SECONDARY AIRLINE MOBILITY DEVICE

Final Report - BME Design 200/300

December 13th, 2017

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ABSTRACT

Airline travel is currently very challenging for individuals in wheelchairs. Due to airplane aisle width and security restrictions, multiple chair transfers are required to move a traveler from their main wheelchair to their seat. When these transfers take place, disabled individuals risk being injured or embarrassed. Current designs that work to eliminate or ease transfers are scarce and expensive. Our client, Dan Dorszynski, has tasked us with creating a design for a secondary mobility device to reduce the number of transfers required to board and exit a plane. The team has created a secondary device that fits over our clients wheelchair and has folding legs. It is manufactured from aluminum extrusions with a padded seat and backrest, as well as instructions for the airline attendants on how to operate the device. Testing has proved that the design can hold 305 pounds statically and can hold at least 200 pounds while moving. This design has the potential to improve travel conditions for disabled persons and the airline workers who assist them.

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I. INTRODUCTION

Currently, airline travel for disabled individuals is inefficient and stressful. Disabled passengers reportedly 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 restricts keeping anyone out of a specific seat 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 US DOT 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 even potentially 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

A. Existing Devices

	(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.

FAA restrictions on airplane designs require that aisles must 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, so our client could potentially use the chair mid flight [7]. We concluded that a foldable or easily stowable chair that eliminates the first transfer would be beneficial to the airline as well as our client.

There are currently a number of companies that produce different models of aisle wheelchairs, and the above table gives a comparison of five of these commercially available chairs. All of the chairs are comparable in width, as this is an inherent requirement of an aisle wheelchair, as well as weight capacity, ranging from 300 to 440 lbs. Models 1 and 2 represent the highest end aisle chairs available, as they visibly have the most robust design and highest quality safety features. This comes at the expense of weight, as 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. In general, cost is a considerable factor with these existing devices. With the exception of model 4, a cost of over $2,000 makes the purchase of devices such as these no small matter to the average disabled consumer.

While these current wheelchair models can move a disabled passenger through the aisle of an airplane, they do not address our client's main problems. Every chair shown still requires a transfer from a personal wheelchair to the aisle chair, with the exception of the convertible model 5 (however, this 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.

B. Client Information

Our client, Dan Dorszynski, approached us with the problem outlined above. Mr. Dorszynski has muscular dystrophy and is confined to a wheelchair, and as a result, 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.

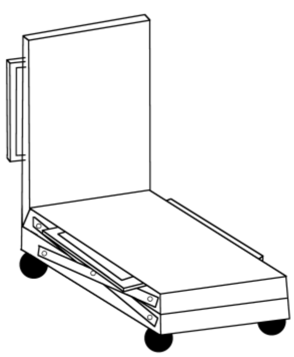
C. Design Specifications

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. PRELIMINARY DESIGNS

A. Design 1: Compact Scissor Lift

Our first design consists of a cushioned chair that is attached to a scissor lift mechanism beneath it. When collapsed down, the entire device would replace the seat cushion of his regular device, so that the height he is seated at changes minimally. Once at the gate, this device would be lifted with the client in the chair and placed on the ground, where a worker would use a crank mechanism to raise the client to a height just above the height of the airline seats.



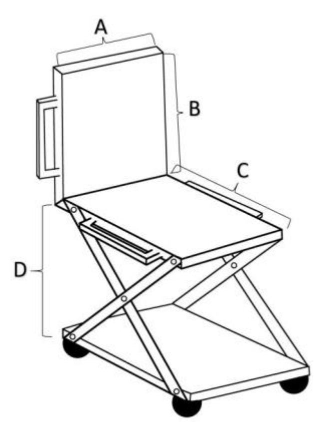


Figure 4: The scissor lift in the compacted position, which would be placed on the client's wheelchair in place of his cushion.

