g)
- Combine rail & seat
- Bolt & hinge
- Braas spacers
- Plate with
- Speed holes
- Seat walker
- Bottom
- Single stud
- From power
- End connector
- Seat belt style
- Solder screw
- Steel with
- Tapped holes
- K-rails bolts
- Together
- Omnibend or track
- Bike tire in a
- Bike rack (array)
5.0 Appendix E
Pugh Matrices for Modularity Concept Ideas

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Sliding Bars</th>
<th>Gliding Bars</th>
<th>Various Moveable Parts</th>
<th>Slide Locks</th>
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<td>Ease of Modularity</td>
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<td>Novel Design</td>
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<td># of Components</td>
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<td>1</td>
<td>5</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>CRITERIA</td>
<td>Concept 1: use of seatbelt harness hardware to quickly attach frame to seat track</td>
<td>Concept 2: rail fitting to attach frame piece to seat track (single pin adjustability on seat track end of frame rail), pin goes in horizontally</td>
<td>Concept 3: rail fitting for adjustability to different seat track widths, pin goes in vertically</td>
<td>Concept 4: rail fitting with pins on both the seat frame and seat track ends of the frame for quick adjustment to different seat track widths, pins go in horizontally</td>
<td>Concept 5: rail fitting with pins on both the seat frame and seat track ends of the frame for quick adjustment to different seat track widths, pins go in vertically</td>
</tr>
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<td>---------------------------------------------------------------------------------------------------------------------------------</td>
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<td>+</td>
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</tbody>
</table>

**Modularity**

**Current Solution:** Aluminum Frame, 2 Pieces
6.0 Appendix F

Preliminary Load Analysis

**Top View**

Assume load of 2160 lb from (SER)

\[ \delta P_x = \frac{1}{c} \]

\[ F_{load} - P_{lt} - P_{rt} - R_{fe} - R_{re} = 0 \]

Assume = 5c/5c leading to left and right
Assume = 5c/5c leading to front and rear

\[ R_{lt} = R_{rt} = R_{fe} = R_{re} = (B) \]

\[ F_{lead} - 4B_x = 0 \]

\[ \frac{F_{lead}}{4} = B_x \]

\[ \frac{2160}{4} = B_x \]

\[ 540 = B_x \]

*If the seat rail attachment points are assumed to be symmetric about CG, then the members at all fixture points cancel out in the x-y plane.*
\[ \sum M_x = 0 \]

\[ M_p + M_{fr} = \]

\[ \frac{F_{lead}(L)}{2} = M_f = M_{rail attachment} = M_{Rc} \]

\[ \frac{10E(L)}{2} = M_{Rc} \]
## 7.0 Appendix G

### Design Hazards Checklist

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

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.
<table>
<thead>
<tr>
<th>Description of Hazard</th>
<th>Planned Corrective Action</th>
<th>Planned Date</th>
<th>Actual Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>There will be moving parts that create the modularity of our design. These parts have a chance of pinching the user by nature.</td>
<td>We will minimize this risk by making the fit between parts as tight as possible. This will make it extremely difficult to get any part of your body pinched because it will not fit.</td>
<td>12/5/19</td>
<td>2/3/20</td>
</tr>
<tr>
<td>Everything is always possible to drop. Our product is no exception and may be dropped during install. It is lightweight and does not pose a large risk or hurting the user but could possibly hurt</td>
<td>This issue cannot be completely prevented. We will mitigate the risk by making the product easy to hold. This will make a drop less likely because it will not be awkward to move to the installation site.</td>
<td>12/5/19</td>
<td>2/3/20</td>
</tr>
<tr>
<td>At this point, it is difficult to tell if the design will have sharp edges. The old design did because it used square tube. Ours may also use square tube and so sharp edges would be present in that case.</td>
<td>We will avoid the use of materials that have sharp edges if possible during the design and selection of materials.</td>
<td>1/9/20</td>
<td>2/3/20</td>
</tr>
<tr>
<td>Our product will have to be able to withstand crash loading of 9G. this will be tested in a static 9G loading test.</td>
<td>As this is one of our main design considerations, this will be sorted out by the time a final prototype is completed. It should be a main focus of the project and is a required function that it survives this.</td>
<td>1/9/20</td>
<td>2/3/20</td>
</tr>
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</table>
# Appendix H
## Manufacturing Plan

