MECH 4860: Engineering Design

Final Design Report:

Modularization and Standardization

Of New Flyer Industries Bus Seat Mounting

Written By:
Team #8
Sponsoring Company: New Flyer Industries

In Partial Fulfillment of the Phase III MECH 4860 Requirement
December 6, 2010

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November 30, 2010

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Re: Final Design Report for the Modularization
And Standardization of New Flyer Industries Bus Seat Mounting

To Tony Huynh,

Our team has competed phase three of the *Modularization and Standardization of New Flyer Industries Bus Seat Mounting* project. The projects final report is attached to the letter for you to review.

The report includes a background on the project, details of the design including limitations, operation of the design, cost analysis and part reduction and recommendations. Hand calculations, FEA, Design For Assembly (DFA) and Design for Failure Modes and Effects Analysis are detailed in various appendices of the report. Also featured in the appendices are engineering drawings, the project schedule from September to December 2010 and the concepts that were considered for the design. The Team has proposed a design that was designed to meet the most needs detailed by New Flyer Industries for this project.

If there are any issues regarding the written Final Design Report, oral and poster presentations or with the Modularization and Standardization of Bus Seat Mounting project, please feel free to contact, Brianne Lagimodiere

Thank-you,

Brianne Lagimodiere
Team New Flyer 8
Team Secretary

Attached: Final Design Report

Executive Summary

The final design report for the Modularization and Standardization of New Flyer Industries (NFI) Bus Seat Mounting outlines the introduction and as such the background of modularized bus seating project. NFI is looking to acquire a Universal Lower Support (ULS) for six of the seats used for NFI bus seat layouts. There is a subsection of the introduction that features the concepts that were considered for the Lower Support Structure (LSS) design. The Features of the proposed design as well as the limitations of the proposed design are detailed in the section titled details of the design. The operation of the design, cost analysis and reduction of parts are sections that are also included in this report.

Simple hand calculations and FEA analysis were completed to analyze the proposed design for the applied loads that are expected to be applied to the LSS. The hand calculations and FEA are included in an appendix of the report. Design For Assembly (DFA), assembly instructions and component weights are included in an appendix of the report. A Design for Failure Modes and Effects Analysis (DFMEA) was conducted on the LSS and is also presented in an appendix of this report.

The LSS meets four out of the six seats specified by NFI that were to be included in the Universal Lower Support (ULS). Therefore the Team designed a LSS instead of a ULS because two seat styles could not be modularized. The Team makes recommendations to NFI for the next phase of the project and concludes that NFI should ask the seat vendors to review their seat styles to make the seat mounting systems universal.

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Abbreviations and Glossary of Terms

APTA: American Public Transportation Association – A North American public transit advocacy organization.

DFA: Design For Assembly – Concepts applied to ensure a good design.

DFMEA: Design Failure Modes and Effects Analysis – A method to analyze what aspect in design can lead to failure.

FEA: Finite Element Analysis – A computational method to calculate stresses in components.

LSS: Lower Support Structure – The proposed design to meet four out of six seat styles.

NFI: New Flyer Industries – A bus manufacturer based in Winnipeg, Canada.

ULS: Universal Lower Support – Support design to fit the six seat styles

1. Introduction

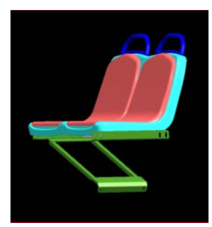
The purpose of this report is to define the recommended Lower Support Structure (LSS) that the Team has designed to address the issue of a Universal Lower Support (ULS) for the six seat types specified by New Flyer Industries (NFI). NFI wants to minimize the time and reduce the costs of designing and installing seating layouts for transit buses by using an ULS. The report details the design features, assembly, operation, cost analysis and reduction of parts. Also the Team makes recommendations to NFI for the projects next phase.

1.1. Background

New Flyer Industries (NFI) manufactures transit buses for various cities across North America. To meet the needs of NFI customers, NFI uses varying seat styles in the interior of the buses [1]. NFI is looking to acquire a Universal Lower Support (ULS) that will attach to the six seats specified by NFI and mount onto the bus for passenger seating [1]. The ULS would make bus seating modularized for the six specified seats. With the ULS, the engineering and installation times will be reduced. Therefore, NFI's cost will reduce on a per contract basis [1].

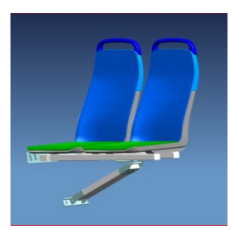
Each of the seat types shown in Figure 1, has a different lower support that is attached at different locations and fastening styles on the bottom of each seatt. Fitting a ULS structure to each seat was a challenge to overcome for this project to meet NFI's needs.





a) b) c)





d) e) f)

Figure 1: Various Bus Seating Styles and Configurations
(a) Aries, (b) Ideo, (c) Metro, (d) Vision, (e) Insight, (f) Mariella [2]

The ULS structure is to work for forward facing seating on the upper and lower decks of the bus as shown in Figure 2 [1]. The lower deck of the bus uses tracks running parallel with the floor and windows to mount the seat to the bus wall [1]. The upper deck of the bus, on the other hand, has a track system that runs parallel with the floor which is sloped and does not run parallel with the windows [1]. Another challenge for the Team was to make the seats on the upper deck parallel with the windows.

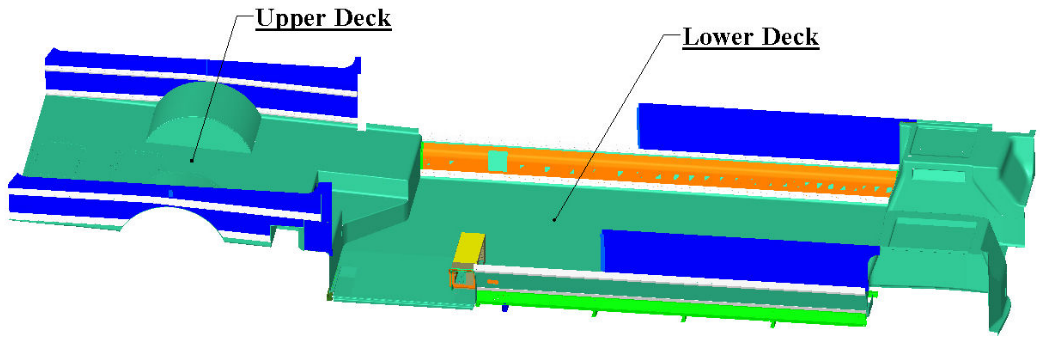


Figure 2: New Flyer Bus Showing the Floor of the Upper and Lower Deck [2]

The Lower Support Structure (LSS) has been designed by the Team and complies with the American Public Transportation Association (APTA) Standards [3]. The LSS complying with APTA standards is a requirement set out by NFI. The LSS consists of three main parts which are the adaptive plate; leg structure and leg-to-bus joint.

1.2. New Flyer's Needs

Knowing the customer needs is an important part of meeting the requirements and solving the modularization of bus seat mounting problem in a way that will satisfy the customer. There are a variety of customer needs that have been met in order for the Team to succeed. The customer needs and importance of customer needs are detailed in Table I. [1].

TABLE I: CUSTOMER NEEDS AND IMPORTANCE

Customer Need	Importance
Ease of Seat Mounting	5
Improvement from the Current Design	5
Works with Any Bus Seating Positions	5
Engineering Time/Installation Time	5
Ease of Future Lower Support Changes	5
Reliability of Lower Support Structure	4
Low Weight	3
Seat Switchability	3
Low Cost	2
Reduction in Parts from Current Design	2

1.3. Relevant Standards

New Flyer is in need of a universal lower support structure for the six specified seats. The lower support structure and seats are to be attached to the bus for passenger seating. The universal seat support structure must comply with American Public Transportation Association (APTA) standards [3]. The Team had to meet many APTA standards [3] in order to design a LSS that would be able to mount onto North American buses which are listed in this section. An APTA standard specifies the seat height H which is shown in
Figure **3**, shall be 17± 1 inch.

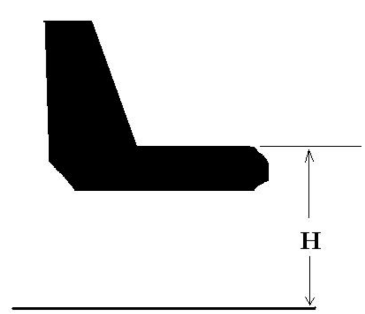


Figure 3: APTA Standard Dimensions

Another APTA standard states that the aisle facing seats shall be attached to the bus wall and that the structure shall be fully cantilevered from the bus wall. The part of the seat assembly that is within 12 inches from the aisle shall be 10 inches above the bus floor is declared in the APTA standards and this standard is shown in Figure 4.

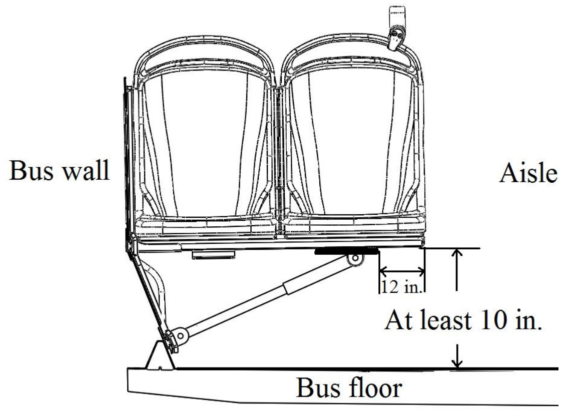


Figure 4: APTA Standards, Under Seat Volume

The APTA standards also include that the distance between the seat rows shall be distance of 20 inches (aisle distance) at the hip height of the seated passenger or greater. As well at a distance of 32 inches above the floor, the distance between seat rows shall be 24 inches or greater. This APTA standard is described in Figure **5**.

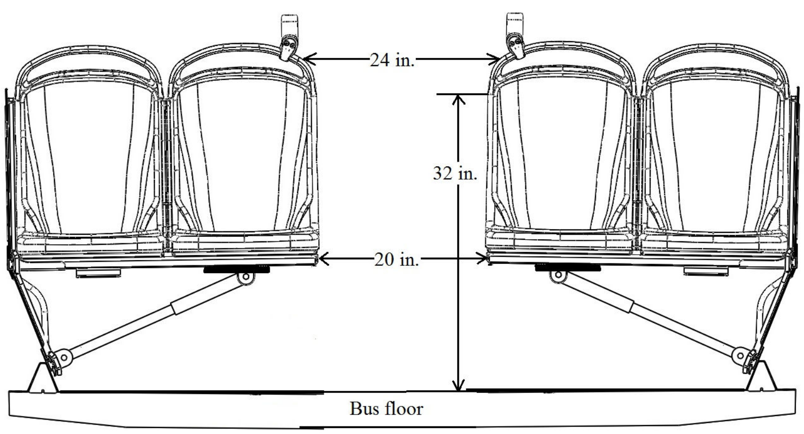


Figure 5: APTA Standard, Aisle Width

Other APTA standards include that the seats structure shall be designed so that when mounted, the room under the seat has no obstacles and is maximized. The seat and supporting structure shall handle a static horizontal and vertical load of 500 lbs per seat position, with less than ¼ inch permanent deformation. Seats are to be attached to the bus using tamper resistant fasteners. The final APTA standard that the Team must meet was that stainless steel shall be the only metal to touch the sides or floor of the bus.

