SECONDARY AIRLINE MOBILITY DEVICE

Final Report - BME Design 301

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TEAM MEMBERS:
Project Leader: Will Fox
Communicator: Grant Karlsson Ellifson
BSAC: Jonathan Evans
BWIG: Desiree Flouro
BPAG: Jonathan Evans

ADVISOR:
Dr. Ed Bersu

CLIENT:
Dan Dorszynski

Abstract

There is a need for a device capable of simplifying transportation for wheelchair-bound individuals during airline travel. Currently, individuals who use wheelchairs must be manually lifted from their personal chairs into specialized airline wheelchairs, and then into their seat. These transfers can result in injuries and embarrassment for individuals with disabilities. Our device would reduce the number of transfers, and overall time required during travel for disabled individuals. This semester's work built on the previous semester's prototype with the goal of providing additional functionality and safety. The design utilizes a steel frame with locking hinges to enable to device to fold down to a size compatible with a standard overhead bin. The new design is stronger, lighter, and can be stored more compactly. Additionally, seat cushions were revamped, and a seatbelt was added to the design. We tested the device based on the Business and Institutional Furniture Manufacturer's Association chair standards. After completing the tests the device was found to be safe, durable, and structurally adequate.

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I. Introduction

Currently, airline travel for disabled individuals is inefficient and stressful. Disabled passengers travel less often than their able-bodied counterparts, while also citing more problems at the airport [1]. The Air Carriers Access Act prohibits discrimination on the basis of disability with regards to airline travel. This prevents seat discrimination on the basis of disability, limiting the number of persons with disabilities on a flight, general accessibility of facilities, and the provision of services and other accommodations, among many others [2]. Despite this, thousands of complaints are filed with the U.S. D.O.T. every year, with more than 32,000 complaints being received in the year 2016 [see Appendix B]. Of these complaints, more than half were from wheelchair-bound passengers complaining of a failure of the airline to provide them with the proper assistance [3].

Airplane boarding practices are a large area of concern for wheelchair-bound passengers. Boarding typically requires multiple transfers of the passenger from a personal wheelchair to a specially designed aisle chair that can fit through the narrow airplane aisles. The passenger must then again be transferred from the aisle chair to their seat on the plane, with the entire process being reversed upon landing. These transfers are typically carried out by airline staff who lack the proper training. If performed incorrectly, these transfers can be embarrassing, or dangerous to the passenger, with drops occurring regularly. Due to these issues, we have been tasked to create a device that will limit the number of transfers required during the wheelchair boarding process and to improve the accessibility of airline travel for the disabled population.

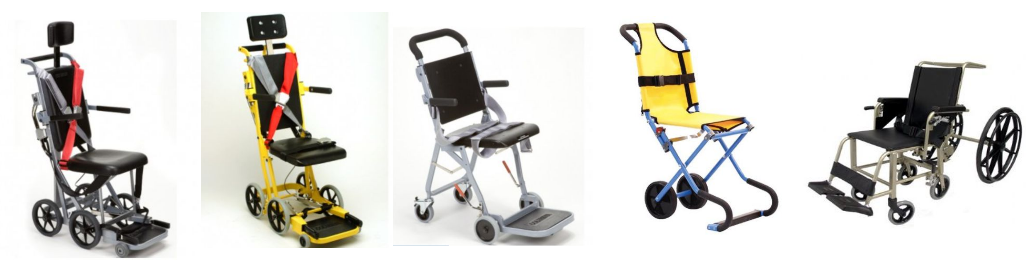
II. Background

Existing Devices

FAA restrictions on airplane designs require that aisles must be greater than 15 inches wide, and that transfer devices can't be sat upon during flight [4,5,6]. This narrowed our scope to strictly eliminating the first transfer from the user's wheelchair to the airplane chair. Further research revealed that most airlines allow stowable chairs and transfer devices to be stowed on the plane during the flight, potentially allowing our client to access our chair immediately upon landing [7]. We concluded that a foldable chair that eliminates the first transfer would be beneficial to our client while following airline restrictions.

There are currently a number of companies that produce different models of aisle wheelchairs, and the table below gives a comparison of five of these commercially available chairs. All of the devices are comparable in width as well as weight capacity. Models 1 and 2 represent the highest end aisle chairs available, as they visibly have the most robust design and highest quality safety features. However, these models weigh more than twice as much as other existing devices. In the case of model 1, this robustness comes at the cost of collapsibility. Models 3 and 4 are lightweight chairs whose designs focus on collapsibility. Interestingly, both claim to support more weight than any of the other chairs (440 lbs), despite their considerably lighter weight, and in the case of model 4, considerably lower cost. Model 5 is a more novel solution to wheelchair user airplane access, as it is a traditional self-propelled wheelchair with the ability to convert to an aisle chair. The specifications on the actual aisle chair portion of the convertible chair are comparable to the others. Cost is an issue with the existing devices. With the exception of model 4, a cost of over $2,000 makes the purchase of these devices cost prohibitive to the average disabled passenger, and represents a significant investment for airlines and airports.

While these current wheelchair models can move a disabled passenger through the aisle of an airplane, they do not address the issue of transfers. Model 5 eliminates half the transfers, however this design would be inapplicable for persons using electric wheelchairs instead of traditional, self-rolling wheelchairs. Mobility throughout the cabin mid-flight is another common obstacle. Models 1 and 2 are larger, heavier, and their robust design makes them inappropriate for in-flight use. While models 3 and 4 are lighter and designed to be stowable, their overall size still makes them difficult to access and use in practice.