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Assy.</th>
<th>Part Description</th>
<th>Material Procurement</th>
<th>Cost</th>
<th>Manufacturing Plan</th>
<th>Assembly</th>
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<tbody>
<tr>
<td>A1</td>
<td>Support Beams</td>
<td>Beam, Front</td>
<td>6061-T6 AL Rect. Tube, .5” x 1”, 1/16” Wall</td>
<td>McMaster</td>
<td>$32.25 1. Cut to length with abrasive cutoff wheel 2. Slot both ends for bolts 3. Break sharp edges</td>
<td>1. Attach mid support connector, doubler connector front left, and doubler connector front right 2. Connect doublers to seat frame assembly front</td>
</tr>
<tr>
<td>A2</td>
<td>Support Beams</td>
<td>Beam, Aft</td>
<td>6061-T6 AL Rect. Tube, .5” x 1”, 1/16” Wall</td>
<td>McMaster</td>
<td>$32.25 1. Cut to length with abrasive cutoff wheel 2. Slot both ends for bolts 3. Break sharp edges</td>
<td>1. Attach mid support connector, doubler connector aft left, and doubler connector aft right 2. Connect doublers to seat frame assembly aft</td>
</tr>
<tr>
<td>B1</td>
<td>Doubler Connectors</td>
<td>Doubler Connector Aft Left</td>
<td>6061-T6 AL 0.19” Plate</td>
<td>Online Metals</td>
<td>$12.10 1. Waterjet plate profile 2. Break sharp edges</td>
<td>1. Align doubler tab holes 2. Fasten doubler connector to doubler tab with two bolts 3. Align doubler connector holes with doubler holes on composite frame assembly, fasten with bolts</td>
</tr>
<tr>
<td>B2</td>
<td>Doubler Connectors</td>
<td>Doubler Connector Aft Right</td>
<td>6061-T6 AL 0.19” Plate</td>
<td>Online Metals</td>
<td>$12.10 1. Waterjet plate profile 2. Break sharp edges</td>
<td>1. Align doubler tab holes 2. Fasten doubler connector to doubler tab with two bolts 3. Repeat 1 and 2 for second tab 4. Align doubler connector holes on composite frame assembly, fasten with bolts</td>
</tr>
<tr>
<td>B3</td>
<td>Doubler Connectors</td>
<td>Doubler Connector Front Left</td>
<td>6061-T6 AL 0.19” Plate</td>
<td>Online Metals</td>
<td>$12.10 1. Waterjet plate profile 2. Break sharp edges</td>
<td>1. Align doubler tab holes 2. Fasten doubler connector to doubler tab with two bolts 3. Align doubler connector holes with doubler holes on composite frame assembly, fasten with bolts</td>
</tr>
<tr>
<td>B4</td>
<td>Doubler Connectors</td>
<td>Doubler Connector Front Right</td>
<td>6061-T6 AL 0.19” Plate</td>
<td>Online Metals</td>
<td>$12.10 1. Waterjet plate profile 2. Break sharp edges</td>
<td>1. Align doubler tab holes 2. Fasten doubler connector to doubler tab with two bolts 3. Align doubler connector holes with doubler holes on composite frame assembly, fasten with bolts</td>
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<tr>
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<tr>
<td><strong>C1</strong> Mid Frame Support</td>
<td>Mid Support Doubler Connector Front</td>
<td>6061-T6 AL 0.19” Plate</td>
<td>Online Metals</td>
<td>$12.10</td>
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<td>1. Waterjet plate profile 2. Break sharp edges</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1. Align mid support tab holes 2. Fasten mid support connector to mid support tab with two bolts 3. Align mid support connector holes with doubler holes on composite frame assembly, fasten with bolts</td>
<td></td>
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</tr>
<tr>
<td><strong>C2</strong> Mid Frame Support</td>
<td>Mid Support Doubler Connector Aft</td>
<td>6061-T6 AL L-Bracket Stock, 0.25” wall</td>
<td>Online Metals</td>
<td>$1.76</td>
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<tr>
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<td></td>
<td>1. Trace profile of bracket 2. Angle grind and belt sand as necessary to remove excess stock 3. Drill holes via drill press or mill</td>
<td></td>
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<tr>
<td></td>
<td></td>
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<td></td>
<td>1. Align mid support holes with doubler holes on composite frame assembly 2. Fasten mid support to doubler with bolts</td>
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<td>Mid Support Beam Connector</td>
<td>6061-T6 AL 1.25” Plate</td>
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<td></td>
<td></td>
<td>1. Insert helicoils 2. Slide mid support beam connector onto beam before it is attached to composite frame 3. Align top holes with holes on mid support doubler connector 4. Attach to mid support doubler connector with bolts 5. Clamp down on beam by tightening bolt and nut on clamping portion of part</td>
<td></td>
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</tr>
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<td><strong>C4</strong> Mid Frame Support</td>
<td>Mid Support Tab</td>
<td>6061-T6 AL Bar Stock</td>
<td>Online Metals</td>
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<td>1. Fasten mid support doubler connector to mid support tab with two bolts</td>
<td></td>
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<tr>
<td><strong>D1</strong> Beam to Connector Fitting</td>
<td>Beam Clamp Aft Left</td>
<td>6061-T6 AL 1.25” Plate</td>
<td>Online Metals</td>
<td>$19.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1. Insert helicoil 2. Slide onto support beam aft along with the other necessary support beam components 3. Join support beam doubler connectors (left and right) to composite seat frame assembly doublers 4. Align countersunk hole with seat track fitting and slide part along beam as necessary 5. Connect to seat track fitting via bolt 6. Clamp down on beam by tightening bolt into helicoil</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>D2</strong> Beam to Connector Fitting</td>
<td>Beam Clamp Aft Right</td>
<td>6061-T6 AL 1.25” Plate</td>
<td>Online Metals</td>
<td>$19.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1. Insert helicoil 2. Slide onto support beam aft along with the other necessary support beam components 3. Join support beam doubler connectors (left and right) to composite seat frame assembly doublers 4. Align countersunk hole with seat track fitting and slide part along beam as necessary 5. Connect to seat track fitting via bolt 6. Clamp down on beam by tightening bolt into helicoil</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
|   | D3 Beam to Connector Fitting | Beam Clamp Front Left | 6061-T6 AL 1.25” Plate | Online Metals | $19.98 | 1. Waterjet side profile out of stock  
2. Mill, remove excess material to produce side tab  
3. Drill press, drill and countersink holes as necessary  
4. Break sharp edges |
|---|---|---|---|---|---|---|
|   | D4 Beam to Connector Fitting | Beam Clamp Front Right | 6061-T6 AL 1.25” Plate | Online Metals | $19.98 | 1. Waterjet side profile out of stock  
2. Mill, remove excess material to produce side tab  
3. Drill press, drill and countersink holes as necessary  
4. Break sharp edges |
|   |   |   |   | Total |   | 1. Insert helicoil  
2. Slide onto support beam front along with the other necessary support beam components  
3. Join support beam doubler connectors (left and right) to composite seat frame assembly doublers  
4. Align countersunk hole with seat track fitting and slide part along beam as necessary  
5. Connect to seat track fitting via bolt  
6. Clamp down on beam by tightening bolt into helicoil |
|   |   |   |   | Total | $209.12 |
### Senior Project DVP&R

**Date:** 2/1/30  
**Team:** 73  
**Sponsor:** Safran Seats  
**Description of System:** Business class Modular Seat Shell attachment System  
**DVP&R Engineer:** ???

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<th>Test Plan</th>
<th>Test Report</th>
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<td><strong>TEST REPORT</strong></td>
</tr>
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<td><strong>Specification #</strong></td>
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<td>3</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>
10.0 Appendix J

Hand Calculations for Verification of Design
STRESS EQUATIONS

\[ \sigma_y = \frac{Mc}{I} \]

\[ \sigma_y = \frac{90.77 \times 10^6 \text{ (psi)}}{6.25 \times 10^{-3} \text{ in}^4} \]

\[ \sigma_y = \frac{145}{6.25 \times 10^{-3} \text{ in}^4} \]

\[ \sigma_y = 23,051 \text{ psi} \]

\[ \varepsilon_y = \frac{4V_3}{3A} \]

\[ \varepsilon = \frac{4(167.5)}{3(100.05\text{ in})} \]

\[ \varepsilon = 0.045 \text{ in}^2 \]

\[ \sigma_x = 2492 \text{ psi} \]

\[ \varepsilon_{max} = \sqrt{\left(\frac{2}{E}\right)^2 + 2} \]

\[ \varepsilon_{max} = \sqrt{\left(\frac{195,180 \text{ psi}}{2}ight)^2 + 2492^2} \]

\[ \varepsilon_{max} = \sqrt{23,985,000 \text{ psi}^2 + 2492^2} \]

\[ \varepsilon_{max} = 27,528,883 \text{ psi} \]
Beam sizing (front beam)

Diagram:

1. Beam dimensions:
   - Width: 1.25 in
   - Height: 1.25 in
   - Length: 10 in

2. Force considerations:
   - Load on beam: Right and left are equally spaced (6 in)
   - Load distribution: Right and left is 50/50

3. Load equations:
   - \( F_L = \frac{20000}{2} \)
   - \( F_R = \frac{20000}{2} \)

4. Stress equations:
   - \( \sigma_y = \frac{6F_y}{I} \)
   - \( \sigma_z = \frac{3F_y(2c)}{2A} - \frac{X(2y)}{2A} \)
WANT: \( F_c \) for a \( F_d \) of 52.5 lb, such that \( \mu_s \) has a factor of 1.5.