1.4. Design Concepts

During the concept design phase of the project the Team conducted research for products on the market similar to a ULS and could not find similar products. Therefore the team concluded that designing a ULS was an industry first.

Based on NFI's needs and constraints, several design ideas were developed during the brainstorming process and the design ideas were developed in three sections to represent the three components that were needed to meet the LSS design a description of each concept for the three components is detailed in Appendix A. The customer need**s** and constraints are an important part of meeting the requirements and solving the modularized bus seating problem in a way that will NFI.

Based on NFI's needs**,** the Team has evaluated the design ideas by using the Triz method, Screening matrix, Sensitivity matrix and Scoring matrix. The Scoring Matrix evaluates the concept designs to NFI's needs based on a scale of one to five. NFI's needs are given a scale of importance and a corresponding weight based on the ratio of importance to the total number of customer needs. The scoring matrix helped the Team to determine the total score per concept. The concepts were then ranked based on the total score. The Triz method, Screening matrix and Sensitivity matrix are not shown in the report as they result in similar outcomes to that of the Scoring matrix. The Scoring matrix is shown in Appendix A along with the design concepts.

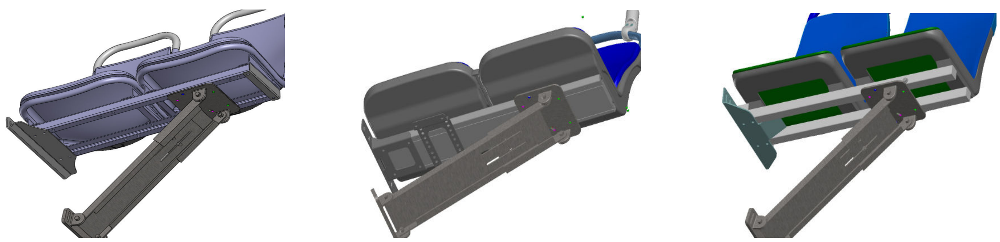
2. Details of the Design

The Team has created an LSS able to mount four out of the six seat models to the bus. Design requirements, such as cost, modularization, upper and lower deck compatibility, appearance and practicality were addressed to meet NFI's needs and design of the LSS. The details of the LSS design are covered in the following sections.

2.1. Features of the Design

To solve NFI's problem of modularized bus seating and meet the most requirements set out by NFI, the Team designed the LSS with special features. The three components that make-up the LSS are the adaptive plate, leg structure and leg-to-bus joint. Each of these components has features that make modularized bus seating possible and solving the modularization and standardization of the bus seat mounting for four out of the six seats. To determine the LSS dimensions, the LSS was analyzed for the loads and stresses that would be applied. Appendix E details the calculations and analysis of the LSS. Once the LSS was designed the Team prepared drawings of each of the three LSS components that are featured in Appendix G.

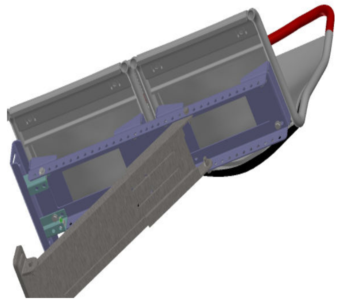
The adaptive plate meets the attachment requirements for the seat types Vision, Mariella and Ideo which are shown in Figure 6. The adaptive plate is designed to start the same distance from the wall on every seat type to decrease the number of adjustments that would need to be made to the leg structure length if seat styles were changed. The adaptive plate has hinge attachment points welded to it for the pin that attaches the leg structure to the adaptive plate. The thickness of the adaptive plate is designed to be ¼ inch thick and with a minimum allowable area to accommodate the three seats so that the weight is reduced and the ease of assembly process could be improved from the current installation. The weight of the LSS components as well as the assembly instructions are proposed in Appendix H and the detailed adaptive plate drawing is featured in Appendix G.



(a) (b) (c)

Figure 6: Lower Support Structure Mounted to Seats
(a)Vision, (b) Ideo and (c) Mariella

The leg structure meets the attachment requirements for the Aries seat structure, shown in Figure 7 and the adaptive plate. The Aires seat has flanges that protrude from the seats bottom beam therefore the adaptive plate could not be attached to the Aries seat. Since the adaptive plate could not be attached to the Aries seat the Team decided to make the lower leg attach to the Aries seat and the adaptive plate. The leg structure is designed as a C-channel beam that can be adjusted depending on the length of leg required to properly mount the seat to the bus. The adjustability of the leg structure is determined by two bolts that connect the outer C-channel to the slots on the inner C-channel to allow for infinite adjustment possibilities. The lip near the bolts that adjust the leg length was removed to increase the ease of length adjustment. The leg structure is joined to the adaptive plate by a pin hinge joint and to the leg-to-bus joint by an identical joint on the leg-to-bus plate. The hinge joints allow the angle from the leg structure to the bus wall to change and accommodate both the upper and lower decks of the bus. The adjustable length of the leg structure also accommodates the changes needed depending on the placement of the seat on the bus. The leg-to-bus joint is designed with the hinge attachment to mount the leg structure via a pin and slots to attach the plate parallel with the windows at any seating location on the bus. The overall LSS is shown in Figure 8 and the detailed design drawings for the LSS assembly, leg support and leg-to-bus joint are shown in Appendix G.



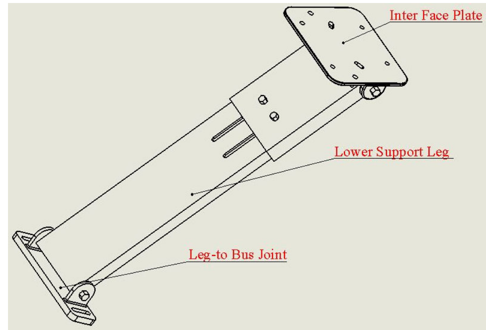


Figure 7: LSS Mounted to Aries

Figure 8: LSS and Labeled Components

The Team conducted a Design Failure Modes and Effects Analysis (DFMEA) and incorporated Design For Assembly (DFA) concepts in the final LSS design. The DFMEA was used to mitigate potential failure modes and is shown in Appendix F. The DFA concepts, on the other hand, were used to increase the LSS's ease of assembly and are detailed in Appendix H. Also the cost and installation of the LSS was taken into account in the final design.

2.1. Design Limitations

The final LSS design did not meet NFI's need of modularized bus seating for the seat styles Metro and Insight. When the seat styles were analyzed to fit on the recommended adaptive plate; Insight was found to have restrictions on how wide the adaptive plate could be. The Insight seat has the smallest width of the beam under the seat. The width restriction was also due to a lip over the beam, shown in Figure 9, that meant if the adaptive plate was bigger than the beam width the plate could not be centered causing applied loads to be off center. For an esthetically pleasing look and due to concerns of un-centered applied loads, the Insight seat was eliminated from the adaptive plate.

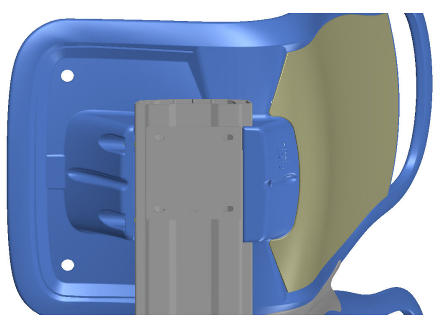


Figure 9: Bottom of Insight Seat Showing Lip over Beam

When the Metro seat shown in Figure 10, was being added for consideration to the recommended adaptive plate, issues arose on how wide the bolts were from the center of the plate. The holes for the Metro seat were added to the adaptive plate and the adaptive plate was attached to the remaining seats using SolidWorks. From the placement of the recommended adaptive plate on the remaining seats, the plate was determined to be too wide for use because it was over 12 inches wide which was three inches wider than the next seat style needed the plate to be. By eliminating Metro the adaptive plate's width decreased, resulting in the adaptive plate accommodating the remaining three seats Vision, Mariella and Ideo and was therefore more esthetically pleasing. Along with esthetics, Metro was eliminated due to concerns of passengers hitting the sharp edges of the adaptive plate and hurting themselves if the plate was attached to the chairs with a smaller width between holes and therefore, smaller under chair beam widths.

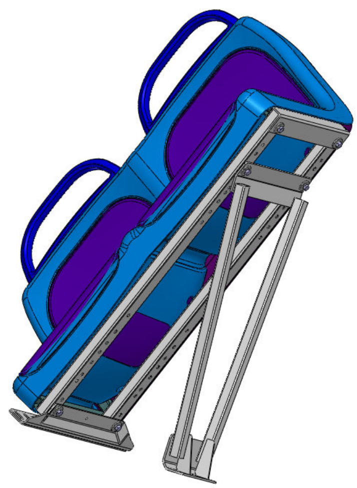


Figure 10: Metro Seat Bottom

The assembly components are limited because they are not interchangeable for use with other seating components. The leg structure is also restricted in the length that can be obtained, which may cause issues if the seats were to be used for aisle facing seats.

The LSS does not meet the dynamic loading requirements determined by the Team. The failure of the LSS during the dynamic loading is a major concern for the Team and this issue should be addressed before manufacture and installation of the LSS. Due to the failure of the LSS with dynamic loading the team did not consider it for this report and the calculations used to determine the dynamic loading force are detailed in Appendix E. The Team did note that the current lower support systems for the six seats are lighter and more stream line than the LSS design the Team proposes however due to the scope of this project the Team was unable to address this issue.

2.2. Operation and Assembly

The adaptive plate has different holes to mount onto the three different seats Vision, Ideo and Mariella and the leg structure attaches to the fourth seat, Aries. The corresponding holes of the adaptive plate can be matched to a specific seat by adjusting the position of the plate with respect to the lower seat beam. The complete LSS is shown in Figure 11 and shows the adaptive plate, upper part of the leg assembly, lower part of the leg assembly and the leg-to-bus joint.