	(1) AisleMaster Unfoldable Boarding Wheelchair	(2) TravelAide & RescueMate Transfer Chair	(3) Aislemaster TransportMate Compact Wheelchair	(4) CarryLite Evacuation Chair	(5) Karman Aisle Wheelchair/Transport Chair (mid-conversion depicted)
Width (in.)	13-16	16	16	16	15
Weight (lbs)	40	36	16.7	16	29
Weight Capacity (lbs)	400	300	440	440	300

Notable Features	Moveable armrests, double shoulder straps	Moveable armrests, double shoulder straps, collapsable	Collapsible, waist strap	Collapsible, single chest strap	Convertible from traditional to aisle wheelchair
Cost	$2,650	$2,400	$2,100	$699	$2,199

Table 1. Comparison of five existing aisle wheelchairs. Although more aisle chairs/manufacturers exist, these five chairs represent general solutions for handicap airline travel now commercially available.

Client Information

Our client, Dan Dorszynski, approached us with the problem outlined above. Mr. Dorszynski has muscular dystrophy and is confined to a wheelchair. He relies on the current transfer methods to travel by plane. He travels 3-4 times a year because of his career in computer graphics service, and experiences accessibility issues almost every flight. He has asked us to build a secondary mobility device that can be used on airplanes in order to create a safer, more accessible option for passengers that use wheelchairs.

Design Specifications

Our design should eliminate as many transfers as possible. It will consist of a secondary device that can be sat upon while placed on top of our clients wheelchair, and used independent of our clients wheelchair. The chair should have a width of 15 inches or less, support up to 720 pounds and be approximately the height of an airline seat to aid in the final transfer required. The design should require minimal upkeep and maintenance, be easy to use for airline attendants, and not be heavier than 50 pounds. A detailed explanation of these specifications can be found in the appendix.

III. Fall 2017 Prototype

Materials

- 2 x T-slotted Extrusion, 15s, 72” Lx1.5” H
- T-slotted Extrusion, 15s, 72” Lx3” H
- 2 x Pivot Joint, 40 Series, Width 1-9/16 In.
- 16 x Hidden Corner Connector: Inside-Inside

- 15 x M6 Slide-in Economy T-Nut - Centered Thread
- 4 x Threaded Stem Swivel Caster: 7/16-14 x 1.5"
- 2 x 80/20 Handle,15 & 40 Series,Width 1 In.
- 5 x ⅜” bolts
- 1 ⅜”-16 nut
- 2’x2’ 3” Plywood
- 36 sq. feet Cotton Fabric

We decided on 80/20 as the main material of our prototype for a variety of reasons. Aluminium is a relatively easy metal to work with. The T-slotted profiles also simplify the fabrication process. Additionally, 80/20 manufactures a variety of different fasteners, casters, and the other materials necessary to build this initial prototype. This makes the sourcing of materials a simpler matter as a majority of them are coming from the same manufacturer. A material such as steel would’ve likely been much heavier and required a significant amount of welding, while a more novel material such as carbon fiber would’ve been out of our budget, and difficult to machine.

Methods

Our prototype fabrication began by constructing the frame out of the 80/20 aluminium extrusions. These 1.5” x 3” extrusions were cut into four pieces: two were 11” long and two were 22” long. These components were then connected utilizing the inside-inside 80/20 connector pieces to form a rectangular frame. The 1.5” x 1.5” extrusions were then cut to form four 12” long segments to form the legs, and 2 18” long segments to form the backrest.

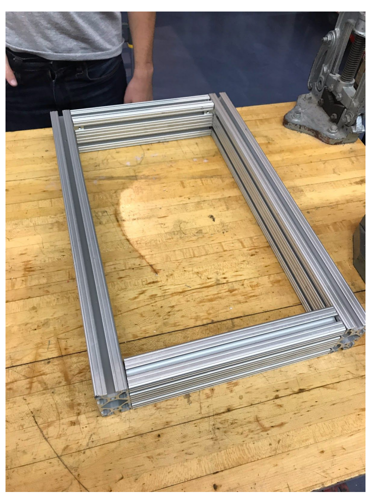


Figure 6 (left): Cutting of the 80/20 extrusions using a drop saw.

Figure 7 (right): Four pieces of seat frame following cutting 1.5” 3” extrusions.

The cross bar for the backrest was cut to a length of 14”, and the cross bar for the rear legs was cut to a length of 6.75”. Both were cut from the 1.5” x 1.5” profile. These extrusions were connected to the frame using inside-inside connectors from 80/20. After our redesign failed in testing, the rear frame was connected using ⅜” bolts through holes that were drilled and tapped to a ⅜-16 threading size.

Figure 8: Tapping of the upper portion of the legs to allow for the attachment of the hinge. Hole for wheel has already been expanded and tapped, with wheel attached in image.

After the sample frame was built, the legs were drilled to a depth of 1.5 inches and tapped with a 7/16-14 tap to accommodate the threaded stem swivel casters. The wheels were then attached to the legs, and the front legs were connected to the frame using the inside-inside connectors from 80/20. The rear legs were connected to the frame using our two pivot joints which were bolted into the frame.

Figure 9: One of the rear legs attached to the back portion of the chair frame.

Next, the backrest and seat were created by first cutting plywood to size using a table saw. This was accomplished by simply lining up our purchased pieces of 2x2 plywood with our frame and sketching the guidelines directly on the wood. It was then fixed onto the frame by drilling into the wood with a 5mm drill bit. The four drilled holes were positioned to line up with the track in the 80/20 extrusions. They were then affixed using four M6 x 1 bolts and four 80/20 brand M6 T-nuts. The process was repeated to build the backrest. The dimensions of the backrest plywood was 14.25” x 18.5”. The dimensions of the seat plywood were 20.25” x 14”

After the backrest and seat were built, we proceeded to cut the foam to size. The foam size was determined by positioning it over the cut pieces of wood, creating an outline, and then cutting to this outline. The foam was then covered in cotton fabric and the pads were then affixed to the wood seat and backrest using Command hanging strips. We then proceeded to attach handles with M6 x 1 screw head bolts connecting into the 80/20 frame and tightened into M6 T-nuts.