\( F_d = \text{Displacement force} \)
\( F_c = \text{Clamping force} \)
\( \mu_s = \text{Static COF for extruded AL} \)
\( F_c = \text{Force of friction} \)

**Given / Known**

\( F_d = 52.5 \text{ lb} \)
\( \mu_s = 1.05 \text{ (clean, dry)} \)

\[
\begin{align*}
F_c &= 0 \\
F_d - F_c &= 0 \\
2 \mu_s F_c - F_c &= 0 \\
F_c &= \frac{52.5}{\mu_s} \\
\mu_s &= 1.05 \\
F_c &= 47.957 \text{ lb} \\
F_c(1.5) &= 71.785 \text{ lb} \\
&\text{Desired Clamping Force...}
\end{align*}
\]
**FORGE specifications:** 

**Thread type:** N10-32  
**Diameter:** 0.10"  
\( \lambda = 8^\circ \)  
\( d_m = 0.1735'' \)  
\( \pi d_m = 0.593'' \)  
\( h = \tan \lambda = 0.14 \)  
\( h = 0.1428'' \)  

**Distance to screw = 0.25 in**  

\[ T_0 = \frac{F d}{2 \pi} \]  

\[ T_c = \frac{(5.79.28)(0.028)}{2 \pi} \]  

\[ T_c = 8.04 \text{ in-lb} \]  

**Power screw equations**  

\[ T_c = \frac{F d_c}{2} \]  

\[ T = \text{Torque} \]  

\[ F = \text{Force} \]  

\[ d_c = \text{mean diameter of helix} \]  

\[ T_R = \frac{F d_c (3 + \pi d_m)}{2} + 2 \lambda_k \frac{d c}{2} \]  

\[ T_c = \frac{F l}{2 \pi} \]  

\[ d_m = \frac{F_B d}{l_0} \]  

\[ F_{cl} = F (1.25) \]  

\[ F = 5.79.28 \]
11.0 Appendix K

MATLAB Script for Iterating Beam Shape and Thickness

% Craig Kimball
% Senior Project Team 73
% 1/13/20

% Front and Aft Beam Stress Analysis

% The purpose of this script is to allow quick testing of different front
% and aft beam sizes and shapes using a stress equation derived from hand
% calculations. The load case for this scenario uses two equal loads
% applied symmetrically from the center of the bar. For this program only
% rectangular tubing can be tested.

%Input Variables
Beam_Width  = 1; % in
Beam_Height = 0.5; % in
Thickness    = 1/16; % in
Sigma_Yeild = 40000; % psi
Applied_Load = 1005; % psi (Note: This is Half the expected 9G load: Assuming 50/50 distribution
on left and Right side)
Reaction_F = (2*Applied_Load)/3;

%Intermediate Calculations
Calculating the Area of the beam cross-section
A = ((Beam_Width)*(Beam_Height)) - (Beam_Width - Thickness)*(Beam_Height - Thickness); % in^2

Calculating the Area of the beam cross-section
I = ((1/12)*(Beam_Width)*(Beam_Height)^3) - ((1/12)*(Beam_Width - Thickness)*(Beam_Height - Thickness)^3); %in^4 cross sectional MOI

% Stress Equation
sigma_Y = ((Reaction_F*30*c)/(I)) - ((Applied_Load*20*c)/I);
sigma_Z = ((3*(2*Applied_Load))/(2*A)) - ((3*Reaction_F)/(2*A));

% Max Stress and FOS
Sigma_Max = sqrt((sigma_Z/2)^2 + sigma_Y^2)
FOS = Sigma_Yeild/Sigma_Max
<table>
<thead>
<tr>
<th>System / Function</th>
<th>Potential Failure Mode</th>
<th>Potential Effects of the Failure Mode</th>
<th>Severity</th>
<th>Potential Causes of the Failure Mode</th>
<th>Current Preventative Activities</th>
<th>Document</th>
<th>Detection</th>
<th>RP</th>
<th>Recommended Action(s)</th>
<th>Responsibility &amp; Target Completion Date</th>
<th>Actions Taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modularity / accommodates seat rail standards</td>
<td>Modularity jams or breaks</td>
<td>a) Unable is accommodates all plane configurations b) shell no longer attached</td>
<td>7</td>
<td>a) All fasteners are secured with a cotter b) Slider bars do not experience significant testing c) Slider bar splits at middle to minimize bending moment</td>
<td>3 Teasing ability to span full modularly range: Repeat testing FTA analysis on joints in design</td>
<td>4 B4</td>
<td>a) Pay significant attention to detail to each seat configuration to ensure, make sure to formulate the solution under each configuration</td>
<td>FEA - Orgy, 1/3/2020</td>
<td>Started learning FEA software</td>
<td>7 3 5 10</td>
<td></td>
</tr>
<tr>
<td>Frame attachment to seat shell</td>
<td>Frame becomes uncoiled from seat shell</td>
<td>a) Seat shell is disconnected from plane</td>
<td>9</td>
<td>b) Bolt shear on doubler c) Double disconnects from shell</td>
<td>1 FEA, visual inspection, static properties on sound parts website</td>
<td>2 18</td>
<td>a) Run FEA on entire assembly, including models of the selected bolts</td>
<td>All - 1/3/2020</td>
<td>Created preliminary sizing of bolts and double connections in CAD</td>
<td>9 4 35</td>
<td></td>
</tr>
<tr>
<td>Base attachment to seat rails</td>
<td>a) Attachment point breaks b) Attachment point exerts tension to floor track</td>
<td>a) Seat shell is no longer attached to plane b) Design breaks requirements from floor track</td>
<td>9</td>
<td>c) Bolt shear d) Fittings not installed correctly e) Vertical disconnects f) Horizontal design</td>
<td>3 FEA, 90 FWD test</td>
<td>2 54</td>
<td>a) Consider vibration testing or testing into vibration analysis for necessary parts. Ask Safari for more details or recommendations. b) FEA to see how stresses flow through body</td>
<td>All - 1/3/2020</td>
<td>FEA has been started. We received Safari’s hardware curve</td>
<td>9 3 4 10</td>
<td></td>
</tr>
<tr>
<td>Frame / Provide structural reinforcement</td>
<td>Frame breaks or cracks</td>
<td>a) Seat shell attachment b) Frame is no longer structurally stable c) Sharp protrusions edges</td>
<td>9</td>
<td>a) Frame is not manufactured correctly or with defects b) Non-definitive case occurs</td>
<td>2 Instron testing of composite samples, Inspections during layout and vacuum</td>
<td>3 54</td>
<td>a) verify calculations with Instron testing of all critical frame components, focus on areas where frame is most likely to fail</td>
<td>All - 1/3/2020</td>
<td>Each person will run this verification for the parts they design</td>
<td>9 2 5 30</td>
<td></td>
</tr>
<tr>
<td>Easy to install</td>
<td>Takes more than 12 minutes to install, is a safety hazard to the installer</td>
<td>Seat shell is not installed on boarding rack for failure to meet time constraint or safety requirements</td>
<td>9</td>
<td>a) Too many components b) Fasteners do not connect easily to access locations during installation</td>
<td>2 Instron simulation, runs on rack members</td>
<td>1 80</td>
<td>a) design with as few parts as possible b) Risk use parts where possible for different areas</td>
<td>All - 1/3/2020</td>
<td>Each person has been designing their parts with as little components as possible</td>
<td>9 3 2 30</td>
<td></td>
</tr>
</tbody>
</table>
13.0 Appendix M