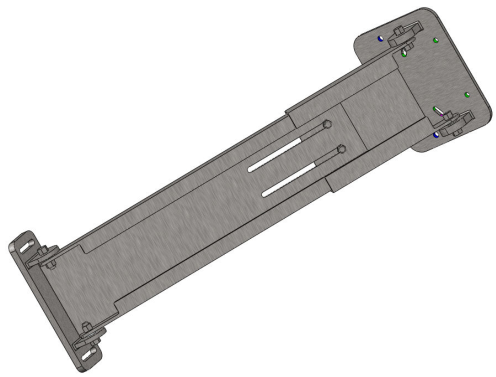


Figure 11: Lower Support Structure

The recommended leg structure adjustment design is an advantage of the LSS for the four seats Mariella, Aries, Ideo and Vision. By using the recommended leg structure design the length of the leg can be adjusted to meet the different positions of the seats when attached to the bus. The adjustment of the leg structure works by sliding the lower part of the leg along the slots to the required length. At first the bolts are unfastened to allow the length adjustment of the leg. Once the correct length is determined the bolts are then fastened to the sliding slots on the leg. The assembly instructions are detailed in Appendix H.

The leg-to-bus joint uses the length of two bolt slots to fit the slope of the upper deck on the bus. To make the leg-to-bus joint parallel with the windows on the upper deck the joint needs to be tilted then the bolts need to be tightened. Figure 12 shows how the joint is tilted on the sloped upper deck.

(a) (b)

Figure 12: Leg-to-Bus Joint Mounted on Bus
a) Upper Deck Track; b) Lower Deck Track

2.3. Cost Analysis and Bill of Materials

When determining the cost for the implementation of the LSS, three factors were explored the LSS material cost (steel), the hardware cost (bolts, nuts), and fabrication cost (machining). With the assistance of the McMaster-Carr website [4], cost values for the materials and hardware were determined and are detailed in Appendix C. Due to the design's specific dimensions, materials with similar (not exact) properties were found. The material choice resulted in assumptions that were made to determine a cost value. Assumptions include all materials are purchased from an outer source and are not made within New Flyer, and hardware for the attachment of the adaptive plate to the seat are included with the seat package received from the vendor.

Development and manufacturing of the LSS parts must be completed in order for part creation; hence there is a fabrication cost. The fabrication cost, featured in Appendix C, was estimated by the Team to be five hours per LSS at $100 per hour for labor. This value was determined based on the costs that the company would charge for the benefits and other incentives the NFI workers are entitled to. It is assumed that the seats come as a package already equipped with the bolts required for the adaptive plate to mount to the bottom of the seat. The assumption of a seat package affects the cost analysis because installation hardware for the four seat models is not needed for the cost analysis of the LSS. The LSS costs in Table II shows the Vision, Mariella and Ideo LSS cost is $728.89 per seat. To determine the cost, shown in Table II of the Aries seat, the adaptive plate cost was subtracted from the total cost, equaling $680.52. The Team was unable to compare the cost of the proposed LSS with the currently used designs due to a lack of information at the time this report was printed. Therefore there are not criteria to compare the proposed design cost with the currently used design. The Team determined that the cost comparison is an important part of the project and should be continued in the projects next phase.

TABLE II: TOTAL LSS COST PER SEAT STYLE

Seat Style	Total LSS Cost
Aries	$680.52
Vision	$728.89
Mariella	$728.89
Ideo	$728.89

2.4. Reduction of Parts

NFI required that the Team reduce the number of parts currently used by 20%. The Team tried to incorporate a reduction of parts in the final design by using the DFA concepts. Due to other NFI needs such as an adjustable leg so that the seat can be mounted to the bus in any seat position the team determined the reduction in parts to be customer need that was low on the scale of importance. The number of parts for the proposed design was compared with the number of parts on the currently used design and it was determined that the proposed design did not reduce the number of parts from the current design for the designs that the LSS satisfies. The values for the increase in part numbers are shown in Table III. The Aries seat and the Vision seat styles had an increase in part numbers by 50% and 42.86% respectively. The Ideo and Mariella seat styles had the number of parts reduced from the current design by 7.69% and 36.84% respectively.

TABLE III: PERCENTAGE INCREASE IN PARTS

Seat Style	Number of Parts in Current Design	Number of Parts in Proposed Design	Percentage of Increased parts
Aries	6	9	50%
Ideo	13	12	-7.69%,
Vision	7	10	42.86%
Mariella	19	12	-36.84%

NFI also required that the Team to reduce the number of engineering hours from 130 hours per bus contract to 78 hours (40% reduction) and from eight man hours per bus seat layout installation to 6.8 hours (15% reduction). Machine shop companies were contacted to find a price to produce a prototype but the quotes were above the Team's budget. Since the Team was unable to get a prototype and produce seat installations with the proposed design there was no data to determine if the man hours or engineering hours were reduced. The Team also assumed that due to the simplicity of the design and the repeatability of seat installations, there will be a learning curve at the beginning of the installation process causing an increase in expenses followed by a decrease as the number of repetitions increases. The Team did not meet the requirement of NFI to have a reduction in parts for the recommended LSS which is detailed in Appendix D.

3. Recommendations

Due to the scope of the standardization and modularization of NFI bus seating project the Team recommends the following issues be addressed in the next phase of the project. The recommendations are not listed in order of importance and all should be reviewed before the LSS is commissioned for production and installation.

The first recommendation is to build on the dynamic loading analysis to make sure the structure will withstand the actual applied loadings. The second recommendation is to do a cost comparison of the current design and the LSS design as outlined in this report. Additionally, an in depth cost analysis should be conducted on the LSS design to include multiple part ordering as well as contract costs for contracting out, or in house manufacturing of the LSS. The third recommendation is that the LSS design should be analyzed for a reduction in complexity and a reduction of parts for the assembly. The DFMEA should also be assessed again to make sure that there is no concern for the failure modes defined by the LSS for the fourth recommendation. The Team has also discussed whether the vendor could make another adaptive plate to accommodate both the Insight and Metro seat styles for the fifth recommendation. The sixth recommendation is that the extra adaptive plate could accommodate other seat styles that are used by NFI in bus seating layouts. The seventh recommendation is that the LSS final design could be analyzed and adjusted to work for the forward facing, aisle facing, heater mounted and wheel mounted seat positions. Finally New Flyer could approach the vendors to review their seating styles and recommend designs for a more universal seat mounting system. With a universal or even semi-universal seat mounting system, NFI would be able to meet the need to reduce engineering and installation time.

4. Conclusion

In conclusion, the Team has analyzed many different concepts and designed a LSS that met the most needs of NFI. The final design meets the modularization of bus seating for four out of six seat styles. The four seat styles are Vision, Mariella, Ideo and Aries. The Metro and Insight seat styles were not added due to a large under the seat beam and lip over the beam on the Metro and Insight seats respectively.

The operation of the LSS was analyzed for different failure aspects and the failure modes were mitigated using DFMEA. The DFMEA was iterated once for a new risk priority number and the Team determined that another iteration of the DFMEA is required so that there is better coverage on mitigating the failure modes and effects. DFA concepts were considered to ease the assembly of the LSS which the Team believes will reduce the installation time on the bus which was a need of NFI but due to a lack of prototypes the actual time reduction could not be determined. Assembly instructions and weights of the LSS components were determined for the report. Simple hand calculations and FEA analysis for double the determined static loads were conducted and the LSS could withstand the applied loads. The dynamic loading was not considered in the analysis because the applied forces failed the LSS and the LSS needs to be further analyzed as a result. The proposed design does not meet NFI's need to have a reduction in parts from the current design and the Team concluded that this issue was due to the required versatility of the LSS design.

Engineering drawings were done for the assembly of the LSS as well as the LSS components for ease of manufacture and installation. The cost for Vision, Mariella and Ideo seats was determined to be $680.52 and the Aries seats cost was determined to be $728.89. Various recommendations for NFI were given in this report for the next phase of the project. The Team concludes that the vendors should review their seat styles and make the seat mounting systems more universal because NFI's engineering time and man hours per seat installation layout would be drastically reduced not only for the four seats that the LSS satisfies but for all seat styles used by NFI.

5. Acknowledgements

Team New Flyer-8 would like to thank Tony Huynh, P. Eng., New Flyer Industries, for the guidance and information he has given for the project. Also from New Flyer, the Team would like to thank Kirk Burcar, M. Eng, P. Eng., and Paul Zanetel, P. Eng. for their time and information when meeting with the Team. Furthermore, the Team would like to acknowledge the recommendations and direction for this report that we have received from Dr. Peng, Engineering Librarian Head Norma Godavari, Technical Communications Specialist Melissa Haresign and MECH4860's T.A. Curtis Carrick.

6. References

[1] T. Huynh (private communication), September 21, 2010.

[2] T. Huynh. (September 21, 2010). "Seating project meeting." Personal e-mail.

[3] American Public Transportation Association, *Standard Bus Procurement Guidelines*. Washington DC: American Public Transportation Association, 2009.

[4] McMaster-Carr, "McMaster-Carr," [Online] Available: www.mcmaster.com. Accessed: November 16-21, 2010.

[5] American Fastener. *ASTM, SAE and ISO Grade Markings and Mechanical Properties for Steel Fasteners* [Online]. Available: http://www.americanfastener.com/technical/grade_markings_steel.asp [November 12, 2010]

[6] F.P. Beer, E.R. Johnston and J. T. DeWolf, Mechanics of Materials. New York, NY: McGraw Hill, 2006.

[7] E. Oberg, F. Jones and H. Horton, *Machinery's Handbook*. Syracuse, NY: Dix Type Inc., 1988.

[8] G. Boothroyd, *Assembly Automation and Production Design*. New York, NY: Marcel Dekker, INC, 1992.

[9] M. Symonds (private communication), November 5, 2010.

Appendix A: Concepts Considered

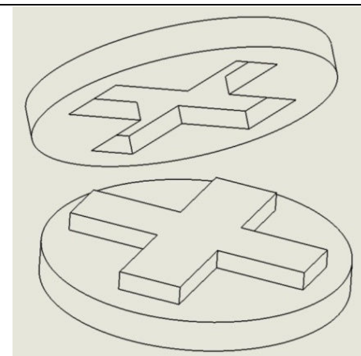
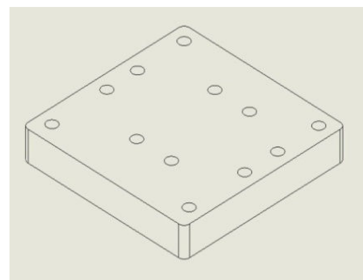
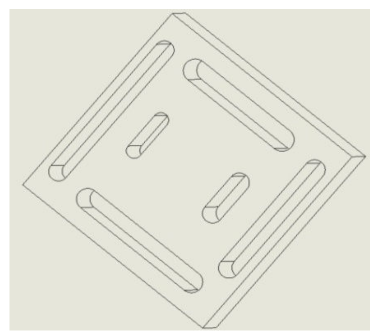
Appendix A.1: Brainstorming

The Team brainstormed and came up with results for the three components that make up the LSS. .The three components that make up the LSS include the adaptive plate, leg support and leg-to-bus joint. The concepts that were developed for the adaptive plate are the pre-fabricated combination plate with locking structure, the combination plate with sliding channels, prefabricated plate, plate with sliding channels and circular locking structure. The concepts developed for the leg structure include an adjustable leg with holes, an adjustable leg with inner gears, adjustable leg with thread, ordinary supporting leg and adjustable leg with sandwich gears. The concepts results are presented in the following sections.