Figure 5: The scissor lift in the upright position. The dimensions of the chair are as follows:

A: 15 inches
B: 18 inches
C: 20 inches
D: 18 inches

The portion of the chair marked by 'D' corresponds to the scissor lift mechanism

B. Design 2: Two Piece Scissor Lift

Our second design would be very similar to the compact scissor lift in function, but in this design the chair portion and structural scissor lift portion would be completely detachable. The chair portion would sit on top of the client's current wheelchair, while the bottom structure would be collapsed and stored in the back of our client's wheelchair. Once at the gate, the structural portion would be taken out, expanded, and the client, while sitting on the secondary chair, would be lifted on top of the scissor lift. These two portions would have a mechanical attachment point. This two-piece design would prevent an airline worker from having to crank the scissor lift up with the full weight of the client on it, however, this also creates the hazard of a lifting transfer that requires attaching mechanical pieces. The dimensions of the chair when put together can be seen in Figure 5 (above).

Figure 6: This figure shows the two pieces of the chair separated. The part marked A is the part which will sit on the client's wheelchair until he reaches the gate. Part B will then be put into position, and part A will be lifted off of the current wheelchair onto B in order to form the chair seen in Figure 5.

C.Design 3: Rigid Chair with Folding Back Wheels

This design would consist of a rigid chair structure with back wheels that fold toward the front of the device and sit in a grove underneath the main seat. The device could then sit on top of the client's current wheelchair, which would allow for the secondary chair to be pushed off of/pulled back onto the current wheelchair, ideally with minimal effort. Tracks would be build onto the current wheelchair to assist in this process, and fold-in bracing structures would also be built into the legs of the secondary chair. This device would completely eliminate the transfer from our client's chair to an aisle chair, and the client would essentially be able to sit in the same chair all the way through the airport until he needs to be moved to his actual seat on the airplane.

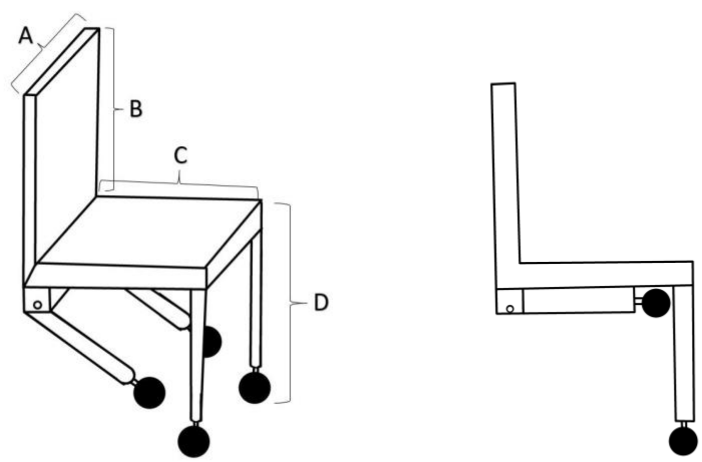


Figure 7: Foldable Rear Wheels. The image to the right displays how the chair would fit over the client's current wheelchair, while the left image shows how the back legs would swing down and lock into place after pushing it off of the current chair. The dimensions of the chair, as denoted in the left figure, are as follows: A: 15 inches, B: 18 inches, C: 20 inches, and D: 18 inches.

IV. PRELIMINARY DESIGN EVALUATION

A. Design Matrix

	Design 1 (Scissor Lift One Piece)		Design 2 (Scissor Lift Two Piece)		Design 3 (Folding Rear Wheels)	
Strength (25)	20	4/5	20	4/5	10	2/5
Size (10)	6	3/5	8	4/5	4	2/5
Cost (15)	9	3/5	9	3/5	12	4/5
Stowability (5)	4	4/5	5	5/5	2	2/5
Comfort (10)	4	2/5	6	3/5	8	4/5
Ease of Use (15)	9	3/5	9	3/5	15	5/5
Manufactu rability (20)	18	2/5	18	2/5	16	4/5
Total (100)	64		65		67	

Table 1: Design Matrix. Each design idea was rated based on weighted criteria for the project. The Folding Rear Wheels Design scored highest based off of these criteria.