Instron Testing Procedure

Instron Testing Procedure for Doubler Tab screw verification

Objective

The purpose of this document is to outline a testing procedure for verifying the choice of #6-32 screws in securing the doubler tab to endplates. This document will focus specifically on testing procedure and manufacturing of necessary fixtures for testing. For manufacturing of end plate doubler tab assemblies see Assembly manual

Materials Needed:

- Safety glasses
- 1 manufactured Doubler Tab
- Instron pull tester with associated software (Instron 3400 Series or better) (BlueHill Software)
- Pyramid jaws
- Knurled grip plates
- End plate testing fixture

Fixturing

Refer to End of Document for drawings on Manufacturing fixturing components. The following is steps for installing the Doubler tab to the fixturing mount

1. Screw in “bottom pull” to “tab mount” to using #6-32 screws
2. Apply adhesive to the back of doubler tab
3. Screw in doubler tab to Tab mount using specified #6-32 screws from BOM
4. Let sit for 2 hours to allow adhesive to reach 85% strength
5. Using #10-32 bolt align the U in the “Top Pull” with the Doubler tab and when through use a nut to secure the bolt in place
Testing Procedure

1. Install knurled clamp jaws into the pyramid grips on the Instron tester
2. Take the bottom end of the fixture and clamp it into the Lower jaws making sure at least 60% of the jaws are engaged with the material
3. Lower the top grips until 60% of each jaw face is engaged with the top surface and lock the jaws onto the material.
4. Check to make sure each jaw is secured and will not come undone during the test
5. Turn on the Computer attached to the Instron and launch the Instron recording software
6. Setup a Pull test with a max pull stress at 502.5 lbs. Set a hold time at max force for 3 seconds. The hold time is to simulate the required standard the screws will need to hold in the 9G test
7. Make sure all people present are wearing proper PPE
8. Check again to make sure both jaws are secure and locked into place
9. Start pull test and watch the stress strain curve on the computer as well as the doubler tab.
10. When the test has concluded use the data analysis tool to show the max stress on the stress strain curve and save the data.
11. Remove the fixturing from the top and lower jaws and unscrew the #10-32 screw removing the Top Pull from the part.
12. Take out the two #6-32 screws holding the “bottom pull” to the “tab mount”
# 14.0 Appendix N

## Time and Cost Study

### Part 1: Rear Beam to Connector Component

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
<th>Machine Used</th>
<th>Time (min)</th>
<th>Cost per minute</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a.</td>
<td>Cutting Aluminum Stock</td>
<td>Vertical Bandsaw</td>
<td>20</td>
<td>0.76</td>
<td>15.2</td>
</tr>
<tr>
<td>1b.</td>
<td>Setting Up Waterjet fixturing</td>
<td>Operator</td>
<td>35</td>
<td>0.8</td>
<td>28</td>
</tr>
<tr>
<td>1c.</td>
<td>Waterjet Op1: Cutting side profile</td>
<td>Waterjet</td>
<td>45</td>
<td>0.13</td>
<td>5.85</td>
</tr>
<tr>
<td>1d.</td>
<td>Waterjet Op2: Cutting top profile</td>
<td>Waterjet</td>
<td>30</td>
<td>0.13</td>
<td>3.9</td>
</tr>
<tr>
<td>1e.</td>
<td>Cutting off tabs to remove part from stock</td>
<td>Hacksaw</td>
<td>10</td>
<td>0.76</td>
<td>7.6</td>
</tr>
<tr>
<td>1f.</td>
<td>Milling rear recess</td>
<td>HAAS VF2</td>
<td>30</td>
<td>1.5</td>
<td>45</td>
</tr>
</tbody>
</table>

**Total Time**: 340  
**Total Cost**: 211.1

Note: Total Cost and Time doubled because two parts must be created.

### Part 2: End Plates

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
<th>Machine Used</th>
<th>Time (min)</th>
<th>Cost per minute</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>2a.</td>
<td>Cutting Aluminum Stock</td>
<td>Vertical Bandsaw</td>
<td>20</td>
<td>0.76</td>
<td>15.2</td>
</tr>
<tr>
<td>2b.</td>
<td>Setting Up Waterjet fixturing</td>
<td>Operator</td>
<td>35</td>
<td>0.8</td>
<td>28</td>
</tr>
<tr>
<td>2c.</td>
<td>Waterjet Op1: Cutting Doubler Plates</td>
<td>Waterjet</td>
<td>25</td>
<td>0.13</td>
<td>3.25</td>
</tr>
<tr>
<td>2d.</td>
<td>Drilling out Holes</td>
<td>Drill Press</td>
<td>5</td>
<td>0.76</td>
<td>3.8</td>
</tr>
</tbody>
</table>

**Total Cost**: 0  
**Total Cost**: 0

---

N-1
### Part 3: Doubler Tabs

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
<th>Machine Used</th>
<th>Time (min)</th>
<th>Cost per minute</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>3a.</td>
<td>Cutting Aluminum Stock</td>
<td>Vertical Bandsaw</td>
<td>20</td>
<td>0.76</td>
<td>15.2</td>
</tr>
<tr>
<td>3b.</td>
<td>Milling stock to size</td>
<td>Manual Mill</td>
<td>40</td>
<td>0.82</td>
<td>32.8</td>
</tr>
<tr>
<td>3c.</td>
<td>Cutting Aluminum to size</td>
<td>Bandsaw</td>
<td>5</td>
<td>0.82</td>
<td>4.1</td>
</tr>
<tr>
<td>3d.</td>
<td>Finish pass on mill</td>
<td>Manual Mill</td>
<td>30</td>
<td>0.82</td>
<td>24.6</td>
</tr>
<tr>
<td>3e.</td>
<td>Drill Doubler Holes</td>
<td>Manual Mill</td>
<td>25</td>
<td>0.76</td>
<td>19</td>
</tr>
</tbody>
</table>