Appendix A.1.1: Seat Lower Structure Mounting

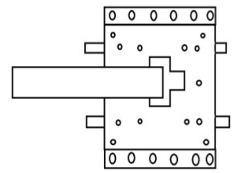
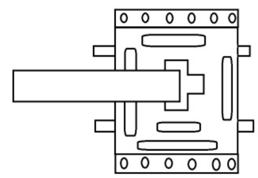
The Team brainstormed how to accommodate the 6 types of seats into one universal mounting structure to face the front. The brainstorming results are presented in Table A.I.

TABLE A.I: CONCEPTS OF SEAT MOUNTING STRUCTURES

Name	Description	Illustration
Circular locking structure	One half of the structure connects to the lower supporting leg and the other half is attached to the bottom of the seat. The circular locking structure is designed in such a way that the seat can rotate 90^{o} to face front or aisle.	
Pre-fabricated square plate with holes	The square plate has pre-positioned holes to accommodate the 6 seat types.	
Square plate with sliding bolt channels	The square plate has sliding channels to accommodate the 6 types of seats and corresponding bolts.	

The circular locking structure's purpose is to enable the seat to turn the direction from front facing to aisle facing. As a brainstorming result, the circular support locking structure has not included how the structure is connected to the bottom of the seat and the lower support leg. The square plate with pre-fabricated-holes has to be a relatively large size to function as a plate that accommodates the six different seat mountings. The purpose of the sliding channel plate is to adjust the bolts along the sliding channels to mount the six different seat types. For the same reason as the square plate with pre-fabricated holes the sliding channel plate has to be relatively large. After reviewing the concepts for the seat mounting plates the team integrated the brainstorming ideas into two concepts shown in Tabel A.II.

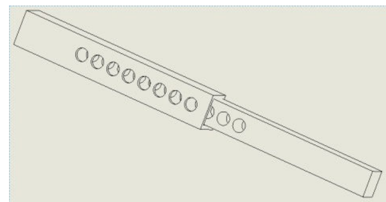
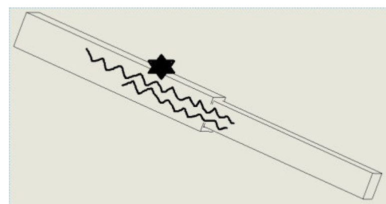
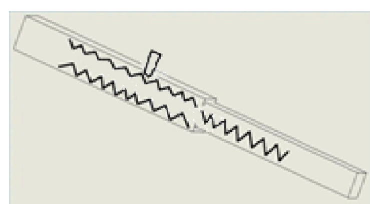
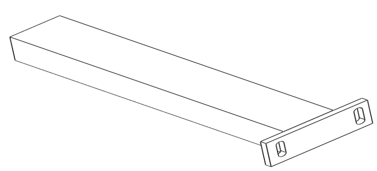
TABLE A.II: CONCEPTS FOR LOWER SUPPORT ATTACHMENT TO SEAT MOUNT

Name	Description	Illustration
Combination pre-fabricated square plate with locking structure	The pre-fabricated square plate combined with the locking structure. Design details two side walls to mount on the sides of the seat and the middle is the circular locking structure.	
Combination sliding channels with locking structure	The sliding channel square plate combined with the locking structure. Design details two side walls to mount on the sides of the seat and the middle is the circular locking structure.	

Appendix A.1.2: Lower Support Leg

The lower support leg brainstorming was focusing on how to adjust the length to fit the different mounting positions of the seats. The adjustable leg assists in keeping the height of the seat within APTA standards of 17± 1 inch [3]. The lower support leg brainstorming ideas are shown in Table A.III.

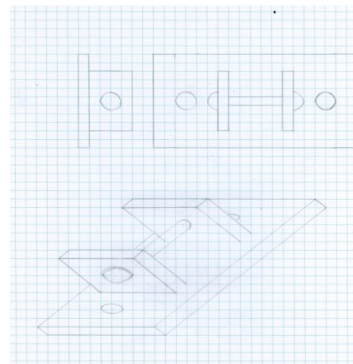
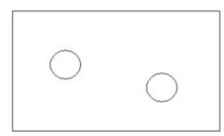
TABLE A.III: CONCEPTS FOR LOWER SUPPORT LEG

Name:	Description:	Illustration:
Adjustable leg with holes	By using different holes, the length of the leg can be adjusted.	
Adjustable leg with inner gears	The length of the leg can be adjusted by turning the star shaped gear. Turning the star shaped gear lengthens the leg by specified increments.	
Adjustable leg with thread	One portion of the leg is threaded into the other to complete the leg.	
Adjustable leg with sandwich gears	The half outer leg has gear teeth; inner half leg has gear teeth. The leg can be locked by a pin.	
Ordinary support leg	Non-adjustable leg.	

Appendix A.1.3: Leg-To-Bus Joint

Due to the slope of the upper deck of the bus being parallel with the floor and not with the window and the seats on the upper deck must be leveled with the window. The problem of the seat not being level to the windows due to the sloped tracks was mitigated by the concepts shown in Table A.IV.

TABLE A.IV: CONCEPTS FOR ATTACHMENT TO BUS'S UPPER DECK

Name:	Description:	Illustration:
U-shape joint	This U-shape joint can rotate so that it will keep the seat leveled.	
Angled-holes joint	This rectangular plate joint can simply level the seat by angling two holes	

Appendix A.1.4: Scoring Matrix

In summary of the scoring matrix shown in Figure A.1, results from all the design concepts for the seat structure mounting, leg structure and leg-to-bus joint were analyzed and ranked. The concepts were ranked within the concept category they were developed for. The Team concluded that the top ranking concept from each category was the best design idea and should be sought out to implement in the final LSS design. The top designs include the combination plate, adjustable leg with holes and angled hole leg-to-bus joint. The concepts that were chosen were developed in more detail with NFI's input until the recommended LSS design was complete.

Customer Need:	Importance	Weight	Combination pre-fabricated square plate with locking structure		Combination sliding channels with locking structure		Adjustable leg with hol		Adjustable leg with inn		U-shape joint		Angled-holes joint	
			rating	score	rating	score	rating	score	rating	score	rating	score	rating	score
Ease of Bus Mount	5	9%	N/A	N/A	N/A	N/A	4	0.36	3	0.27	4	0.36	4	0.36
Ease of Chair Mount	5	9%	4	0.36	3	0.27	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Improvement from the Current Design	5	9%	5	0.45	5	0.45	5	0.45	3	0.27	5	0.45	5	0.45
Works Anywhere	5	9%	5	0.45	5	0.45	5	0.45	4	0.36	5	0.45	3	0.27
Re-Engineering Time	5	9%	5	0.45	4	0.36	5	0.45	4	0.36	2	0.18	4	0.36
Manufacturing Time	5	9%	5	0.45	4	0.36	5	0.45	3	0.27	4	0.36	5	0.45
Ease of Future Changes	5	9%	3	0.27	3	0.27	2	0.18	3	0.27	3	0.27	4	0.36
Reliability	4	7%	4	0.28	5	0.35	4	0.28	2	0.14	3	0.21	5	0.35
Low Weight	3	5%	3	0.15	3	0.15	5	0.25	3	0.15	4	0.2	4	0.2
Switchability	3	5%	5	0.25	5	0.25	5	0.25	5	0.25	5	0.25	4	0.2
Economical	3	5%	4	0.2	3	0.15	5	0.25	2	0.1	4	0.2	5	0.25
Repairability	2	4%	1	0.04	1	0.04	1	0.04	1	0.04	1	0.04	1	0.04
Total Score				3.35		3.1		3.41		2.48		2.97		3.29
Rank				1		2		1		2		2		1
Continue? Yes or No				Y		N		Y		N		N		Y

Figure A.1: Scoring Matrix with Seat Structure Mounting (red), Leg Structure (purple) and Leg-to-Bus Joint (blue)

Appendix B: Project Schedule

The project schedule is detailed in the following pages. The schedule includes a Work Breakdown Structure (Figure B.1) and a Gantt Chart (Figure B.2) that show the Teams progress and accomplished tasks throughout the projects phases.

Work Breakdown Structure

Figure B.1: Work Breakdown Structure

Gantt Chart

Figure B.2: Gantt Chart

Appendix C: Cost Analysis

The cost analysis was determined based on the three LSS components, hardware cost and fabrication costs. The costs per seat assembly were determined based on the parts required from the LSS to fully mount the seats to the bus. The seat style Aries does not take into account the adaptive plate in the cost because of the flanges on the bottom beam of the Aries seat. The Vision, Mariella and Ideo seats take into account all parts that make up the LSS because all parts are used to mount the seat to the bus. Table C.I, Table C.II and Table C.III detail the costs associated with the LSS components for the material, hardware and fabrication costs as well as the total cost per cost category.

TABLE C.I: ADAPTIVE PLATE, LEG SUPPORT, LEG-TO-BUS JOINT COST ANALYSIS

Adaptive Plate	Material	Product Number	Dimensions (inches)	Cost per Unit	Units per Adaptive Plate	Cost per Seat
Plate	Multipurpose 4140/4142 Alloy Steel (unpolished)	6544K24	10*10*1/4	$35.12	1	$35.12
Hinge	Multipurpose 4140/4142 Alloy Steel (unpolished)	6554K311	12*3*1/2	$26.50	0.5	$13.25

Leg Support	Material	Product Number	Dimensions (inches)	Cost per Unit	Units per Leg Support	Cost per Seat
C-channel	General Purpose Low-Carbon Steel (unpolished)	7779T16	2*5/8*72	$41.57	3	$124.71

Leg-to-Bus Joint	Material	Product Number	Dimensions (inches)	Cost per Unit	Units per Adaptive Plate	Cost per Seat
Plate	Multipurpose 4140/4142 Alloy Steel (ground)	8892K88	6*3*1/2	$22.88	1	$22.88
Hinge	Multipurpose 4140/4142 Alloy Steel (unpolished)	6554K311	12*3*1/2	$26.50	0.5	$13.25

TABLE C.II: HARDWARE AND FABRICATION COST ANALYSIS

Hardware	Product Number	Size	Quantity (per Seat Assembly)	Price	Cost
Steel Washer	91083A031	3/8 inch	10	$ 3.07 per pack of 140	$0.22
Standard Hex-Grade 5 Steel Bolt	92190A111	3/8 * 1.5	6	$ 3.07 per bolt	$18.42
Heavy Hex Nuts-Grade 5 Steel	95045A031	3/8 inch	6	$ 8.67 per pack of 50	$1.04

Fabrication	Shop Procedure	Hours	Price	Cost
The Cost Takes into Account the Price to Fabricate One Lower Support Strucutre	Welding, Machining, Etc.	5	$100/hour	$500

TABLEC.III: TOTAL COSTS PER LSS PART

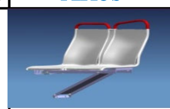
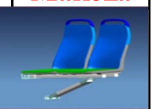
Cost Type	Cost per Seat [$]
Adaptive Plate	48.37
Leg Support	124.71
Leg-to-Bus Joint	36.13
Hardware	19.68
Fabrication Costs	500.00

Appendix D: Reduction of Parts

One of the main factors to confirm whether to implement the recommended design or not, is by determining whether it reduces the amount of parts needed. Table D.I shows a direct comparison between the current seat design parts needed and the recommended design parts needed.