The next step of fabrication involved creating the locking mechanism. We created brackets out of stock aluminum sheet metal which were cut and drilled to length. Next we cut the stabilizing 1.5” x 1.5” extrusion to a length of 6.25”. Following that we procured an 8” long ⅜-16 bolt and a ⅜-16 nut. The two manufactured brackets were attached to the frame using M6 x 1 bolts and M6 T-nuts.

The final step of fabrication was installing the holder for the locking mechanism This was accomplished by cutting a 1” diameter PVC to a length of 6” and fixing to the back of the design with hot glue. To manufacture the locking mechanism extrusion holder, we drilled through the wood backrest using a U drill bit and attached an M6 T-Nut to a M6 x 1 bolt. The T-nut was then affixed in a vertical orientation.

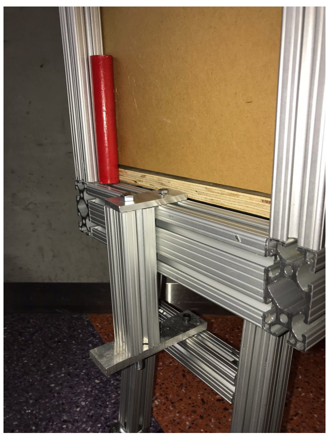


Figure 10: Completed final locking mechanism with attached holder in place.

Final Device from Fall 2017

The final prototype of our design is 14” wide, with a seat height of 18”, and a total height of 36”. Its main features include the rear legs attached on hinges that allows them to fold flush into the bottom of the seat frame. Each of the four legs has a 4” diameter caster that can turn in any direction, with brakes on the front wheels. On the back of the device, seen in Figure 12, there is a locking mechanism that is implemented when the device is taken off of the client’s wheelchair, in order to prevent the back legs from folding when the chair is in motion. To aid the attendants who will be using the locking mechanism, there are laminated directions with pictures posted on the back of the chair.

Figure 11 (left): Final design with rear wheels folded down

Figure 12 (right): Final design sitting atop the client’s wheelchair with rear wheels folded into place underneath the seat.

Testing

The first phase of our testing was through SolidWorks. A SolidWorks model of the initial design was created, and each leg of this model were tested using a force of 1000 lbs compression. This testing was done to ensure the legs could withstand a worst case scenario compression. SolidWorks testing was only performed on the legs as incorporating full joints into assembly wasn't plausible.

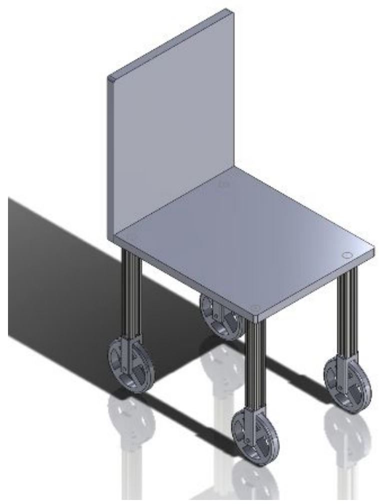


Figure 13: Assembly of individual SolidWorks parts into final design

Following fabrication, testing consisted of static load tests and mobile load tests as a method of evaluating the preliminary locking mechanism. The static load test involved the loading of the seat with weight, and evaluating the joints for any sign of fracture or failure. Our client desired the chair hold 250 pounds, and 305 pounds were applied to the prototype. A higher factor of safety wasn't achieved due to the desire to present the prototype to the client intact. The mobile test consisted of loading the chair with weight and moving the chair forwards. 200 pounds were applied to ensure the device could function with loading. This dynamic test was applied as the chair moved forward, backward, and turned at different speeds.

Figure 14 (left): Static load test with 305 lbs loaded onto the chair.
Figure 15 (right): Mobile load test with the weight of 155 loaded onto the chair.

In addition an impulse loading test was performed on the front legs. This impulse loading test was performed by rapidly applying and removing a force of 155 pounds to the front wheels. The test was performed to simulate the wheels hitting a small bump in the airport. The impulse loading was applied 15 times over a 30 second period.

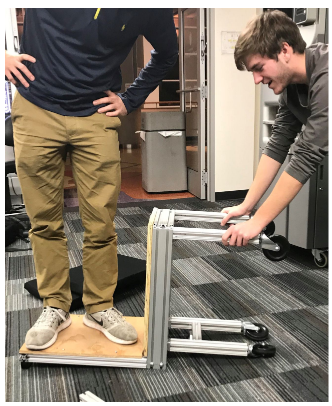


Figure 16: Impulse loading test using weight of team member

Results

SolidWorks testing showed that each leg individually could hold 1,000 lbs of compression without any risk of fracture or failure. Initially, the fully fabricated device was able to support 200 pounds statically, but during the mobile tests two failures occurred. The first was the failure of our locking mechanism. The locking mechanism failed as a result of of the rear legs rotating past 90 degrees and transferring the load from the seat onto the bolt. The second failure was the fracture of two of the inside-inside connectors on the joints of the seat frame. Following redesign and reapplication of our different testing scenarios, the device was able to hold a static load of 305 lbs, as well as a mobile load of 200 lbs without any noticeable failure. Additionally, the 155 lbs impulse loading tests on the front legs of the device showed no noticeable deformations.