B. Summary of Design Matrix

Our design matrix consisted of 7 categories with varying weight. Our first category was strength with a weight of 25, the highest weight among the categories. Strength is most important concern when designing the device because if the device were to break under a load it would pose large safety concerns to both the user and those aiding them. Manufacturability was the next highest weighted category, with a weight of 20. The resources available to us through the student shop, as well as the time constraints that a single semester brings made this an important category, as we want to be able to present the client with a finished prototype by semester's end. Ease of use and cost were both given a weight of 15. Ease of use is an important consideration, as airline staff will be the primary users of this device. Because of this, the device and processes required to use it should be very self explanatory. Additionally, cost is important as our client has given us a budget of $500. Comfort, size, and stowability, while still considerations, were given the least weight, at 10, 10, and 5 respectively. Our client specified that comfort was not as large of a concern when compared to overall function of the device. Size and stowability, while important considerations in the long term, will not be the focus of the design this semester as overall functionality is the main area of concern.

Both scissor lift devices scored similarly, with the two piece design scoring slightly higher in size and stowability due to its ability to break down into multiple pieces. These two designs scored highly in strength due to the structural stability of a scissor lift, however scored lower in both cost, ease of use, and manufacturability. The folding rear wheels design poses difficulties in terms of strength, size, and stowability, and had lower scores in these categories. The design scored higher in comfort, ease of use, and manufacturability.

C. Proposed Final Design

The folding rear wheels design won the design matrix with a score of 67. The scissor lift designs, while more structurally stable, posed too many problems in terms of fabrication and function of the device. In addition to a high material cost of creating a scissor lift, a crank mechanism to raise and lower the lift would have to be designed. Additionally, this lift would have to be very robust and able to safely lower and raise the full weight of the client. Designing and manufacturing such a gear/crank mechanism would have been difficult. This also brings the ease of use of the device into question, as airline workers would need to be able to easily manipulate this scissor lift mechanism.

The folding rear wheels design will be much easier for airline attendants to use, as it involves simply pushing the device on or off of the client's current chair. The leg hinges and locking mechanism will pose the greatest difficulties, however this will be easier to manage than a full crank or gear mechanism for the scissor lift devices. This design largely will not address the size and stowability criteria of the design matrix, for this is not the main concern of the client. Although there is concern for the structural stability of the device, with our choice of material, as well as final construction of the locking mechanism, we should be able to create a device with an adequate factor of safety that functions in the way the client desires.

V. Fabrication/Development Process

A. Materials

- 2 x T-slotted Extrusion, 15s, 72 Lx1.5 In H
- T-slotted Extrusion, 15s, 72 Lx3 In 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
- 2x2 3” Plywood
- Cotton Fabric

We decided on 80/20 as the main material of our final 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.

B. 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 rectangle. 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 8 (left): Cutting of the 80/20 extrusions using a drop saw.

Figure 9 (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 10: 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 11: 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 picture 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 final 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 12: Completed final locking mechanism with attached holder in place.

C. Final Prototype

The final prototype of our design is 14” wide, with a seat height of 18”, and a total height of 36”. 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 wheel 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 13 (left): Final design with rear wheels folded down

Figure 14 (right): Final design sitting atop the client's wheelchair with rear wheels folded into place underneath the seat.