Assumptions that are made within this analysis are, that each part needed for each design has equal importance to the installation process (i.e. If a design has 10 parts and the majority of parts are bolts, compared to another design that has 10 parts and very little bolts needed, the difficulty of installing and cost are equal). Also assumed, are that each of the four seat designs are made in equal quantities. With these in mind the percentage of parts increased for Aries, Ideo, Vision and Mariella are 50%, -7.69%, 42.86% and -36.84% respectively. Therefore, on average the parts are actually increased by 12.08% by implementing this design. A notable point to take into account when looking at this value, is that the parts required for all four designs are the same for the recommended design and could possibly decrease the time and cost of installation even with the increase in parts. Therefore another aspect for determining whether to implement this design must be done.

TABLE D.I: REDUCTION IN PARTS

Seat Type	**Aries**	**Ideo**	**Vision**	**Mariella**
Current Design				
No. Beams in Lower	1	2	1	2
leg support to seat joint	0	1	1	1
leg-to-bus joint parts	1	4	1	2
total number of bolts	4	6	4	14
Total Number of Parts and	6	13	7	19

Recommended Design	**Aries**	**Ideo**	**Vision**	**Mariella**
Adaptive Plate	**0**	**1**	**1**	**1**
Upper Part of Leg Support	1	1	1	1
Lower Part of Leg Support	1	1	1	1
Leg-to-Bus Joint	1	1	1	1
Bolts to Secure Upper and Lower Leg Support	2	2	2	2
Bolts to Secure Adaptive Plate/Leg Support (for	2	4	2	4
Bolts to Secure Leg Support to Leg-to-Bus	2	2	2	2
Total Number of Parts for Recommended Design	9	12	10	12

Percentage of Increase in Parts From Current to	50.00%	-7.69%	42.86%	-36.84%
Average Decrease	12.08%			

Appendix E: Analysis of LSS

Hand calculations and FEA analysis were conducted on the LSS. The reaction forces required by the LSS to handle the loads applied did not take the weight of the seat and corresponding hardware into account. The weight of the seat and hardware was assumed to be negligible for the simplicity of these calculations. However, it was necessary to assume that people will drop their weight onto the seat, at times causing a dynamic load. The dynamic load was taken into consideration by assuming the value of the solved load. The LSS with the applied load of P was also assumed to have a minimum cycle life of $5*10^5$ cycles. The cycle life was determined by assuming that the seat structure will experience the increase in load due to a slight drop of weight once every mile. An FEA analysis of the LSS components was conducted at a load of 2P to take into account the drop of weight as well as the seat and hardware weights.

The hand calculations and FEA analysis are detailed in the following sub-sections.

Appendix E.1: Hand Calculations

The hand calculations were prepared to support the FEA analysis and to further prove that the LSS would not fail. The hand calculations are detailed in the following sub-sections.

Appendix E.1.1: Force on Supporting Leg Calculation

Forces and Moments were first calculated about the horizontal seat structure before calculating the components that make up the LSS reaction force P. Figure E.1 shows the LSS layout in general for all four of the seat configurations. For the Vision, Ideo, Aries and Mariella seat styles the reaction force required by the LSS to hold the seat up was determined. The maximum force that was required from the four seats was determined to be Mariella and therefore the reaction force from Mariella was used for the calculations in the rest of the report.

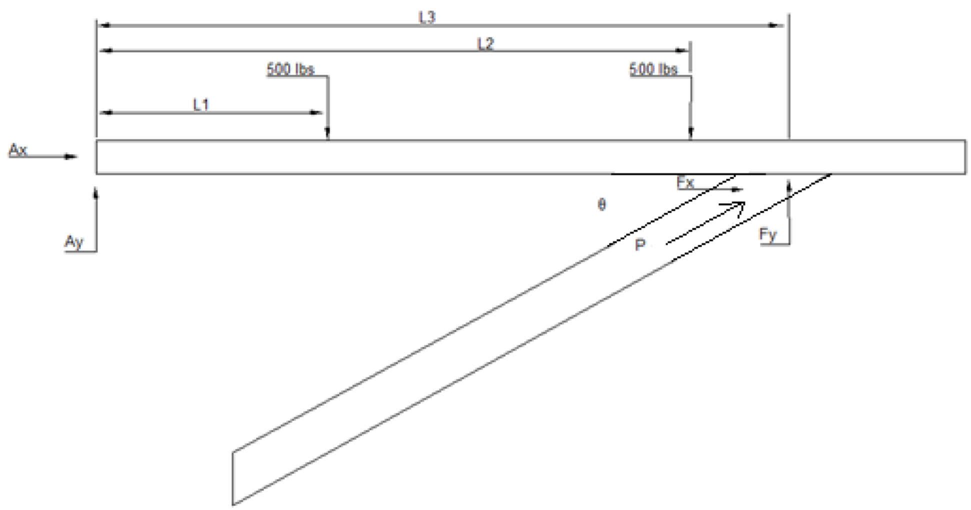


Figure E.1: Seat Assembly Layout

Mariella Seat Style

Assume:

- Two passengers sitting on the seat
- Weight 500 lbs per passenger
- L_1 = 9.71 inches
- L_2 = 27.4 inches
- $\theta = 23^{o}$
- L_3 = 27.25 inches

1. Taking the moment about point A:

$$\sum M_A = -500L_1 - 500L_2 + F_y L_3 = 0$$
$$F_y = 680.91\ lbs \approx 680\ lbs$$

2. Solving For F_x and P:

$$F_x = \frac{F_y}{\tan\theta}$$
$$F_x = \frac{680}{\tan 23°}$$
$$F_x = 1601.98\ lbs \approx 1602\ lbs$$

$$P = \sqrt[2]{(F_x)^2 + (F_y)^2}$$
$$P = \sqrt[2]{(1602)^2 + (680)^2}$$
$$P = 1740.35\ lbs\ \approx 1740\ lbs$$

Mariella's P is the highest of all the seats therefore it was used for the calculations in the rest of the report

Vision Seat Style

Assume:

- Two passengers sitting on the seat
- Weight 500 lbs per passenger
- L_1 = 9.47 inches
- L_2 = 27.47 inches
- $\theta = 26^o$
- L_3 = 27.25 inches

1. Taking the moment about point A:

$$\sum M_A = -500L_1 - 500L_2 + F_y L_3 = 0$$
$$F_y = 677.80\ lbs \approx 678\ lbs$$

2. Solving For F_x and P:

$$F_x = \frac{F_y}{\tan\theta}$$
$$F_x = \frac{678}{\tan 26°}$$
$$F_x = 1390.12\ lbs \approx 1390\ lbs$$

$$P = \sqrt[2]{(F_x)^2 + (F_y)^2}$$

$$P = \sqrt[2]{(1390)^2 + (678)^2}$$

$$P = 1546.54\ lbs \approx 1547\ lbs$$

Ideo Seat Style

Assume:

- Two passengers sitting on the seat
- Weight 500 lbs per passenger
- L_1 = 9.18 inches
- L_2 = 27.01 inches
- $\theta = 26^o$
- L_3 = 27.25 inches

1. Taking the moment about point A:

$$\sum M_A = -500L_1 - 500L_2 + F_y L_3 = 0$$

$$F_y = 664\ lbs$$

2. Solving For F_x and P:

$$F_x = \frac{F_y}{\tan\theta}$$

$$F_x = \frac{664}{\tan 26°}$$

$$F_x = 1361.40\ lbs \approx 1361\ lbs$$

$$P = \sqrt[2]{(F_x)^2 + (F_y)^2}$$

$$P = \sqrt[2]{(1361)^2 + (664)^2}$$

$$P = 1514.34\ lbs \approx 1514\ lbs$$

Aries Seat Style

Assume:

- Two passengers sitting on the seat
- Weight 500 lbs per passenger
- L_1 = 8.75 inches
- L_2 = 26.46inches

- $\theta = 31^o$
- L_3 = 27.25 inches

1. Taking the moment about point A:

$$\sum M_A = -500L_1 - 500L_2 + F_yL_3 = 0$$
$$F_y = 646.06\ lbs \approx 646\ lbs$$

2. Solving For F_x and P:

$$F_x = \frac{F_y}{\tan\theta}$$
$$F_x = \frac{646}{\tan 31°}$$
$$F_x = 1075.22\ lbs \approx 1075\ lbs$$

$$P = \sqrt[2]{(F_x)^2 + (F_y)^2}$$
$$P = \sqrt[2]{(1075)^2 + (646)^2}$$
$$P = 1254.35\ lbs\ \approx 1254\ lbs$$

Appendix E.1.2: Bolt and Pin Stress Calculations

1. Bolts of Supporting Leg

   The bolts are used in fixing the length of the adjustable supporting leg as shown in Figure E.2.

   Assume:

   - P = 2*1740 lbs = 3480 lbs (this value is from Mariella which had the highest load value and is valid for any further calculations)
   - t = 0.2 inch
   - d = 0.375 inch
   - Two bolts used

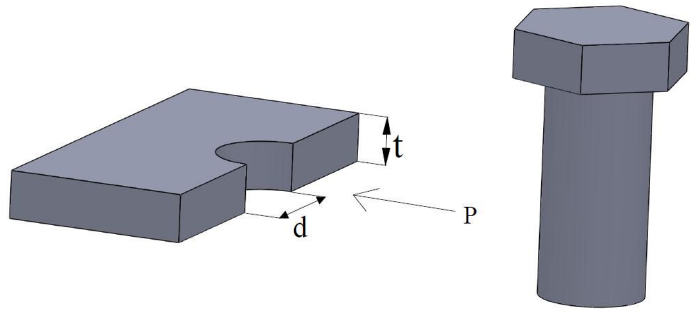


Figure E.2: Supporting Leg Bolt

Solving for bearing stress gives:

$$\sigma_b = \frac{P}{2A} = \frac{P}{2td}$$

Above equation was taken from [6].

$$\sigma_b = \frac{3480\ lbs}{2 * 0.2 * 0.375} = 23{,}200\ psi$$

The yield strength of the hinge and pin materials are 43,251.02 psi (using SolidWorks) and 120,000 psi (SAE J429 Grade 8) [5] respectively. Assuming endurance strength of sixty percent yield strength for the hinge and pin materials would give: 25,950.61 psi and 72,000 psi respectively. Both yield strengths are in excess of the bearing stress therefore the pin and hinge joints will not fail.