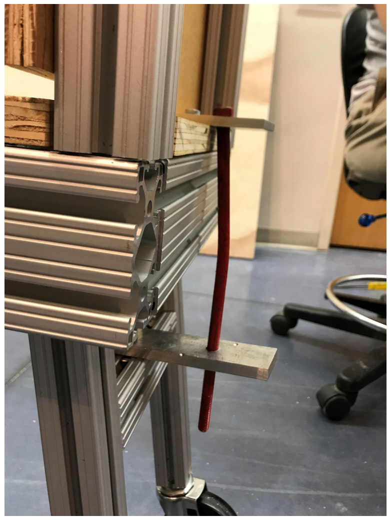
 

Figure 17 (left): The results of our initial test of the locking mechanism. The bolt shows significant bend and led to a redesign of the bolt.
Figure 18 (right): Failure of internal fasteners on the joint of the seat frame, leading to considerable redesign work.

IV. Preliminary Design Improvements

Several aspects of the previous prototype needed to be redesigned. Most of the actual materials used to construct the previous device will not be reused with the new iteration of the device, however some of the ideas and mechanisms will be brought over and improved upon. The major areas of focus for this semester included the folding mechanism for the back set of legs, the seat cushion, and the capacity of the device to fit within an overhead bin on a standard airplane.

Improvement 1: Collapsibility

An issue with the prototype was its lack of collapsibility. Due to its size, the prototype could not be stowed in an overhead compartment for use during flight, or for use immediately after flight. In order to maximize collapsibility, the front legs, rear legs, and back rest will all have foldable hinges so that the chair can collapse and be stored in an overhead compartment during flight. The front legs, back legs, and backrest will collapse using joints that will lock in place at 90 degrees and 0 degrees. The backrest will fold on top of the seat, and the legs will fold underneath the seat pan. The combination of these hinges will create a secondary chair that can bear weight and collapse for easier storage.

Improvement 2: Seat Cushion

The previous chair design used a foam slab to provide a cushion on top of the aluminum frame. One of the goals for this semester is to improve the comfortability of the device, along with providing a seat that allows one to slide on and off the device with ease. The proposed improvements to the seat cushion include building an entire seat from scratch, using a weight bench design as a guide. The cushion will include multiple layers of carpet foam along with a final layer of headliner foam and a vinyl wrap to give the outside a clean appearance as well as provide low friction to the user. The marine vinyl wrap will also increase the durability of the cushion by waterproofing it. The same procedure will be used to create a cushioned backrest. The vinyl wrap was requested by our client to aid in transferring into and out of our device.

Improvement 3: Steel Frame

The frame used in the fall prototype was made of aluminium extrusions. These were very strong, and where shown in mechanical testing to be at a minimal risk of buckling or any other form of failure. One downside to these extrusions was their weight. The weak point of our design was the connections between the extrusions. These were prefabricated connectors made by 80/20, and through our testing they proved to lack the proper strength for our purposes. In an effort to improve the strength of our frame, this semester we will use steel tubing to manufacture our frame, and will weld it together, rather than using aluminium connectors. The steel tubing will be lighter than the aluminium extrusions from the previous semester. The combination of using steel and welding our frame should reduce the weight of our design, while increasing the maximum load it can support.

Improvement 4: Seat Belt

The prototype from last fall lacked many safety features. One of these features was a basic seatbelt. After researching prefabricated seat belt options, it became clear that there were 4 options available. The seatbelt could either be retractable, or non-retractable, and it could have a latch buckle, or a button to release the buckle. We presented these options to Mr. Dorszynski, and he informed us that having a retractable option with a latch buckle would be ideal. We will be using this option in our final design.

Improvement 5: Footrest

The client expressed a desire to include a simple footrest to the device. This will aid the client during transportation as his feet will not be dragging or get stuck and cause damage to his legs while being transported on this secondary wheelchair. The plan is to attach a basic, folding footrest to each leg in order to continue with the goal of minimizing the size of the device during storage. Adding a footrest to the design will provide additional comfort to the user during use of the device.

V. Preliminary Design Evaluation

Many criteria were considered with each design improvement option and was weighted during the evaluation of each. However, the majority of the design improvements did not require a design matrix because many of the options did vary significantly in their specifications . A design matrix was also not used since the team knew what needed to be improved and how those improvements were going to be made. The specific improvements of focus this semester include the collapsibility of the entire wheelchair and the backrest, the frame material, and adding safety and comfortability mechanisms. As a team it was decided that these improvements were necessary because the current design was not fully collapsible and was excessively heavy. The prototype also did not include a safety belt or footrests, and had a seat cushion that was not comfortable or practicle for different uses.

Collapsibility indicates the capacity of the device to fold the back legs with ease during wheelchair transfers along with its ability to be stored in an overhead compartment of a standard airplane. Ideas for improvement included the addition of simple locking hinges to each of the legs and backrest. This improvement will streamline the use of the device during wheelchair transfers. A folding backrest is also needed so that the device can be stored in the overhead compartment. This improvement will allow the client to have access to this device as soon as the plane lands instead of having to wait for the attendants to get a different wheelchair to transport him.

The second improvement includes the fabrication of cushions for the seat and backrest of the device. Our client expressed desire for a cushion that is waterproof and that provides low friction, allowing him to slide on and off the seat with ease. This being said, the team will use a weight bench idea for the cushion as well as the backrest. The cushion will consist of multiple layers of carpet foam along with a final layer of headliner foam and a vinyl wrap to make the cushion waterproof and frictionless.

The third improvement involves making the frame out of steel. The last design was made with aluminum, which had the strength the device needed, but made the device too heavy. This semester, the team wants to improve on the aluminum connections by taking them out and replacing them with a steel tubing that is welded. Using steel will lighten the device, allowing it to be lifted into the overhead compartment of an airplane.

The fourth and fifth improvement of adding a seat belt and footrests are needed to provide safety and comfortability. Last semesters device lacked both a seatbelt and footrests. The seatbelt is essential to provide safety to the client and ensure he does not fall out of the device. The footrests are wanted by the client so that he does not have to drag his feet on the ground.