D. 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.

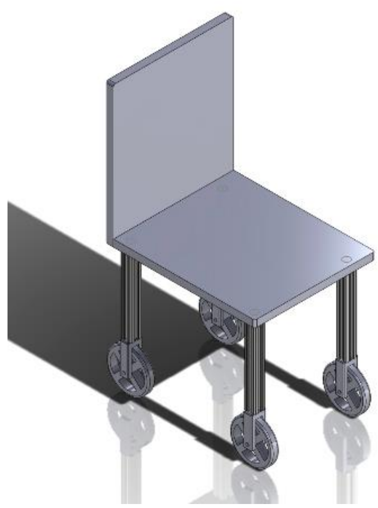


Figure 15: Assembly of individual SolidWorks parts into final design

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 16 (left): Static load test with 305 lbs loaded onto the chair.
Figure 17 (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.

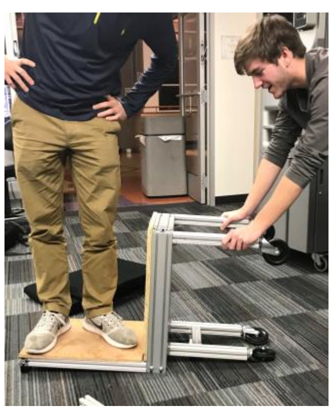


Figure 18 : Impulse loading test using weight of team member

VI. 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 19 (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 20 (right): Failure of internal fasteners on the joint of the seat frame, leading to considerable redesign work.

VII. Discussion

During the design process, the two major turning points were the two separate failures during mobile load testing. After the initial failure of the locking mechanism, see Figure 19, we had to rethink the potential loading on the lock and where the stress concentrates while the chair is moving backward. In the first design, all stress was focused on a single point of the locking bolt, causing the failure. As a result, our redesign used another 80/20 extrusion against the back frame to better distribute that loading, and failure was not seen. During initial mobile load testing, we also saw failure of the rear connecting joints as is seen in Figure 20. We realized that using the connectors in the application was a mistake, as they were supporting a large shearing load perpendicular to the larger face of the fastener, which eventually led to the failures. To correct for this, we drilled and tapped the material perpendicular to the surface of the frame in order to attach two large bolts on either side. In this way the bolts would tighten the two sections of the frame together, with any load being evenly distributed between four fasteners as opposed to two in the initial design. With continued testing deformation and failure were not seen.

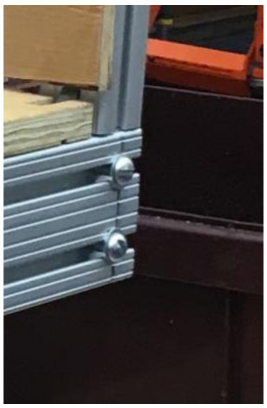


Figure 21 : Bolts used to fasten the frame together after internal fastener failure.

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 [8,9,10]. While these fines are not exclusive to violations of the rights of disabled passengers, they constitute a large percentage 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 significant economic benefit to the airlines serving these passengers.

VIII. Conclusion

Current airline travel practices are difficult for wheelchair-bound passengers, and our client experiences these issues firsthand. The main problem facing disabled persons using air travel is the number of transfers required between the main wheelchair, airplane aisle chairs, and their seat on the airplane. When the passengers are lifted drops, injuries, and overall embarrassment can occur. Our device aids disabled passengers by eliminating the transfer required between the main wheelchair and the aisle chair. It does this by having folding rear legs that allow the device to slide over the top of the main wheelchair and by adhering to FAA regulations for aisle width. The chair can be moved over and off of the client's current chair, and the user is able to stay in the same chair until they reach their assigned airplane seat.

A high factor of safety was not achieved during our testing period. Ideally, a device such as this has a factor of safety of at least three. Due to joints failing under the weight of a team member, and the team's desire to present a finished prototype to the client, the chair was not loaded to achieve this factor of safety due to fear of failure. Testing as whole will need to be improved to produce a suitable final product. Numerical data on a physical device is necessary when establishing safety parameters. Our testing proved our concept worked, but did not quantify it's peak performance.