Total Time: 120  Total Cost: 95.7

### Part 4: Front Beam to Connector Component

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
<th>Machine Used</th>
<th>Time (min)</th>
<th>Cost per minute</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>4a.</td>
<td>Cutting Aluminum Stock</td>
<td>Vertical Bandsaw</td>
<td>20</td>
<td>0.76</td>
<td>15.2</td>
</tr>
<tr>
<td>4b.</td>
<td>Setting Up Waterjet fixturing</td>
<td>Operator</td>
<td>35</td>
<td>0.8</td>
<td>28</td>
</tr>
<tr>
<td>4c.</td>
<td>Waterjet Op1: Cutting side profile</td>
<td>Waterjet</td>
<td>45</td>
<td>0.13</td>
<td>5.85</td>
</tr>
<tr>
<td>4d.</td>
<td>Waterjet Op2: Cutting top profile</td>
<td>Waterjet</td>
<td>30</td>
<td>0.13</td>
<td>3.9</td>
</tr>
<tr>
<td>4e.</td>
<td>Cutting off tabs to remove part from stock</td>
<td>Hacksaw</td>
<td>10</td>
<td>0.76</td>
<td>7.6</td>
</tr>
<tr>
<td>4f.</td>
<td>Milling rear recess</td>
<td>HAAS VF2</td>
<td>39</td>
<td>1.5</td>
<td>58.5</td>
</tr>
</tbody>
</table>

Total Time: 358  Total Cost: 238.1

Note: Total Cost and Time doubled as two parts need to be created
### Part 5: Middle Plates

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
<th>Machine Used</th>
<th>Time (min)</th>
<th>Cost per minute</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>5a.</td>
<td>Cutting Aluminum Stock</td>
<td>Vertical Bandsaw</td>
<td>20</td>
<td>0.76</td>
<td>15.2</td>
</tr>
<tr>
<td>5b.</td>
<td>Setting Up Waterjet fixturing</td>
<td>Operator</td>
<td>35</td>
<td>0.8</td>
<td>28</td>
</tr>
<tr>
<td>5c.</td>
<td>Waterjet Op1: Cutting Doubler Plates</td>
<td>Waterjet</td>
<td>25</td>
<td>0.13</td>
<td>3.25</td>
</tr>
<tr>
<td>5d.</td>
<td>Drilling out Holes</td>
<td>Drill Press</td>
<td>5</td>
<td>0.76</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td><strong>Total Time</strong></td>
<td></td>
<td><strong>85</strong></td>
<td></td>
<td><strong>50.25</strong></td>
</tr>
</tbody>
</table>

### Part 6: Middle Connectors

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
<th>Machine Used</th>
<th>Time (min)</th>
<th>Cost per minute</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>6a.</td>
<td>Cutting Aluminum Stock</td>
<td>Vertical Bandsaw</td>
<td>20</td>
<td>0.76</td>
<td>15.2</td>
</tr>
<tr>
<td>6b.</td>
<td>Milling stock to size</td>
<td>Manual Mill</td>
<td>40</td>
<td>0.82</td>
<td>32.8</td>
</tr>
<tr>
<td>6c.</td>
<td>Water Jet Setup</td>
<td>Bandsaw</td>
<td>5</td>
<td>0.8</td>
<td>4</td>
</tr>
<tr>
<td>6d.</td>
<td>Water Jet Profile</td>
<td>Manual Mill</td>
<td>30</td>
<td>0.13</td>
<td>3.9</td>
</tr>
<tr>
<td>6e.</td>
<td>Drilling Connector Holes</td>
<td>Manual Mill</td>
<td>30</td>
<td>0.76</td>
<td>22.8</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td><strong>Total Time</strong></td>
<td></td>
<td><strong>125</strong></td>
<td></td>
<td><strong>78.7</strong></td>
</tr>
</tbody>
</table>
Part 7: Front / Rear Beam

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
<th>Machine Used</th>
<th>Time (min)</th>
<th>Cost per minute</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>7a.</td>
<td>Cutting Aluminum Stock</td>
<td>Vertical Bandsaw</td>
<td>20</td>
<td>0.76</td>
<td>15.2</td>
</tr>
<tr>
<td>7b.</td>
<td>Marking Hole Location</td>
<td>Operator + scribe</td>
<td>15</td>
<td>0.76</td>
<td>11.4</td>
</tr>
<tr>
<td></td>
<td>Drilling Holes</td>
<td>Drill Press</td>
<td>5</td>
<td>0.76</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Total Time</td>
<td></td>
<td>40</td>
<td></td>
<td>30.4</td>
</tr>
</tbody>
</table>

| Total Manufacturing Time | 1153 | Total Manufacturing Cost | 754.5 | Dollars |


15.0 Appendix O

CAD Package
<table>
<thead>
<tr>
<th>QUANTITY TRACKING</th>
<th>UNLESS OTHERWISE SPECIFIED</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL QUANTITY</td>
<td>DIMENSIONS ARE IN INCHES</td>
</tr>
<tr>
<td>DRAWN BY</td>
<td>TOLERANCES:</td>
</tr>
</tbody>
</table>
| """"""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""
| QTY.    | MADE   | DATE  | INITIALS |
| 1      |        |       |          |

**DIMENSIONS (INCHES):**

<table>
<thead>
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<th>TOLERANCE</th>
<th>VALUE</th>
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</thead>
<tbody>
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<td>1&quot; BEND</td>
<td>.500</td>
</tr>
<tr>
<td>ANGULAR</td>
<td>.438</td>
</tr>
</tbody>
</table>

**NOTES:**

- THRU ALL
- MADE:
- DATE:
- INITIALS:

**SCALE:** 2:3

**MATERIAL:** 6061-T6 AL

**TITLE:** BACK CONNECTOR BAR

**Part:** A2

---

SOLIDWORKS Educational Product. For Instructional Use Only.
SOLID WORKS Educational Product. For Instructional Use Only.
MID SUPPORT - FRONT DOUBLER CONNECTOR

QUANTITY TRACKING:
- TOTAL QUANTITY NEEDED: 1

UNLESS OTHERWISE SPECIFIED:
- DIMENSIONS ARE IN INCHES
- TOLERANCES:
  - ANGULAR: ± 1° BORE: ± 1°
  - TWO PLACE DECIMAL: ± 0.05
  - THREE PLACE DECIMAL: ± 0.005
  - DISSINCLINE PER MM:
  - BREAK SHARP EDGES: 0.02 MAX

TITLE: MID SUPPORT - FRONT DOUBLER CONNECTOR

PART: C1

SOLIDWORKS Educational Product. For Instructional Use Only.
# Appendix P

## Bill of Materials

### Team #73, Safran Seats Universal Seat Attachment

<table>
<thead>
<tr>
<th>Part #</th>
<th>Description</th>
<th>Qty</th>
<th>Cost</th>
<th>Total</th>
<th>Single (lb)</th>
<th>Total (lb)</th>
<th>Material</th>
<th>Source, Part #</th>
<th>Source</th>
<th>Additional Manufacturing Detail</th>
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<td>B</td>
<td>Double Connectors</td>
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<td>C</td>
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<td>D</td>
<td>Beam to Connector Fittings</td>
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<td>E</td>
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**Totsals**: 147 | $529.98 | 3.8214 | 4.1834
## 17.0 Appendix Q

Links to Product Literature and Project Budget

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<th>Product Literature Link</th>
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<td>M1</td>
<td><a href="https://www.rockwestcomposites.com/14058-d-group">https://www.rockwestcomposites.com/14058-d-group</a></td>
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<td><a href="https://www.amazon.com/Henkel-Loctite-Bolt-Threadlocker-50mL/dp/B01N9A9O9L/ref=sr_1_1?keywords=threadlocker+242%2C+50ml&amp;qid=1581062828&amp;sr=8-1">https://www.amazon.com/Henkel-Loctite-Bolt-Threadlocker-50mL/dp/B01N9A9O9L/ref=sr_1_1?keywords=threadlocker+242%2C+50ml&amp;qid=1581062828&amp;sr=8-1</a></td>
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<td><a href="https://www.mcmaster.com/96246a278">https://www.mcmaster.com/96246a278</a></td>
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<td><a href="https://www.mcmaster.com/96246a109">https://www.mcmaster.com/96246a109</a></td>
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### Initial Budget

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### What’s Left?