Both the seatbelt and footrests will ensure that the client is comfortable when using this device and will lower his risk of getting injured while in the device.

VI. Fabrication of Spring 2018 Design

Materials

- 3x Tubing, Sq, 1015 LCS, 1 OD x 1/8 In T, 6 Ft L
- 3x 2 PCS Heavy Duty Stainless Steel Folding Bracket
- 2 Point Retractable Lap Belt With Chrome Lift Latch
- 2'x 4' ¾ in. Plywood
- Carpet Padding, 24 sq. ft.
- Headliner Fabric, 5 sq. ft.
- Vinyl, 12 sq. ft.
- 6 x 7/16"-14 Nuts
- 4 x Threaded Stem Swivel Caster
- 2 x 1.5" Threaded Rod 7/16"-14
- 14" x ½" Stainless Rod

A low carbon steel tubing was chosen as the final material for fabrication of the seat frame. The use of this steel allowed our design to be MIG welded using the facilities available on campus. The steel chosen was less expensive than the aluminum extrusions used in 2017, and has a reduced linear density, thus reducing the weight of our frame. The steel also has an increased yield strength when compared to aluminium. While steel is more difficult to fabricate than aluminum, the advantages listed above outweighed any fabrication concerns, and led to the use of steel in our final design. The only component of our design the was reused was our casters. These were reused to reduce the cost of our prototype, and because they were easy to integrate into this semester's final design.

Methods

Fabrication of the frame began by measuring and cutting our steel tubing. We cut the tubing into 4 x 20", 2 x 14", 2 x 19", 1 x 12", 4 x 15", and 1 x 6" lengths. We also cut the ½" stainless rod to a length of 14 inches. Burs from these cuts were then filed, and the carbon steel was sandblasted to remove and surface contaminants that would affect the quality of the welds.

The next step in fabrication was building the seat pan. The seat pan was to be 14" wide, and 22" long. As shown in our Solidworks model, this was accomplished by welding the two 14" steel lengths in a rectangular shape with 2 of the 20" steel lengths. 2 additional 20" steel lengths were added to the inside of the frame to serve as anchor points for the front wheel hinges. This was done by using the precision welding table in the TEAM Lab. These welds were done with Argon gas, 20 volt power, and a 220 wire speed setting.

After the seat pan was welded, the backrest was attached. This process started by welding the backrest hinges onto the seat pan, and then welding the 2 19” steel lengths onto the hinges. After these posts were placed, a 12” steel cross beam was welding to the top of the posts. These welds also utilized the precision table in the TEAM Lab. The settings for welds involving the stainless steel hinges were 18 volt power and 180 wire speed. The settings for welding the cross bar were 20 volt and 220 wire speed. Argon gas was utilized for these welds as well.

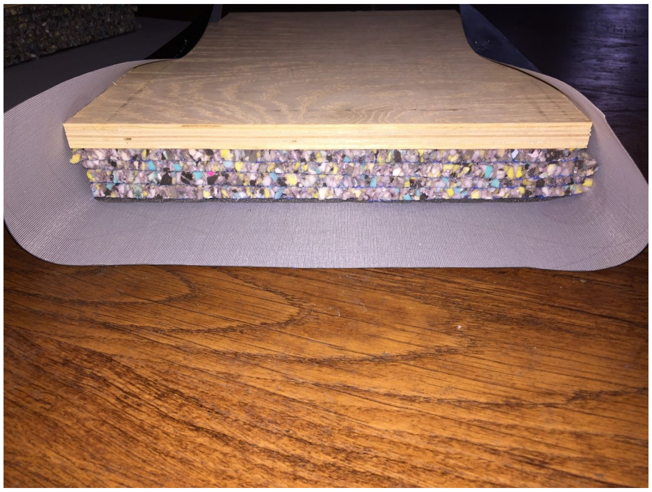
Once the back rest was attached, the hinges for the legs were attached to the frame using the same settings and process used for the backrest hinges. The legs were then welded onto the hinges. A 6” length cross bar was then attached to the front legs, and the 14” stainless rod was attached to the rear legs. 20 volt and 220 wire speed were again utilized for attaching the cross bars. Once the legs were attached, the two 1.5” threaded rods were welded the the side of the seat pan, and the seatbelt was fixed using 2 of the 7/16-14 nuts.

The wheels were then attached to the legs by welding 1 7/16-14 nuts inside each of the legs. The 4 casters were then tightened into the nuts on the inside of the legs. The front legs were then fixed by tack welding the casters bearings in place. The rears legs were then left free to swivel to aid in comfort while our device is on top of Mr. Dorszynski’s electric wheelchair. These welds were done using 20 volt power and 220 wire speed settings.

In order to create the seat cushions the ¾ in. plywood was first cut into two pieces, each 21 in. long and 14 in. wide. The individual boards were then cut down to size, with consideration of the height of the final height of the seat taken. The base board remained at the original dimensions, with two twelve-inch extrusions made along the length of the board, taking one inch off the width on each side. This was done to account for the placement of the hinges, which lie along the edge of the seat and the back of the frame.

Figure 19: Plywood bases cut to size. The seat and backrest are shown on the left and right, respectively.

Three-eighths inch carpet padding was then cut out to match the two plywood boards, with a final layer of headliner foam cut for each as well. The seat base contains seven layers of carpet foam, giving it a final height of approximately 2.75 inches with the headliner foam on top. The backrest contains only four layers of carpet padding, again with a final layer of headliner foam. Layers of carpet foam were adhered to the plywood and each other using Loctite Heavy Duty Construction Adhesive. Finally, each assembly was wrapped in vinyl, which was secured to the plywood with a series of staples.