In the future, a high factor of safety will need to be established. Making the device lighter and placing handles on the front will allow for attendants to slide the device on and off the chair with greater ease and could prevent potential injuries. Additionally, the locking mechanism could be simplified to be made more user friendly because bolting the extrusion into place is time consuming and difficult. A lap belt and foot rests will need to be added to improve the safety. As of now, this device has been made to our client's specifications. Due to the vast need for this device in the airline industry, working with other disabled people and airline personnel to make a standardized device that could be commercialized would be beneficial. It would aid in improving the overall accessibility of airports and simplifying the boarding process for disabled individuals.

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X. APPENDIX

A. Product Design Specifications Document:

Secondary Mobility Device for Airline Travel

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Date of most recent update: October 9, 2017

Function:

Currently, airplane travel for disabled passengers is a very difficult and arduous process, involving multiple wheelchair transfers, the assistance of untrained airline workers, and multiple times and sites of possible injury or embarrassment. The current procedures in place are so inefficient and tedious that many wheelchair-bound people refrain from flying at all. This 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. This 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 (or identify other places to simplify disabled travel process in general throughout the entire airport ie. security checkpoint)
- Minimize the number of airline workers/outside help involved during transfers
- Some level of foldability/stowability for when device is not in use

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

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 up to multiple hours at a time. The device should be able to conveniently fold or condense to be stowed in a reasonable manner. This device will be used approximately three to four times a year, the approximate number of times the client flies per year.

b. Safety:
The structure of our device must be able to withstand a load of 300 lbs.t. It must have a factor of safety of 3.0 as well [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 preform consistent with the needs of our client. Failure to consistently support upwards of 250 pounds and maintain our clients stability could result in undue attention to our client, 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 to prevent potential injury 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 for as long as the client needs to use the device. This will typically include attaching it to his regular chair at home, traveling to the airport with it, and moving all the way to the gate with it where it 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 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 without use. 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 250 pounds. 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 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.

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 wheelchair devices that do not compress and that rely on batteries from being carry ons [7]. This device must comply with these regulations. We may try to make a device with no metal so the client can easily pass through security, but we are more likely going to use metal parts for a secondary wheelchair.

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:

We are designing one unit for the client

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 720 pounds
- 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, 17 to 19 inches

- Restraints securely support the torso, pelvis, knees and feet
- Footrests adjustable 16 to 30 inches 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. If possible, he would like to 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 he owns that can be used on airplanes.

c. Patient-related concerns:

The device will be able to be cleaned easily, however does not need to be cleaned 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].

References:

[1] (2017). *Karman Healthcare Airplane Aisle Chair* [Online]. Available: https://www.activeforever.com/karman-healthcare-airplane-aisle-chair

[2] (2012, June 29) *Aircraft Boarding Equipment* [Online] Available: https://www.faa.gov/documentlibrary/media/advisory_circular/150_5220_21c.pdf

[3] American Institute for Research (1987 March 9) *Guidelines for Aircraft Boarding Chairs* [Online] Available: https://ntl.bts.gov/DOCS/T10.html

[4] (2017). *Columbia Medical Aislemaster Unfoldable Boarding Chair*. [Online] Available: http://www.1800wheelchair.com/product/aislemaster-unfoldable-boarding-wheelchair/

[5] (2017). *Columbia Medical Aislemaster TransportMate Compact Chair*. [Online]. Available: http://www.1800wheelchair.com/product/aislemaster-transportmate-compact-wheelchair/

[6] Sunrise Medical. (2017). *QUICKIE S-636 Electric Power Wheelchair*. [Online] Available: http://www.sunrisemedical.com/power-wheelchairs/quickie/rear-wheel-drive/s-6-series

[7] FAA (2017, July 25). *Pack Safe*. [Online] Available: https://www.faa.gov/about/initiatives/hazmat_safety/

[8] National Transportation Library (1987). *Guidelines for Aircraft Boarding Chairs.* [Online] Available: https://ntl.bts.gov/DOCS/T10.html