- **Initial Budget:** $1,000.00
- **What’s Left:** $413.44
18.0 Appendix R
Assembly & Installation Instructions

Universal Seat Attachment
Installation Instructions

Notes Before Beginning Assembly
- Some areas within the seat may be difficult to reach and may require some awkward positioning in order to access and tighten the hardware.
- Unless otherwise specified, tightening all hardware to hand-tight is considered sufficient.
- All parts are colored for increased visibility.
- Total pre-assembly & assembly time (single person): 70 minutes

Full Assembly Reference for Part Locations & Naming Convention
Contents
Part 1: Pre-Assembly of Doubler Connector Components ................................................................. 3
Part 2: Pre-Assembly of Beam Clamp Components ........................................................................ 5
Part 3: Installing the Front Assembly ............................................................................................. 6
Part 4: Installing the Aft Assembly ................................................................................................ 9
Part 5: Mid-Support Pre-Assembly of Components ...................................................................... 13
Part 6: Installing Front & Aft Mid-Support ................................................................................... 15
Part 7: Installing Front Beam Clamps .......................................................................................... 17
Part 8: Installing Aft Beam Clamps ............................................................................................... 21

Workflow: Order of Steps

Part 1: Pre-Assembly of Doubler Connector Components
Est Time: 11 minutes

Part 2: Pre-Assembly of Beam Clamp Components
Est Time: 5 minutes

Part 5: Mid-Support Pre-Assembly of Components
Est Time: 11 minutes

Part 3: Installing the Front Assembly
Est Time: 9 minutes

Part 4: Installing the Aft Assembly
Est Time: 14 minutes

Part 6: Installing Front & Aft Mid-Support
Est Time: 9 minutes

Part 7: Installing Front Beam Clamps
Est Time: 4-6 minutes

Part 8: Installing Aft Beam Clamps
Est Time: 6-8 minutes
Part 1: Pre-Assembly of Doubler Connector Components

Time: 11 minutes

Components Needed:
1 X Doubler Connector Aft Left
1 X Doubler Connector Aft Right
1 X Doubler Connector Front Left
1 X Doubler Connector Front Right
5 X Doubler Tab
10 X #6-32 x 5/8"L Flat Head Machine Screw
10 X #6-32, 0.207" L Self-Locking Helical
1 X Structural Adhesive Epoxy

Tools Needed:
1 X Helical Insertion Tool
1 X Philips Screwdriver

1. Insert #6-32 Helical threaded inserts into all doubler tabs. There are 2 pre-threaded holes per tab that require Helical inserts.

2. Apply epoxy to the rear of each doubler tab. The glue layer should completely cover the rear face of the doubler tab, as shown. Provide clearance for the #6-32 screw holes to avoid getting epoxy in the holes.

3. Using the #6-32 flat head screws, align the holes of the doubler tab with the doubler connector. Ensure that the epoxy is sandwiched properly between the two components, then tighten the flat head screws into place.
4. Ensure that all 4 doubler connectors are fully assembled as shown below.

Front Left Doubler Connector

Front Right Doubler

Aft Left Doubler Connector

Aft Right Doubler
Part 2: Pre-Assembly of Beam Clamp Components

Time: 5 minutes

Components Needed:
1 X Aft Left Beam Clamp
1 X Aft Right Beam Clamp
1 X Front Left Beam Clamp
1 X Front Right Beam Clamp
4 X #10-32, 0.285" L Self-Locking Helical

Tools Needed:
1 X Helical Insertion Tool

1. Insert Helicals into all beam clamp components. There is 1 pre-threaded hole per component that requires a Helical insert.

2. Ensure that all 4 beam clamp components have Helical inserts that are properly installed as shown.
Part 3: Installing the Front Assembly
Time: 9 minutes

Components Needed:
1 X Assembled Doubler Connector Front Left
1 X Assembled Doubler Connector Front Right
1 X Front Beam
1 X Front Left Beam Clamp
1 X Front Right Beam Clamp
2 X #10-32 x 1.0”L NAS 1801 Bolt
2 X #10-32 MS21042L Self-Locking Nut
6 X #10-32 x 5/8”L NAS 1801 Bolt
6 X #10 NAS 1149 Washer

Tools Needed:
1 X 10-32 Socket, with ratchet and extension tool

1. Pre-assemble all hardware by sliding a #10 washer onto each #10-32 bolt, then apply Loctite to the threads.

2. For each of the 2 front doubler connectors, line up the part holes with the corresponding doubler holes on the seat assembly. Ensure that you have the correct two doublers, as the holes on the doubler should match with the part holes. Place the components on the ground near their final installation location preparing the next step.

Front Left Doubler Connector

Front Right Doubler Connector
3. Place the front beam between the two doubler connectors, and slide the left beam clamp component onto the left side of the beam. Slide the right beam clamp component onto the right side of the beam. Feel free to slide the beam clamp components to the center of the beam. They will not be touched until later installation instructions.

Slide the doubler connector tabs into both the ends of the beam once both beam clamp components are on the beam. Loosely attach the beam to each doubler tab using 1 #10-32 x 1.0”L bolt, 2 washers, and a nut on the end as shown. Do not tighten the hardware yet.

4. Lift the entire assembly so that the front left doubler holes are lined up with the corresponding doubler holes on the seat. Attach the front left doubler to the seat assembly with 3 of the pre-assembled #10-32 x 5/8”L bolts and washers. Do not tighten the hardware yet.
5. Align the front right doubler holes with the corresponding doubler holes on the seat. Attach the front right doubler to the seat assembly with 3 of the pre-assembled #10-32 x 5/8"L bolts and washers. Do not tighten the hardware yet.