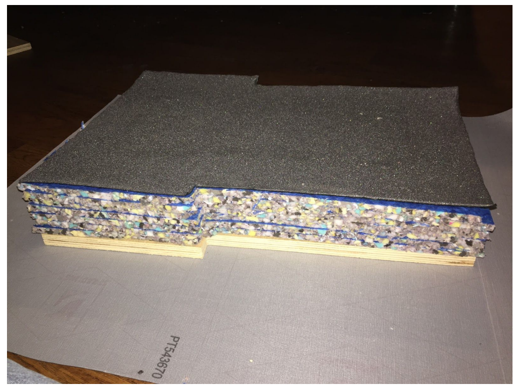


Figure 20 and 21: The layered foam on top of the plywood base for the cushion

Finally, the seat cushions were made removable from the frame. This was done by drilling two 1.5” long screws with 0.5” heads into the plywood so that the head would stick 0.5” out of the wood. This was done on both the backrest and seat. These screws were placed at the halfway point of each board and 0.5” in on both sides. They were placed at these locations, so they would overlap with the metal frame. Once the screws were attached, a 0.5” drill bit was used to drill into the metal so that the screwheads could fit through the holes allowing the cushions to be placed at a proper location. These cushions can be removed by lifting the cushions so screwheads leave the drilled holes.

Figures 22 and 23: The screws attached to the back of the wood to allow the seats to be removable.

VII. Testing of the New Prototype

Testing

The first phase of the testing was through SolidWorks. A SolidWorks model of the design without the seat cushions and wheels was created to perform various tests. A SolidWorks analysis of the steel frame was conducted following the protocol for a buckling test with a 400 lb load. This test showed no signs of buckling or bending.

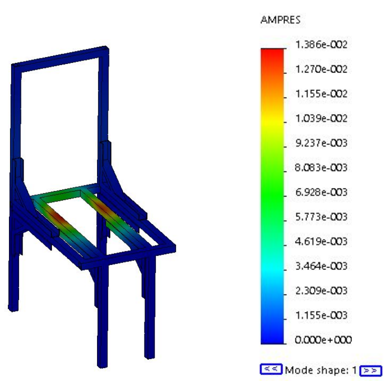


Figure 24. SolidWorks Testing

After frame fabrication was completed, the wheels were added, and the device underwent various testing using free weights. The testing for the device was based on the Business and Institutional Furniture Manufacturer's Association (BIFMA) chair standards tests. Eight out of the nine tests were performed on the device. The final test was not performed because it involved cyclic loading, which was unable to be performed due to the equipment constraints the team faced. The first performed test was the back strength functional load, in which a 150 lbs weight was applied to the chair back for a period of one minute. The next test was the back strength proof load in which a 250 lbs weight was applied to the chair back. The third and fourth tests that were conducted tested the stability. To test the stability of the back legs, a 173 lbs weight was set on the seat of the chair and the entire weight was transferred to the rear legs. To test the stability of the front, a 12 lbs force was applied to the front legs at a 45 degree angle. The device then underwent a chair leg strength functional load and proof load.

Figure 25: Chair leg Strength Proof Load Test

Figure 26: Chair leg Strength Functional Load Test

For these tests, a 75 lbs weight (functional load) and a 115 lbs weight (proof load) was positioned at the bottom of the front legs for one minute. These tests were then repeated on the back legs. The last two tests on the BIFMA standards included a chair drop proof and functional load. For the functional load, a 225 lbs weight was positioned 6 inches above the seat was allowed to free-fall onto the center of the seat. For the proof load, the same procedure was followed but with a 300 lbs weight instead of 225 lbs.

Figure 27: Chair Drop Proof Load Test

Finally the team wanted to test how much the device could actually hold. For this the team placed weights on the seat and stacked them. With the weights that were available, the chair could hold 440 lbs. If more were available, the team would have liked to keep adding weights to see how much the chair could hold.

Results

The SolidWorks testing showed no signs of buckling or bending of the frame. The device sufficiently passed each of the BIFMA tests without sudden failure or indication of structural failure. Each test showed complete structural integrity throughout the test. The wheelchair was also able to hold a load of 440 lbs with no structural damage. Therefore, the device was found to be safe, durable, and structurally adequate.

VIII. Discussion

Our design passed both the SolidWorks testing and the BIFMA testing, and it can be considered safe based on the preliminary testing we were able to accomplish. As of now, no mechanical redesigns need be made. However, this may not always be the case. Due to limitations of our facilities, further testing will be needed to ensure the viability of our design. In order to fully ensure its safety, BIFMA testing should be performed using BIFMA's machinery to ensure accuracy and to generate graphs that show deflection. These tests will fully show if our design qualifies as safe for industrial use. This design should also be used by our client during a future flight. This functionality test would demonstrate whether the design we created is viable and easy to use in a typical flying situation. After receiving further feedback from BIFMA and our client, we will be able to decide if our design is safe, or if it will require a redesign to ensure improved safety or ease of use.

This device, with further testing and development, could have a significant impact on the flying experience of disabled individuals. It could also have a major impact on airlines and their employees. Airlines should be especially concerned with the problems currently faced by disabled passengers. In recent years, many of the largest airlines, including American, Delta, and Frontier, have been fined for passenger rights violations. These fines have been substantial, sometimes being in excess of two million dollars [11,12,13]. Fines pertaining to lawsuits from disabled passengers represent the majority of these fines. The use of our device would not only increase the autonomy of wheelchair-bound individuals, but would also hopefully decrease the number of complaints and lawsuits filed by these disabled passengers against airlines. The size of these fines are significant, and eliminating them would have a financial benefit to the airlines serving these passengers.