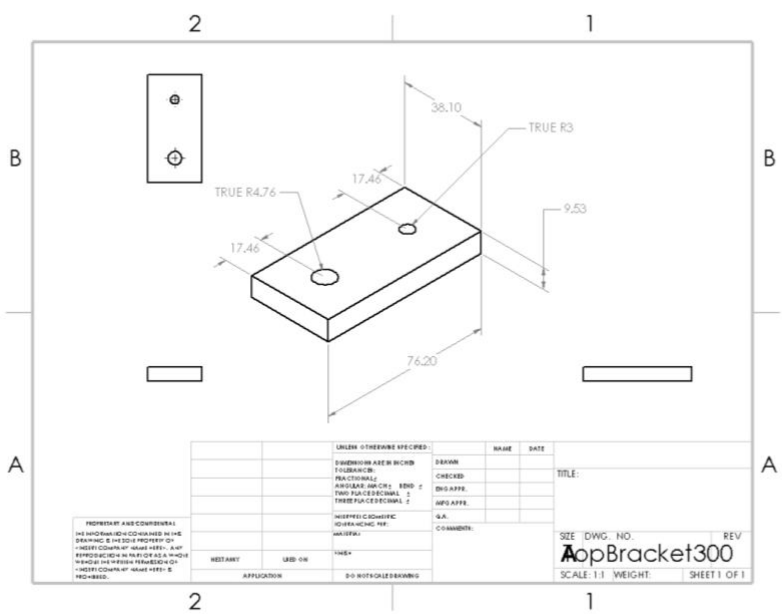
B. Department of Transportation Disability Complaints

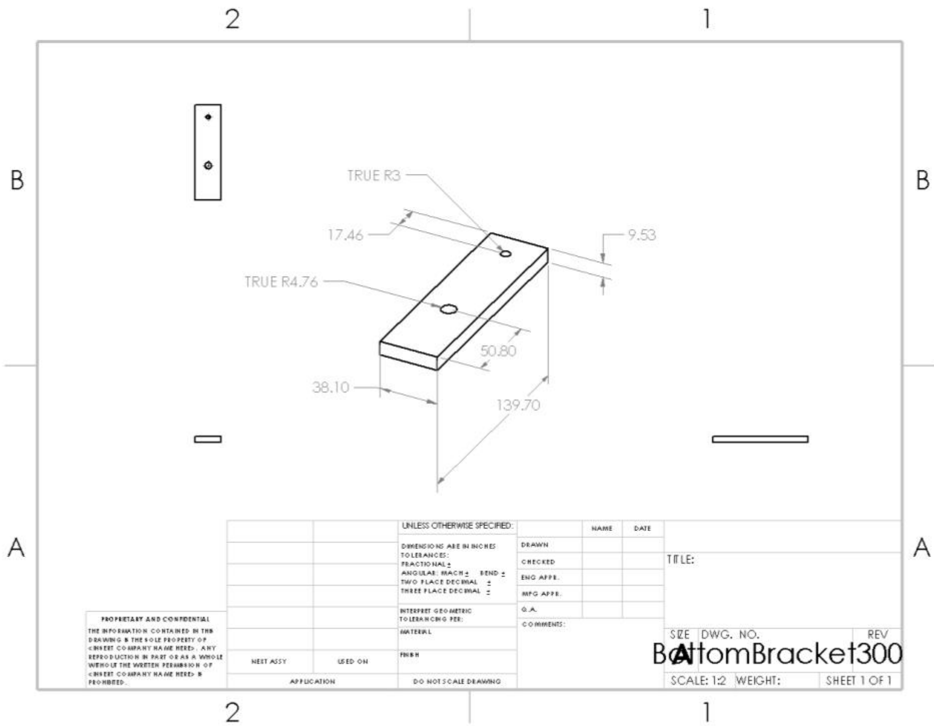
Summary of Disability-Related Complaint Data