6. Ensure that the entire front beam assembly is properly aligned within the seat shell, and that there is no missing hardware. Tighten the connections between the doubler plates and the front beam assembly. After all doublers have been fully installed, tighten the #10-32 x 1.0"L bolts that hold the beam between the two doublers.
Part 4: Installing the Aft Assembly
Time: 14 minutes

Total Components Needed:
1 X Assembled Doubler Connector Aft Left
1 X Assembled Doubler Connector Aft Right
1 X Aft Beam
1 X Aft Left Beam Clamp
1 X Aft Right Beam Clamp
2 X #10-32 x 1.0”L NAS 1801 Bolt
2 X #10-32 MS21042L Self-Locking Nut
9 X #10-32 x 5/8”L NAS 1801 Bolt
13 X #10 NAS 1149 Washer
1 X #10-32 x 1.5” L NAS 1801 Bolt

Total Tools Needed:
1 X 10-32 Socket, with ratchet and extension tool

1. Pre-assemble all hardware by sliding a #10 washer onto each #10-32 bolt, then apply Loctite to the threads.

2. For each of the 2 aft doubler connectors, line up the part holes with the corresponding doubler holes on the seat assembly. Ensure that you have the correct two doublers, as the holes on the doubler should match with the part holes. Place the components on the ground near their final installation location while preparing the next step.
3. Place the aft beam between the two doubler connectors, and slide the aft left beam clamp component onto the left side of the beam. Slide the aft right beam clamp component onto the right side of the beam. Feel free to slide the beam clamp components to the center of the beam, because they will not be touched until later installation instructions.

Slide the left doubler connector tab into the beam once both beam clamp components are on the beam. Loosely attach the beam to the left doubler tab using 1 #10-32 x 1.0”L bolt, 2 washers, and a nut on the end as shown. Then attach the beam between the right doubler tabs using 1 #10-32 x 1.5”L bolt, 2 washers, and a nut on the end as shown. Do not tighten the hardware yet.
4. Lift the entire aft assembly such that the aft left doubler holes are lined up with the corresponding doubler holes on the seat. Attach the aft left doubler to the seat assembly with 5 of the pre-assembled #10-32 x 5/8"L bolts and washers. Do not tighten the hardware yet.
5. Align the aft right doubler holes with the corresponding doubler holes on the seat. Attach the front right doubler to the seat assembly with 4 of the pre-assembled #10-32 x 5/8"L bolts and washers. Do not tighten the hardware yet.

6. Ensure that the entire aft beam assembly is properly aligned within the seat shell, and that there is no missing hardware. Then tighten the connections between the doubler plates and the aft beam assembly. After all doublers have been fully installed, tighten the #10-32 x 1.0"L and 1.5"L bolts that hold the beam between the two doublers.
Part 5: Mid-Support Pre-Assembly of Components
Time: 11 minutes

Components Needed:
1 X Mid-Support Doubler Connector Front
1 X Mid-Support Doubler Connector Aft
1 X Mid Support Beam Connector Front
1 X Mid Support Beam Connector Aft
8 X #6-32 x 0.207”L Helical Insert
8 X #6-32 x 5/8”L Flat Head Machine Screw
1 X Structural Adhesive Epoxy
1 X Loctite

Tools Needed:
1 X #6-32 Helical Insert Tool
1 X Philips Screwdriver

1. Insert Helicals into both mid-support beam connectors. There are 4 pre-threaded holes per part that require Helical inserts.

2. Apply epoxy to the rear face of each mid-support beam connector part. The glue layer should completely cover the area of the component that will be connected to the doubler as shown. Provide clearance for the #6-32 screw holes to avoid getting epoxy in the holes.
3. Using the #6-32 flat head screws, align the holes of the mid-support doubler connector with the mid-support beam connector. Ensure that the epoxy is sandwiched properly between the two components before tightening the flat head screws into place. Do this for both the front and aft mid-support components.

4. Ensure that both the front and aft mid-support components are fully assembled as shown.
Part 6: Installing Front & Aft Mid-Support  
Time: 9 minutes

<table>
<thead>
<tr>
<th>Components Needed:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 X Assembled Mid-Support Doubler and Beam Connector Front</td>
</tr>
<tr>
<td>1 X Assembled Mid-Support Doubler and Beam Connector Aft</td>
</tr>
<tr>
<td>7 X #10-32 x 5/8”L NAS 1801 Bolt</td>
</tr>
<tr>
<td>4 X #10-32 x 1.125”L NAS 1801 Bolt</td>
</tr>
<tr>
<td>4 X #10-32 MS21042L Self-Locking Nut</td>
</tr>
<tr>
<td>15 X #10 NAS 1149 Washer</td>
</tr>
<tr>
<td>1 X Loctite</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tools Needed:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 X 10-32 Socket, with ratchet and extension tool</td>
</tr>
</tbody>
</table>

1. Pre-assemble all hardware by sliding a #10 washer onto each #10-32 bolt, then apply Loctite to the threads.

2. Both the front and aft assembled mid-supports need to be attached to their corresponding doublers on the seat shell. The holes on each doubler plate should align with the corresponding doubler holes on the seat assembly. Attach with the front mid-support assembly with 4 of the pre-assembled #10-32 x 5/8”L bolts. Attach with the aft mid-support assembly with 3 of the pre-assembled #10-32 x 5/8”L bolts.
3. The bolt holes in the beam should line up with their corresponding holes on both the front and aft assembled mid-supports. For both the front and aft, connect the beam to each hole of the mid-support assembly with 1 X #10-32 x 1.125"L bolt, 2 X #10 washer, and 1 X #10-32 self-locking nut per hole.

4. Ensure that all hardware is tightened, starting with the connection to the doublers, then finishing with the connection to the front and aft beams.
Part 7: Installing Front Beam Clamps

Option a: Seat Track Fitting Style - Stud Fitting
Time: 4 minutes

Components Needed:
2 X Front Seat Track Stud Fitting, corresponding hardware
2 X #10-32 x 5/8”L NAS 1801 Bolt

Tools Needed:
1 X 10-32 Socket, with ratchet and extension tool

1. The beam clamps should already be on the front beam assembly due to a previous instruction. Make sure that they are accessible, and loosely add a #10-32 x 5/8”L bolt to the clamping holes of both beam clamps. Do not tighten the hardware yet.

2. Install both the front seat track stud fittings into their proper locations on the front left and front right seat tracks.
3. Slide the beam clamps until they are properly aligned with their corresponding seat track fittings. Use the stud fitting washer and nut to attach both left and right beam clamps to the seat tracks.

4. Tighten all hardware, starting with the connection to the seat tracks, then finishing with the tightening mechanism on the beam clamp. Ensure that the entire front assembly is properly installed. It should feel rigid and not move when jostled.
Part 7: Installing Front Beam Clamps
Option b: Seat Track Fitting Style- Harper Fitting
Time: 6 minutes

Components Needed:
2 X Front Seat Track Harper Fitting, corresponding hardware
2 X #10-32 x 5/8"L NAS 1801 Bolt
2 X Stud Spacer

Tools Needed:
1 X 10-32 Socket, with ratchet and extension tool

1. The beam clamps should already be on the front beam assembly due to a previous instruction. Make sure that they are accessible, and loosely add a #10-32 x 5/8"L bolt to the clamping holes of both beam clamps. Do not tighten the hardware yet.