IX. Conclusion

Currently, there is a need for a device capable of simplifying transportation for wheelchair-bound individuals during airline travel. Our device would shorten the overall time required during wheelchair transfers throughout travel. The design utilizes a steel frame with multiple hinges which enable the device to fold down to a size compatible with a standard overhead bin. This semester's work built on the previous prototype with the goal of providing additional functionality and safety. Seat cushions were revamped, and a seatbelt and footrests were added to the design. We tested the device based on the Business and Institutional Furniture Manufacturer's Association chair standards. After completing the tests the device was found to be safe, durable, and structurally sufficient.

Future Work

The final design still requires additional testing in order to ensure that the device is ready for public use without any fears of failure. Further testing includes repetitive loading and unloading of the device to analyze the long-term durability and following a second wheelchair-specific testing protocol, as the first set of testing was aimed at standard chairs. One goal for the project was to include a footrest which would be attached to the front set of legs. The team did not achieve this goal, however, and adding this feature would provide further comfort and safety to the user during standard transportation. The steel frame remains uncoated an aesthetically displeasing; thus another task is to add a polymer surface coat to the entire frame. This would add to the aesthetics of the device while preventing wear to the frame itself during use. The final step for this prototype is to test its use during actual transportation, and so the team would like to see how it handles in the field either during a mock-flight by one of the team members or the client himself.

Acknowledgements

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XI. Appendix

Appendix A. Product Design Specifications - Secondary Mobility Device for Airline Travel

Function:

Currently, airplane travel for disabled passengers is an arduous process, involving multiple wheelchair transfers, the assistance of untrained airline workers, and the potential for injury and embarrassment. The current procedures in place are inefficient and tedious, causing many wheelchair-bound individuals to refrain from flying at all. The procedure involves the lifting of the passenger from their wheelchair to a small, specially designed aisle wheelchair, and then another transfer from the aisle chair to the passenger's seat. The proposed device will work to eliminate one of the two transfers that are currently required when moving a disabled passenger from the jetway, through the aisle, and to their seat.

Client requirements:

- Minimize number of transfers during boarding process
- Minimize the number of airline workers/outside help involved during transfers
- Allow for foldability/stowability when device is not in use
- Including safety features such as a seat belt and/or footrests
- Design must fit over our clients existing electric wheelchair to streamline use in the airport

Design requirements:

- Must keep within current FAA and U.S Access Board Guidelines for Aircraft Boarding Chairs (detailed below in Standards and Specifications section)
- Proper safety belts/harness must be in place
- Chair height should be approximately equivalent to height of airline seats
- Cushion to be made out a waterproof material and allows for easy sliding

1. Physical and Operational Characteristics

a. Performance requirements:

Our device needs to be able to effectively roll and withstand the 250lbs weight of our client for multiple hours at a time. The device should be able to conveniently fold or condense to be stowed in flight. The device must be lightweight to enable ease of transportation during use. This device will be used approximately three to four times a year.

b. Safety:

The structure of our device must be able to withstand a load of 250lbs with a factor of safety of 3 [8]. Safety straps will be necessary to hold the traveler in place in case of any accidental incorrect movements. The client prefers a lap belt to other types of straps.

c. Accuracy and Reliability:

It is critical that our design perform consistent with the needs of our client. Failure to consistently support upwards of 250lbs and maintain our clients' stability could result in embarrassment, and could injure him as well. This performance includes supporting his weight, maintaining its balance, and allowing for easy transfers. The device must allow for an easy, safe transfer during every use as well as prevent any potential injuries to the client.

d. Life in Service:

Our secondary device should maintain mechanical stability, and be able to traverse a variety of surfaces for extended length and time durations. This will typically include attaching the device to his regular chair at home, traveling to the airport with it, and moving to the gate. At this point the device will then detach and act separately from the primary wheelchair. The time used will vary depending on his distance traveled from home to the airport of departure and from the airport of arrival to his destination. This device should be able to support our client for several hours.

e. Shelf Life:

The secondary device should maintain its ability to withstand our client's weight over long periods of disuse. It should require minimal to no maintenance during periods without use. Ideally, our device would be ready for use whenever our client requires it.

f. Operating Environment:

The secondary device should be able to support upwards of 250lbs. It should be available for use predominantly in an indoor environment, while also having the ability to be used in the outdoors as necessary. This requires it to maintain its stability when exposed to snow and rain, in addition to operating between the temperatures of 0 and 100 degrees fahrenheit. It should be able to move our client effectively on a variety of flooring surfaces including wood, tile, concrete, and carpeting.

g. Ergonomics:

It is important that the secondary device be comfortable for our our client to use over extended durations of travel. This comfort factor can include the use of similar seat padding, and a similar seat height to that of the client's wheelchair for comfort and to make transfers as easy as possible. The padding should be around 2 inches thick, have a vinyl coating and the seat height should be between 18 and 21 inches [6]. The device should also incorporate at least 1 strap for our clients stability while being moved. The device must not restrict or impede use of the electric chair upon which it rests.

h. Size:
Based on the nature of our device, size is an important restriction. The design must be able to transit a variety of plane aisles. This requires that the device have a maximum width of 15 inches from the floor to a height of 25 inches, and a maximum width of 20 inches from 25 inches in height and taller. If we choose to make the device compact enough to be a carry on it should be able to compress down to be smaller than 9”x22”x14” [2] , [3].

i. Weight:
There are no restrictions on weight, as long as the device can be easily pushed or pulled by an adult of average strength with a passenger. The device also has to be light enough to be folded and stowed for when the device is not in use. However, the overall weight should be minimized in accordance with airline boarding chair regulations [8].

j. Materials:
Any materials may be used as long as the parts comply with FAA guidelines. The FAA currently prohibits assistive devices and wheelchair devices that do not compress and ones that rely on batteries from being carry ons [7]. Our device must comply with these regulations.

k. Aesthetics, Appearance, and Finish:
As of now the primary concern is constructing a device that fits the functional requirements. Aesthetics and appearance are less crucial as long as the device works. However, our client mentioned his favorite color is green and he likes the color of his current black wheelchair.