Solving for shear stress gives:

$$\tau = \frac{P}{2A}$$

$$A = \pi r^2 = \pi (\frac{0.375}{2})^2 = 0.11045\ in^2$$

$$\tau = \frac{3480\ lbs}{2 * 0.11045\ in^2} = 15{,}753.73\ psi$$

The shearing force acting on the pins and hinges does not exceed the allowable stress as defined previously as 25,950.61 psi and 72,000 psi for the hinge and bolt respectively. Therefore the bolts will not fail under the given loading conditions.

2. Pin and Hinge Calculations

   The pins are used in attaching the leg support to the adaptive plate and the leg-to-bus joint. The bearing stress is similar to the bolt calculated above but due to the two hinges the force acting on each hinge is half that of the actual force (P).

   Assume:

   - P = 2*1740 lbs = 3480 lbs (this value is from Mariella which had the highest load value)
   - t = 0.2 inch
   - d = 0.375 inch

   Solving for bearing stress gives:

$$\sigma_b = \frac{P}{2A} = \frac{P}{2td}$$

   Above equation was taken from [6].

$$\sigma_b = \frac{3480\ lbs}{2 * 0.2 * 0.375} = 23{,}200\ psi$$

   The yield strength of the hinge and pin materials are 43,251.02 psi (using SolidWorks) and 120,000 psi (SAE J429 Grade 8) [5] respectively. Assuming endurance strength of sixty percent yield strength for the hinge and pin materials would give: 25,950.61 psi and 72,000 psi respectively. Both yield strengths are in excess of the bearing stress therefore the pin and hinge joints will not fail.

   Solving for shear stress for both pin and hinge gives:

$$\tau = \frac{P}{2A}$$

$$A = \pi r^2 = \pi(\frac{0.375}{2})^2 = 0.11045\ in^2$$

$$\tau = \frac{3480\ lbs}{2 * 0.11045\ in^2} = 15{,}753.73\ psi$$

   The shearing force acting on the pins and hinges does not exceed the allowable stress as defined previously as 25,950.61 psi and 72,000 psi for the hinge and bolt respectively. Therefore the bolts will not fail under the given loading conditions.

Using Figure E.3 and solving for the deflection of the pin gives:

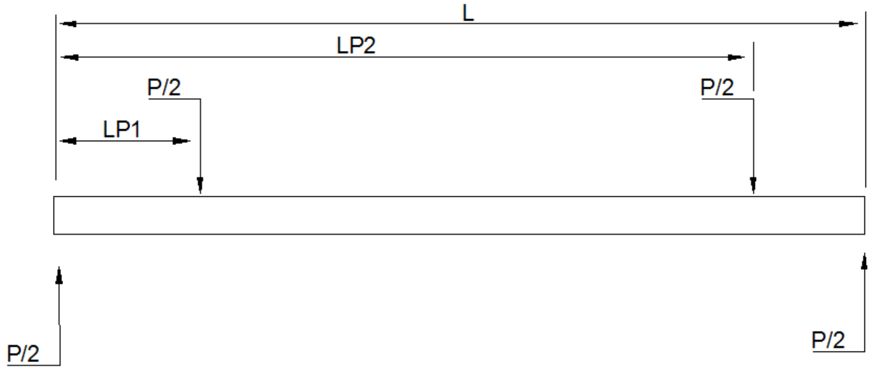


Figure E.3: Simplified Pin Free Body Diagram

Assuming:

- P = 3480 lbs
- L=7 inches
- L_{P1} = 0.5 inches
- L_{P2} = 6.5 inches
- E = 29 x 10^6 psi
- I = 0.25*π*r^4 =0.25*π*$(0.375)^4$ = 0.01553 in^4

Using super position and solving for the deflection caused by P_1 gives:

$$y_{max1} = \frac{-PL_{P1}(L^2 - L_{P1}^2)^{3/2}}{2 * 9\sqrt[3]{3} * EIL}$$

$$y_{max1} = \frac{-3480 * 0.5 * (7.0^2 - 0.5^2)^{3/2}}{2 * 9\sqrt[3]{3} * 29 * 10^6 * 0.01553 * 7.0}$$

$$y_{max1} = 0.00724\ inches$$

Using super position and solving for the deflection caused by P_2 gives the same result as solving for P_1. The only difference is that the beam has to be flipped so that L_{p2} stays smaller than $L_{p1.}$ The lengths are the opposite when solving for P_1.

$$y_{max1} = y_{max2} = 0.00724\ inches$$

Solving for the distance in *x* where the max deflection occurs for both loads gives:

$$x_{max1} = \sqrt[2]{\frac{L^2 - L_{p1}^2}{3}}$$

$$x_{\max 1} = 4.03\ inches$$

$$x_{max2} = 7 - 4.03 = 2.97\ inches$$

When the deflections are added up the max deflection is 0.7% of an inch. Therefore the deflection is negligible

3. T-Bolts of Leg-to-Bus Joint

The bolts are used in fixing the leg-to-bus plate to the bus using T-bolts. There are two bolts therefore the load is half of the total load for each bolt. This case is very similar to the bolts of the supporting leg as seen in the first bolt calculation above.

Assume:

- P = 2*1740 lbs = 3480 lbs (this value is from Mariella which had the highest load value and is valid for any further calculations)
- t = 0.2 inch
- d = 0.375 inch
- Two bolts used

Solving for bearing stress gives:

$$\sigma_b = \frac{P}{2A} = \frac{P}{2td}$$

Above equation was taken from [6].

$$\sigma_b = \frac{3480\ lbs}{2 * 0.2 * 0.375} = 23{,}200\ psi$$

The yield strength of the hinge and pin materials are 43,251.02 psi (using SolidWorks) and 120,000 psi (SAE J429 Grade 8) [5] respectively. Assuming endurance strength of sixty percent yield strength for the hinge and pin materials would give: 25,950.61 psi and 72,000 psi respectively. Both yield strengths are in excess of the bearing stress therefore the pin and hinge joints will not fail.

Solving for shear stress gives:

$$\tau = \frac{P}{2A}$$

$$A = \pi r^2 = \pi(\frac{0.375}{2})^2 = 0.11045\ in^2$$

$$\tau = \frac{3480\ lbs}{2 * 0.11045\ in^2} = 15{,}753.73\ psi$$

The shearing force acting on the pins and hinges does not exceed the allowable stress as defined previously as 25,950.61 psi and 72,000 psi for the hinge and bolt respectively. Therefore the bolts will not fail under the given loading conditions.

4. Bolts Attaching the Adaptive Plate

The bolts attaching the adaptive plate to the seat structure were analyzed for shearing of the threads as well as length of engagement needed. The equations for the analysis were taken from the Machinery's Handbook [7]. The results of these equations are shown in Table E.I and the bolts pass with the loads that are applied.

TABLE E.I: ADAPTIVE PLATE BOLT ATTACHMENT CALCULATIONS

Seat	D [in]	Threads/inch (n)	$E_s$min	$K_n$max	A_t [in]	Allowable L_e [in]	Min L_e [in]	No. of Bolts	Total Force [lbs]	Force/ Bolt (F) [lbs]
Ideo	0.25	20.00	0.21	0.21	0.03	0.17	0.75	4.00	3480.00	870.00
Mariella	0.25	20.00	0.21	0.21	0.03	0.17	0.75	4.00	3480.00	870.00
Vision	0.38	20.00	0.34	0.33	0.08	0.28	0.75	2.00	3480.00	1740.00

Seat	σ= F/A_t [psi]	Shear Strength [psi]	Allowable Shear Strength With SF of 2 [psi]	Constant Dependant on Lubricant Present	Torque [ft-lbs] T=KDF	Comments
Ideo	29262.56	120000.00	60000.00	0.15	32.63	1/4-20 UNC pg 1499 MH class 1A.
Mariella	29262.56	120000.00	60000.00	0.15	32.63	1/4-20 UNC pg 1499 MH class 1A.
Vision	21505.58	120000.00	60000.00	0.15	97.88	3/8-20 UNC pg 1500 MH class 2A.

Appendix E.1.3: Wrench and Socket Clearances

Using the Machinery's Handbook [7] wrench and socket clearances were determined for the bolt sizes used in the LSS. The area around each bolt was then analyzed to make sure that the wrench and socket clearances were met. The clearances are outlined in Table E.II.

TABLE E.II: BOLT SIZES AND REQUIRED INSTALLATION CLEARANCES

Seat	**Hole Size from SolidWorks File (Diameter)**	**Hole Size on Adaptive Plate (Diameter)**	**Possible Bolt Size (Diameter)**		**Face width of Bolt Head (Diameter)**		**Open End Wrench (Diameter)**	**Socket Wrench (Regular Length) (Diameter)**
Ideo	0.354 in.	0.354 in.	0.25 in.	1/4 in.	0.4375 in.	7/16 in.	0.89 in.	0.75 in.
Mariella	0.354 in.	0.354 in.	0.25 in.	1/4 in.	0.4375 in.	7/16 in.	0.89 in.	0.75 in.
Vision	0.41 in.	0.41 in.	0.375 in.	3/8 in.	0.5625 in.	9/16 in.	1.13 in.	0.87 in.
Leg Bolt/ T-Bolt/ Pin			0.375 in.	3/8 in.	0.5625 in.	9/16 in.	1.13 in.	0.87 n.