2. Install both the front seat track Harper fittings into their proper locations on the front left and front right seat tracks.
3. Slide the beam clamps until they are properly aligned with their corresponding seat track fittings. If necessary, add a stud spacer between the bottom side of the beam clamp part and the top surface of the Harper fitting. Use the harper fitting washer and nut to attach both left and right beam clamps to the seat tracks.

4. Tighten all hardware, starting with the connection to the seat tracks, then finishing with the tightening mechanism on the beam clamp. Ensure that the entire front assembly is properly installed. It should feel rigid and not move when jostled.
Part 8: Installing Aft Beam Clamps

Option a: Seat Track Fitting Style- Stud Fitting

Time: 6 minutes

Components Needed:
2 X Front Seat Track Stud Fitting, corresponding hardware
2 X #10-32 x 5/8"L NAS 1801 Bolt

Tools Needed:
1 X 10-32 Socket, with ratchet and extension tool

1. The beam clamps should already be on the front beam assembly due to a previous instruction. Make sure that they are accessible, and loosely add a #10-32 x 5/8"L bolt to the clamping holes of both beam clamps. Do not tighten the hardware yet.

2. Install both the aft seat track stud fittings into their proper locations on the aft left and aft right seat tracks.
3. Slide the beam clamps until they are properly aligned with their corresponding seat track fittings. Use the stud fitting washer and nut to attach both left and right beam clamps to the seat tracks.

4. Tighten all hardware, starting with the connection to the seat tracks, then finishing with the tightening mechanism on the beam clamp. Ensure that the entire front assembly is properly installed. It should feel rigid and not move when jostled.
Part 8: Installing Aft Beam Clamps
Option b: Seat Track Fitting Style- Harper Fitting
Time: 8 minutes

Components Needed:
2 X Front Seat Track Harper Fitting, corresponding hardware (7/16" bolts, nuts, washers)
2 X #10-32 x 5/8"L NAS 1801 Bolt

Tools Needed:
1 X 10-32 Socket, with ratchet and extension tool

1. The beam clamps should already be on the front beam assembly due to a previous instruction. Make sure that they are accessible, and loosely add a #10-32 x 5/8"L bolt to the clamping holes of both beam clamps. Do not tighten the hardware yet.

2. Install both the aft seat track Harper fittings into their proper locations on the aft left and aft right seat tracks.
3. Slide the beam clamps until they are properly aligned with their corresponding seat track fittings. Use the harper fitting hardware (bolt, washer, and nut) to attach both left and right beam clamps to the seat tracks.

4. Tighten all hardware, starting with the connection to the seat tracks, then finishing with the tightening mechanism on the beam clamp. Ensure that the entire front assembly is properly installed. It should feel rigid and not move when jostled.


19.0 Appendix S

Full Assembly Seat Track Distance Fitment Study

Universal Seat Attachment
Seat Track Fitment Study

Summary of Results
The Universal Seat Attachment assembly should be able to fit all seat track distance configurations for all airplane seat tracks. This study shows each possible seat track distance variation, and then examines the ability of the Universal Seat Attachment to meet these requirements without interfering with any of the pre-existing components of the seat. The study found that airplane seat tracks have a minimum distance requirement of 17” and a maximum distance requirement of 36.5”, while the Universal Seat Attachment has a minimum distance requirement of 17” (meeting the minimum distance goal) and a maximum distance of 35” (not meeting the maximum distance goal) before the assembly will interfere with the composite shell of the seat frame. The team suggests that the Universal Seat Attachment will be able to meet the maximum distance goal of 36.5” only if the current seat shell design can be modified with cutouts and covers in order to extend the seat track fitting attachment location beyond the boundaries of the seat shell.

Universal Seat Attachment Installation Location Requirement Study
The purpose of this study is to determine whether the Universal Seat Attachment assembly fits the seat track location requirements of Safran Seats. As stated in the initial requirements of the project, the custom seat attachment must be designed such that it allows the given seat shell to be installed onto the following aircraft seat tracks:

Airbus: A320, A330, A350, A380
Boeing: B747, B777, B787

The additional location information about each seat track layout is displayed in the table below.
<table>
<thead>
<tr>
<th>Plane Type</th>
<th>Dist. Bwn. Tracks</th>
<th>Plane Track Layout Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>A320</td>
<td>21”</td>
<td>![Diagram for A320]</td>
</tr>
<tr>
<td>A330</td>
<td>20”</td>
<td>![Diagram for A330]</td>
</tr>
<tr>
<td></td>
<td>A350</td>
<td></td>
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<tr>
<td>---</td>
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</tr>
<tr>
<td></td>
<td>17” (smallest)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>34.25”</td>
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</tr>
<tr>
<td></td>
<td>22”</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B747</td>
<td>22.5&quot;</td>
<td>23&quot;</td>
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<td>------</td>
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</tbody>
</table>

This table represents measurements for the B747 model, with specific dimensions indicated in inches.
<table>
<thead>
<tr>
<th></th>
<th>B777</th>
<th>34&quot;</th>
<th>22&quot;</th>
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<tbody>
<tr>
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</tr>
<tr>
<td>B787</td>
<td>20.5&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>36.5&quot; (largest)</td>
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<tr>
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<td>20.5&quot;</td>
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<td>20.5&quot;</td>
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<td>20.5&quot;</td>
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<tr>
<td></td>
<td>20.5&quot;</td>
<td></td>
<td></td>
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</tbody>
</table>
All possible seat track widths from the above planes are listed in order here from smallest to largest distance:

17”, 20”, 20.5”, 21”, 21.25”, 22”, 22.5”, 23”, 34”, 34.25”, 36.5”

All seat tracks are designed to always be parallel with the seat track fittings of the seat shell Universal Seat Attachment, therefore they can be used to slide along the length of the front and rear beams to instantly match the necessary seat track distances. Due to this design, the team only has to analyze the minimum and maximum distance cases that the Universal Seat Attachment can accommodate.

The two extreme cases (smallest distance and largest distance) that the Universal Seat Attachment design can fit are modeled in CAD and shown below. The following table models the results of the study.

<table>
<thead>
<tr>
<th>Minimum Distance</th>
<th>17”</th>
<th>17”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Distance</td>
<td>36.5”</td>
<td>36.5” (without modification to the shell)</td>
</tr>
</tbody>
</table>

*The team suggests that the Universal Seat Attachment will be able to meet the maximum distance goal of 36.5” only if the current seat shell design can be modified with cutouts and covers in order to extend the seat track fitting attachment location beyond the boundaries of the seat shell.

Figure 1. Seat track distance: 17” (minimum distance goal achieved)
Figure 2. Seat track distance: 35” (maximum allowable distance of the assembly)

Figure 3. Seat track distance: 36.5” (interference with seat shell; frame design does not satisfy this requirement)
Figure 4. Seat track distance: 36.5” (interference with seat shell; frame design does not satisfy this requirement)