All Carriers
Total number of complaints submitted: 32,445

	Vision Impairment	Hearing Impairment	Vision & Hearing Impairment	Paraplegic	Quadriplegic	Other wheelchair	Oxygen	Stretcher	Other Disability	Other Assistive Device	Mentally Impaired	Communicable Disease	Allergies
Refusal To Board Passenger	2	3	2	3	2	33	127	1	173	20	32	9	18
Refusal to Board w/o Attendant	0	1	2	0	0	3	0	0	5	0	2	0	0
Security Issues Regarding Disability	0	1	1	2	1	12	0	0	11	0	0	0	2
Aircraft Not Accessible	1	10	1	1	2	38	3	1	32	1	0	0	2
Airport Not Accessible	0	0	0	3	1	43	1	2	28	4	0	0	0
Advance Notice Dispute	0	0	0	0	0	124	12	0	41	3	18	0	9
Seating Accommodation	52	19	11	30	7	453	36	0	2,310	30	66	1	79
Failure to Provide Assistance	155	132	81	81	34	14,591	67	1	2,652	200	108	1	262
Damage to Assistive Device	0	3	1	16	5	707	5	0	38	437	0	0	0
Storage and Delay of Assistive Device	4	1	1	14	8	338	22	0	387	817	2	0	2
Service Animal Problem	9	14	5	1	1	9	0	1	2,116	44	222	0	21
Unsatisfactory Info	10	28	4	2	3	127	34	1	242	48	46	0	45
Other	59	97	17	16	9	1,020	76	0	2,093	174	75	2	655

C. Locking Mechanism SolidWorks Brackets:





D. Project Budget:

Item	Description	Manufacturer	Part Number	Date	QTY	Cost Each	Total	
Grainger 11/9/17 Order								
T-slotted Extrusion, 15s, 72 Lx1.5 In H	Seatback and Leg Extrusions	80/20	2RCR3	11/9/2017	2	$43.50	$87.00	
T-slotted Extrusion, 15s, 72 Lx3 In H	Seat Extrusions	80/20	2RCR5	11/9/2017	1	$78.25	$78.25	
Pivot Joint, 40 Series, Width 1-9/16 In.	Joints for Back Legs	80/20	16U367	11/9/2017	2	$20.95	$41.90	
Shipping and Tax on Order							$43.68	
80/20 11/9/17 Order								
Hidden Corner Connector: Inside-Inside	Extrusion Connectors	80/20	33450	11/9/2017	8	$5.15	$41.20	
Shipping							$12.08	
80/20 11/21/17 Order								
M6 Slide-in Economy T-Nut - Centered Thread	Connectors for Legs and Seat Pan	80/20	3836	11/21/201	10	$0.27	$2.70	
90 Degree Inside Corner Connector	Connectors for Seat Back Frame	80/20	3368	11/21/201	6	$6.30	$37.80	
Threaded Stem Swivel Caster: 7/16-14 x 1.5"	Wheels	80/20	2305	11/21/201	4	$9.20	$36.80	
Shipping							$14.25	
Grainger 11/28/17 Order								
80/20 Handle,15 & 40 Series,Width 1 In.	Handles	80/20	2061	11/28/201	2	$8.10	$16.20	
Shipping							$11.47	
Home Depot 11/26/17								
2x2 3 Plywood	Plywood for Seat	Not Listed	99167465333	11/26/17	1	$7.19	7.19	
Cotton Fabric	Black fabric for making padding	Not Listed	34086583676	11/26/17	1	$15.97	15.97	
Tax							$1.27	
80/20 12/1/17								
M6 Slide-in Economy T-Nut - Centered Thread	Connectors for Legs and Seat Pan	80/20	3836	12/2/17	5	$0.27	1.35	
Hidden Corner Connector: Inside-Inside	Extrusion Connectors	80/20	33450	12/2/17	2	$5.15	10.3	
Shiping							12.11	
						TOTAL:	**$471.52**	