Appendix E.1.4: Upper Part of Support Leg stress Calculation

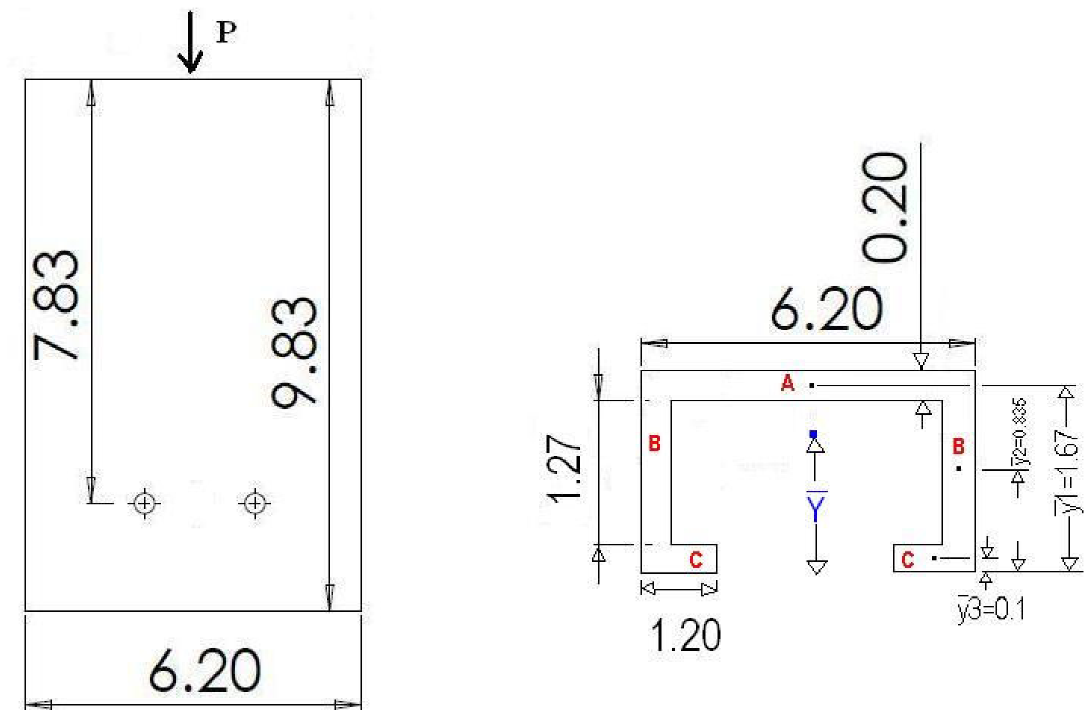


Figure E.4: Leg Support

Due to the complexity of stress concentration calculations at the holes is beyond undergraduate study level, the Team simplified this part of the calculation into eccentric loading on an asymmetric column (Figure E.4). This means that the analysis on the asymmetric column uses the area which is not close to the holes. The analysis on the leg support is detailed below. The load applied to the leg support is assumed to be 3480 lbs (P). The formulae and analysis procedure was defined in the Mechanics of Materials Textbook [6] and part of the procedure is outlined in Table E.III and Table E.IV.

TABLE E.III: LEG STRUCTURE AREA AND CENTER OF GRAVITY DISTANCE

Section	Area (in^2.)	$\bar{y}$ (in.)	$\bar{y}$A (in^3)
A	6.2 * 0.2 = 1.24	1.67	2.0708
B	1.27 * 0.2 = 0.254	0.835	0.21209
B	1.27 * 0.2 = 0.254	0.835	0.21209
C	1.20 * 0.2 = 0.24	0.1	0.024
C	1.20 * 0.2 = 0.24	0.1	0.024
	ΣA = 2.228		Σ$\bar{y}$A = 2.54298

TABLE E.IV: WHOLE LEG STRUCTURE CENTER OF GRAVITY DISTANCE

$\bar{Y}\Sigma A = \Sigma\bar{y}A$
$\bar{Y}$ * 2.228 = 2.54298
$\bar{Y}$ = 1.1414 in.

$$I = \sum(\bar{I} + Ad^2) = \sum\left(\frac{1}{12}bh^3 + Ad^2\right)$$

$$= \left[\frac{1}{12} * 6.2 * 0.2^3 + 6.2 * 0.2 * 0.4286^2\right]$$

$$+ \left[\frac{1}{12} * 0.2 * 1.27^3 + 0.2 * 1.27 * 3.0156^2\right] * 2$$

$$+ \left[\frac{1}{12} * 1.2 * 0.2^3 + 1.2 * 0.2 * 2.70823^2\right] * 2$$

$$I = 0.23192 + 2.343976 * 2 + 1.76108 * 2 = 8.442\ in^4$$

$$r^2 = \frac{I}{A} = \frac{8.442}{2.228} = 3.789$$

Eccentricity (the distance from force P to $\bar{Y}$, and assume P acting on the midpoint):

$$e = 1.1414 – 1.67/2 = 0.3064$$

$$c = \frac{1.27 + 0.2 + 0.2}{2} = 0.835\ in$$

For 201 annealed stainless steel E = 30022800 psi and using [6] for reference the max stress is equal to:

$$\sigma_{max} = \frac{P}{A}[1 + \frac{ec}{r^2}\sec\left(\sqrt{\frac{P}{EI}}\frac{L}{2}\right)$$

$$= \frac{3480}{2.228}\left[1 + \frac{0.3064 \times 0.835}{3.789^2}\sec\left(\sqrt{\frac{3480}{30022800 \times 8.442}} \times \frac{7.83}{2}\right)\right]$$

$$= 1589.77\ psi$$

The max stress value can be seen in the SolidWorks FEA picture. The SolidWorks FEA gave values between 0.8 to 2010.7 psi. Therefore, the above calculation for max stress on the lower part of the leg support is accurate and with the yield strength of 201 stainless steel, being 42351.02 psi and the allowable stress being sixty percent of yield (25,950.61 psi) the leg support should not fail.

Appendix E.1.5: Determination of Dynamic Loading Force

The determination of the dynamic loading force is calculated below. Refer to Figure E.5 for the layout of the dynamic loading force.

Assume:

- Initial Velocity: $V_0 = 0 \ {}^{ft}/_{s}$
- Velocity just before the human body touches the seat: v_1
- Final velocity after human body touches the seat: $V_2 = 0 \ {}^{ft}/_{s}$
- Weight: m = 500 Ibf ÷ 32.2 ft/s2 = 15.528 lbm
- Height: h = 8 feet
- Distance: S = h/2 = 4 feet
- t = 0.1 seconds, time from v_1 to v_2 . also known as the sudden stopping time (impact time)

From V_0 thru V_1, the body is under the gravitational force. During this time the body is in free fall with an acceleration of: g = 32.2 ft/s2 = 9.81 m/s2.

$$V_1^2 = V_0^2 + 2gS = 0 + (2 * 32.2 * 4)$$

$$V_1^2 = 257.6$$

$$V_1 = 16.05 \ \frac{ft}{s}$$

When the human body impacts the seat, the deceleration is:

$$a = \frac{V_2 - V_1}{t} = \frac{0 - 16.05}{0.1} = -160.5 \text{ ft/s2}$$

Therefore the gravitational ratio of the deceleration is

$$G = \frac{160.5}{32.2} = 4.98$$

$$f = 15.528 \ lbm * 160.50 \frac{ft}{s^2} = 2492.244 \ lbf$$

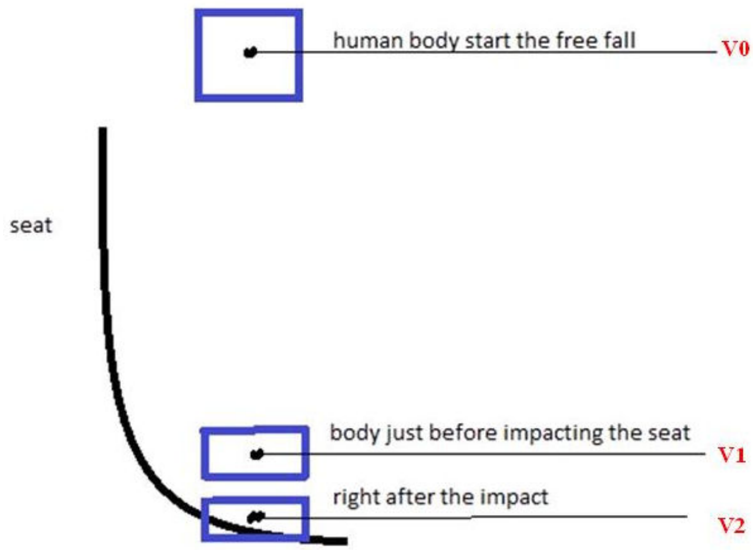


Figure E.5: Diagram of Dynamic Loading Scenario

The Team analyzed the LSS components using FEA for the dynamic loading of 242.244 lbf. The LSS failed when the analysis was conducted. The Team noticed that the currently used LSS were less bulky than the final design detailed in this report. More dynamic analysis needs to be done to make sure the final design parts will not fail in service and a reasonable dynamic loading needs to be used in the analysis.

Appendix E.2: FEA Analysis

SolidWorks was used to conduct the slight dynamic loading analysis for the LSS components. The findings are detailed in the following section.

Assume:

- FEA Loading for the slight dynamic loading on the plate 2P = 3480 lbs
- The allowable stress for 201 stainless steel is 60% of the yield strength therefore σ_{all}=0.6*42351.02 psi = 25,950.61 psi
- Green arrows show the fixed part of the plate and the purple arrows show the applied forces and direction

Appendix E.2.1: Adaptive Plate

A SolidWorks FEA analysis showing the stress concentrations within the plate is shown in Figure E.6. This analysis was done with a static load of 1740 lb_f. Using the hand calculations, the directional forces were found. The force in the vertical direction is 1360 lb_f and the force in the horizontal direction is 3204 lb_f. Due the fact that most of the force in the direction parallel with the aisle would be applied to the back of the chair, there would be little shearing force in the direction parallel with the aisle so the force was taken as the static load force of just 1740 lb_f. Using the previously mentioned forces, the maximum stress that the 201 annealed stainless steel plate experienced was 34,207 psi. With the Yield Strength of this material being 42,351 psi, this confirms that this plate would feasible to withstand such loads.

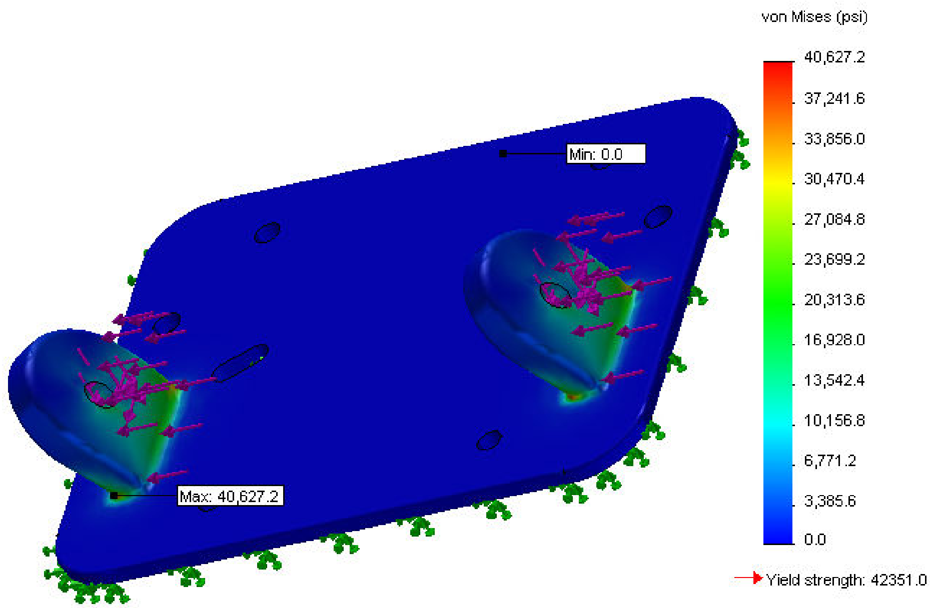


Figure E.6: Contour Plot of VonMises Stress in the Adaptive Plate

Appendix E.2.2: Upper Part of Leg Structure

the area on the upper part of the leg structure was treated as an asymmetric column under compression with applied forces and fixtures as shown in Figure E.7. The FEA analysis, conducted using SolidWorks, shows eccentric buckling with the corresponding minimum and maximum stresses felt by the asymmetric column. The max stress that was calculated on the upper part of the leg structure was 23,991.60 psi (Figure E.7). The max stress is below that of the yield stress for 201 stainless steel. Therfore, the column should not fail. The stress analysis for the lower part of the leg structure is not shown in the report because it was similar to the upper leg and the upper leg was determined to be the worst case senario out of the two parts. The deflections on the upper part of the leg structure are a maximum of 1.995×10^{-2} inches and a minimum 3.937×10^{-32}inches. The lower part of the leg structure was determined to have similar deflections.