2. Production Characteristics

a. Quantity:
A single unit will be designed for the client during the initial phase of product design and development.

b. Target Product Cost:
Our client gave us a relative budget of $500, but he mentioned that if we have a major breakthrough he would not mind us going over. The cost of a current airplane transfer chairs retail for anywhere from $86 to over $2000, so $500 should suffice.

3. Miscellaneous

a. Standards and Specifications:
FAA Operational Standards for Aircraft Boarding Chairs:

- Support passenger weighing 328 kg
- Equipped with braking level that stops all forward and backward movement
- Follow U.S Access Board Guidelines for Aircraft Boarding Chairs

U.S Access Board Guidelines for Aircraft Boarding Chairs:

- Seat height should match aircraft seat height, 43-48 cm
- Restraints securely support the torso, pelvis, knees and feet
- Footrests adjustable 41 to 74 cm from front of seat

b. Customer:

The customer's main concern is the transfers between wheelchairs, and would like us to focus on this issue to minimize transfers and the dangers that go along with them. Ideally, the client would like a device that goes over his existing wheelchair, which would reduce the number of transfers to two from four. If possible, he would like a device that uses no metal, so that he can pass through metal detectors at security instead of being patted down. The very basics of what the customer wants is a device that can be used on airplanes that he personally owns.

c. Patient-related concerns:

The device will be able to be cleaned easily, however is does require cleaning between uses.

d. Competition:

- The Karman Healthcare Airplane Aisle Chair sells for around $2,000. It is designed with detachable wheels that are 61 cm in diameter. When these wheels are detached, the width of the chair decreases to 35.5 cm. Smaller wheels attached to bottom of wheelchair are utilized when larger wheels are detached [1].
- The Columbia Medical Aislemaster Unfoldable Boarding Chair costs around $2,500. It has a width of 33 cm and features padded seat, backrest and headrest, as well as flip-up armrests for ease of transfer [4].
- The Columbia Medical Aislemaster TransportMate Compact Wheelchair was originally designed for an on-flight wheelchair under the 1986 Air Carrier Access Act. It collapses compactly to a height of 18 cm from an unfolded height of 85 cm. It has a width of 41 cm including the wheels [5].

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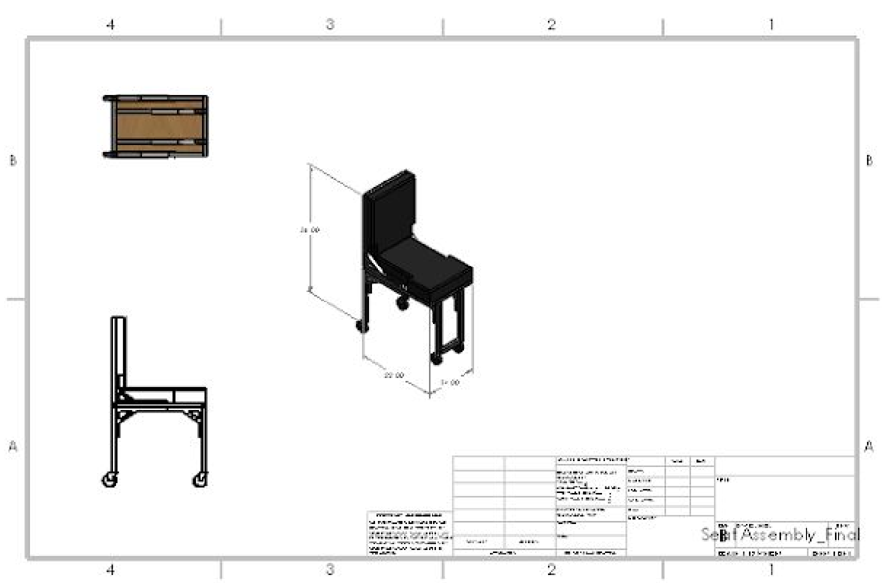
Appendix B. Final Assembly - Solidworks



Appendix C. Project Budget

Item	Description	Manufacturer/Supplier	Part Number	Date	QTY	Cost Each	Total
4/03/18 Order							
Tubing, Sq, 1015 LCS, 1 OD x1/8 In T, 6 Ft L	Steel Tubing	Sustainable Supply	3DRR5	4/3/18	3	$27.10	$81.30
4/12/18 Order							
2 PCS Heavy Duty Stainless Steel Folding Sh	Stainless Steel Bracket	Amarine-made	07995SN	4/12/18	3	$35.99	$107.97
2 Point Retractable Lap Belt With Chrome Lift	Retractable Lap Belt	Seatbelts Plus	HL800	4/12/18	1	$48.95	$48.95
Shipping							$5.00
4/22/18 Order							
3/4 x 2X4 Oak Nom,	3/4 in. Plywood	Menards	1254541	4/22/18	1	$17.99	$17.99
Power Grab Exp Heavy Duty	Loctite Adhesive	Menards	5202620	4/22/18	1	$4.57	$4.57
3/8 Saturn 270 sq. ft./roll	Carpet Pad	Menards	7011183	4/22/18	30 sq. ft.	$11.10	$11.10
Tax							$1.85
BRND HEADLINER BLACK	Headliner Foam	Joann Fabric	400034960729	4/22/18	0.389 Yard	$14.99/Yard	$5.83
SPRA BLACK MARINE VINYL	Marine Vinyl	Joann Fabric	400035263164	4/22/18	0.667 Yard	$19.99/Yard	$13.33
Tax							$1.06
Sum							298.95

Appendix D. Testing Protocol