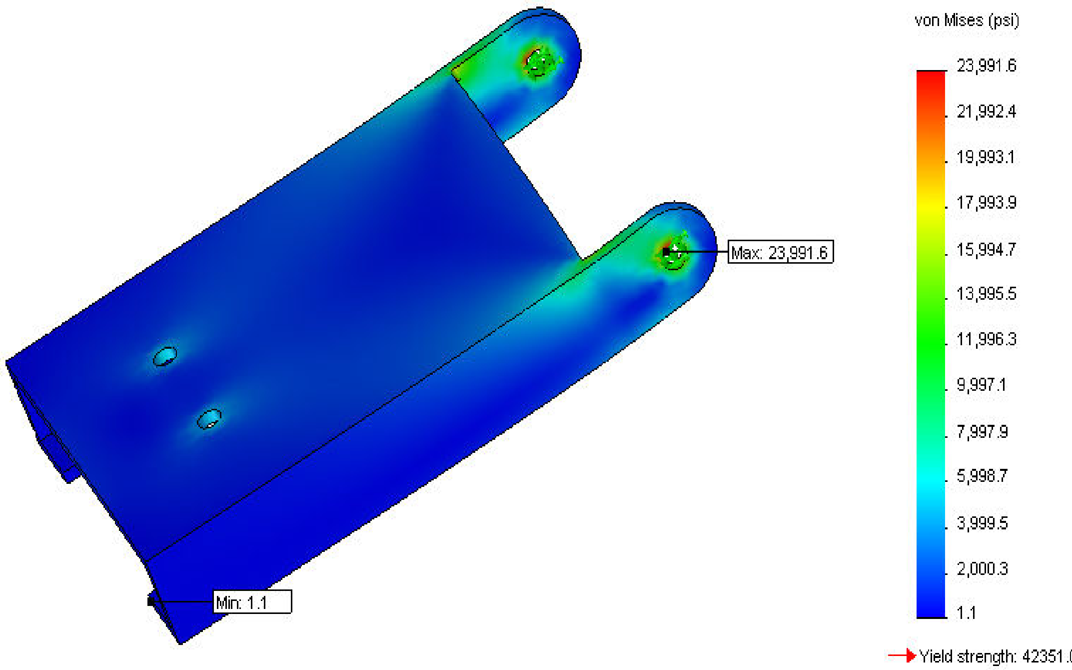


Figure E.7: Contour Plot of VonMises Stress in the Upper Part of Leg Structure

Appendix E.2.3: Leg-to-Bus Joint

The leg-to-bus joint was analyzed under compression with applied forces and fixtures as shown in Figure E.8. The FEA analysis shows applied forces and the corresponding minimum and maximum stresses felt by the leg-to-bus joint. The max stress that was calculated on the upper part of the leg structure was 5907.6 psi. The max stress is below that of the yield stress for 201 stainless steel. Therfore, the leg-to-bus joint should not fail. The deflections on the leg-to-bus joint are a maximum of 7.955×10^{-4} inches and a minimum 3.937×10^{-32}inches.

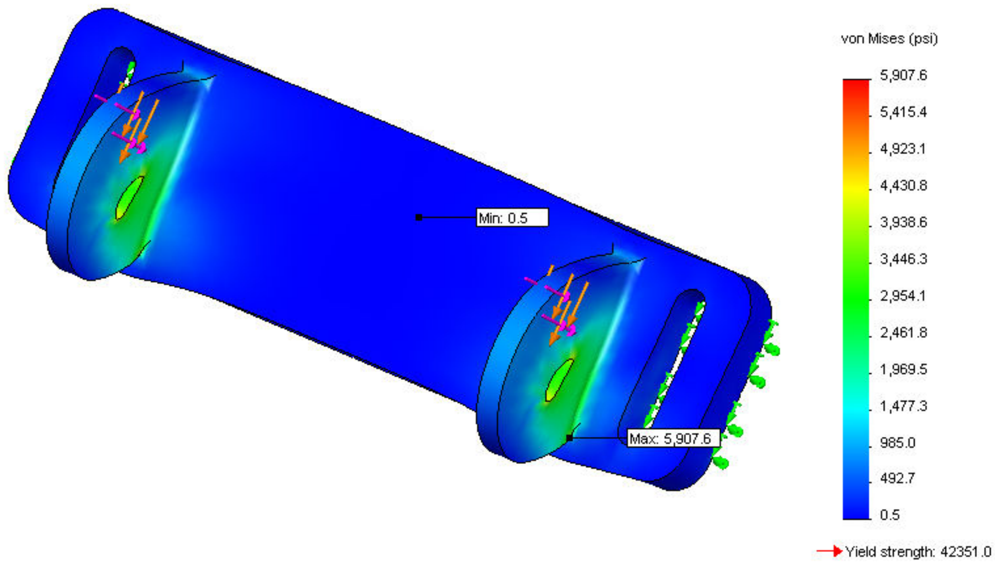


Figure E.8: Contour Plot of VonMises Stress in the Leg-to-Bus Joint

Appendix F: Design for Failure Modes Effects Analysis

During the process of finalizing the LSS design the design failure modes and effects analysis (DFMEA) concepts were implemented. The DFMEA factors and implementations are an important part in optimizing the design and assembly.

DFMEA [9] was conducted on the LSS and each LSS component adaptive plate, leg structure and leg-to-bus joint. The DFMEA helps to determine failure modes in the design and determine the steps to take in the mitigation of the failure modes. The Team conducted an iteration of the DFMEA and reduced the risk priority numbers (RPN) that were determined to be a concern based on the Team's discretion. The DFMEA analysis is presented in Table F.I, Table F.II, Table F.III and Table F.IV.

TABLE F.I: DFMEA ON APDAPTIVE PLATE

TABLE F.II: DFMEA ON LEG STRUCTURE

TABLE F.III: DFMEA ON LEG-TO-BUS JOINT

TABLE F.IV: DFMEA ON LSS

Appendix G: Design Drawings

The design drawings detail the LSS components as well as the whole design. The drawings are for manufacturing and engineering purposes and are detailed in Figure G.1, Figure G.2, Figure G.3, Figure G.4 and Figure G.5.

Figure G.1: Adaptive Plate Engineering Drawing

Figure G.2: Leg-to-Bus Joint Engineering Drawing

Figure G.3: Upper Part of Leg Structure Engineering Drawing

Figure G.4 Lower Part of Leg Structuret Engineering Drawing

Figure G.5: Lower Support Structure Assembly Drawing

Appendix H: Assembly Details

The details of the assembly are featured in the following appendix subsections. The details include the assembly instructions, LSS assembly weight and the Design For Assembly (DFA) analysis that was done on the LSS.

Appendix H.1: Assembly Instructions

For the ease of assembling the LSS a set of simple instructions was put together. The assembly instructions, shown in Table H.I, should be used as a guideline and for New Flyer employees to use when assembling the LSS to the seat. The mounting of the seat to the bus is not covered in these instructions.

TABLE H.I: ASSEMBLY INSTRUCTIONS

Step Number	**Assembly Step**
1	Adaptive plate oriented on seat
2	Mount adaptive plate to seat using appropriate fasteners that were provided with the original seat package
3	Loosely mount top leg structure to hinges of adaptive plate
4	Loosely mount bottom leg structure to upper support leg
5	Loosely mount the bottom leg structure to the leg-to-bus joint
6	Assembly ready to mount to bus

Appendix H.2: LSS Assembly Weight

The weight of the LSS was calculated automatically using a feature available in SolidWorks. The LSS was assumed to be made of 201 stainless steel. The weight of the assembly and corresponding components is detailed in .Table H.II.

TABLE H.II: WEIGHTS OF LOWER SUPPORT STRUCTURE COMPONENTS

Part	**Weight [lbs]**	**Volume [in^3]**
Adaptive Plate	5.44	19.17
Leg-to-Bus Joint	4.04	4.23
Leg structure Lower Part	11.46	40.35
Leg structure Upper Part	5.19	18.29

Appendix H.3: Design For Assembly

DFA involve concepts that are based on making products quick and easy to assemble and reduce the amount of input required from the design engineer for the assembly [8]. In depth DFA analysis can be complete if assembly times are available [8]. The in depth DFA requires the time for each part to be assembled to be recorded and for the description of the operation done on each part. The assembly procedure can then be analyzed to reduce time and part handling steps. The information regarding the analysis of the assembly was not available to the Team because a prototype of the final LSS design was not built and or tested for various trials of assembly to the four seats the assembly is designed for. The in depth DFA analysis can be conducted at a later date when prototypes are built.

DFA concepts that were evaluated for the LSS were access for assembly of components, limit adjustments to be made, mistake proof design, use of standard or common parts, design modular products and reduce connections [8]. Access for assembly of components was implemented in the design of the adaptive plate holes, hinges and the leg structure. The adaptive plate holes and hinges were placed so that the wrench and socket sizes listed in the Machineries Handbook [7] had enough room for easy installation of bolts. The leg structure was built with an opening at the bottom to have easy access for bolt installation and leg adjustment purposes.

For the DFA concept to limit adjustments, the team found this to be difficult to implement in the leg structure because the leg structure must adjust for the seat to be seated at any track position for both the upper and lower bus decks. Therefore, the LSS adjustability was determined to be a necessity for the project to be a success. The adjustments were limited for the adaptive plate assembly to the seat because the plate was placed the same distance away from the wall for the three seats that use the plate. Due to the plate being assembled the same distance from the wall the adjustments needed for the leg structure was reduced. To incorporate a mistake proof design the adaptive plate was built as a square so that there is symmetry to the assembly.

The use of standard or common parts and design of modular products was the foundation for the design. The standard and common parts used would reduce learning curves, cost and time associated with assembly and manufacturing. To reduce the connections required in the design, the Team used the current seat mounting holes to attach the adaptive plate. The design of modular products was what the design of the LSS achieved and therefore met the requirements for DFA and NFI's needs.