SECONDARY AIRLINE MOBILITY DEVICE

Preliminary 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

Airline travel is 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 been tasked with improving upon the prototype from Fall 2017. The prototype was a secondary device that fit over our client's wheelchair and had folding legs. The improved design will be stowable during air travel as well as being able to bear more weight.

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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, so our client could potentially use the chair mid flight [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 chairs 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. 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. 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 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.

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.

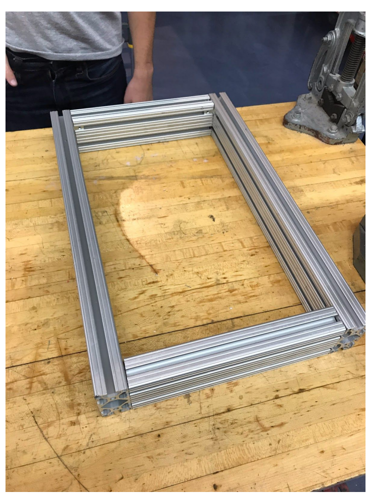


Figure 8 (left): Cutting of the 80/20 extrusions using a drop saw.

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 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.

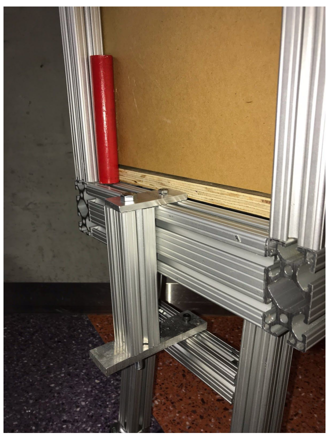


Figure 12: Completed final locking mechanism with attached holder in place.

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 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.

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.

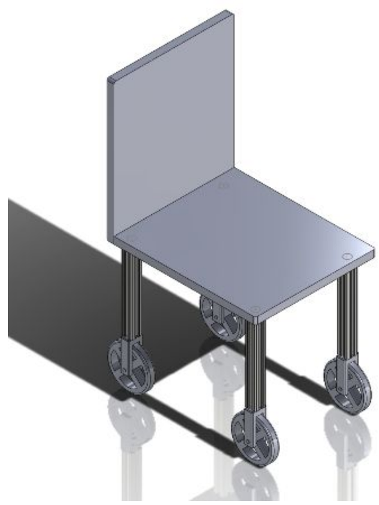


Figure 15: Assembly of individual SolidWorks parts into final design

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.

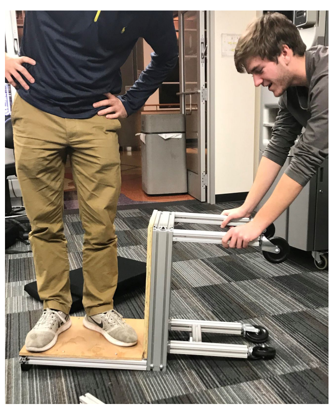


Figure 18 : Impulse loading test using weight of team member

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.

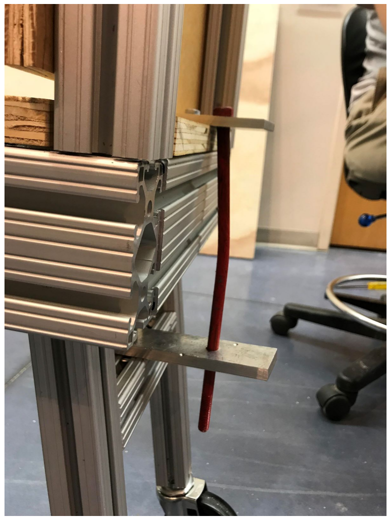


Figure 19 (left): The results of our initial test of the locking mechanism. The bolt shows significant bend and led to a redesign of the bolt.
Figure 20 (right): Failure of internal fasteners on the joint of the seat frame, leading to considerable redesign work.

IV. Preliminary Design Improvements

Several aspects of the previous design needed to be reconsidered to allow for additional revisions this semester. While the actual materials used to construct the previous device will not be reused with the new iteration of the device, 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, it could not be stowed in an overhead compartment for use during flight or immediate use 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 rear legs will collapse using a mechanism similar to stretchers. This mechanism will allow the rear legs to fold when pressure is applied from behind, and the rear legs will fold under the seat. The front legs and backrest will collapse using lockable joints that will lock in place at 90 degrees and 0 degrees. The backrest will fold on top of the seat, and the front legs will fold under the seat like the rear wheels. 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 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 aluminum, 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 significantly 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, was excessively heavy, 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, as well as mimicking the mechanism of folding legs on an ambulance stretcher. The stretcher-like folding mechanism will be used so that when the back legs of the device hit the client's wheelchair, the back legs will fold up automatically. 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 is an important improvement so that the client can 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 of making the frame out of steel is needed so that the device is stronger and lightweight. The last design was made with aluminum, which had the strength the device needed but the downside to using aluminum was that it 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 up so that it will be able 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. Conclusion

Materials

The frame of our prototype will be made out of a high carbon stainless steel. Based on our experiences from last fall, we will require roughly 18 feet of tubing. A specific profile for the tubing will be selected in the upcoming weeks, however it is likely that we will select a square profile for compatibility will our locking hinges. We will also be purchasing and utilizing 4-6 locking hinges for use on our front legs and backrest. If we determine that it is not feasible to utilize a stretcher design in our back legs, we will be using 2 additional hinges for these legs as well. We will be requiring 4 casters for our design. The casters from last semester are made of stainless steel, so it is likely that we will be able to reuse them this semester. If for some reason we are unable to, 4 additional casters will have to be acquired. To cover our frame we will use 2’x2’x.5” plywood that will be cut to size. For our backrest and seat we plan on using 2 pieces of foam. We will manufacture this from an approximately .4 square meter piece of 8 cm thick foam. To cover the foam we will require roughly 2 square meters of vinyl boat seat covers. Footrests will be required for safety. Because the footrests will be attaching to the front legs, and these front legs must fold in, the footrests must be foldable as well. In order to accommodate this, the footrest will consist of one folding panel that fold in to be flush with the front legs.

Fabrication

The chair frame and seat bed will be fabricated using MIG welding techniques. The foam layers of the seat cushion will be adhered together using a spray adhesive. The plywood base of the seat cushion will then be connected to the seat bed with nuts and bolts with the goal in mind of providing the capability to remove the cushions if necessary.

Future Work

The future work for this project includes three main goals: obtain an ambulance stretcher for analysis, research the potential for mass production of the device, and take the prototype on an actual flight. Many modern ambulance stretchers contain a special mechanism within the back legs that allow them to easily rise to be flush with the bed upon contact with the back of the ambulance. Along with this, once removed from the ambulance said legs will automatically release from their resting position and unfold into their mobile position, and finally lock into place. Online research has not provided sufficient insight to the inner-workings of the mechanism, thus observing one in person may provide additional info to allow for the mechanism to be implemented within our device. Being able to take the device an on actual flight will give the team an insight on what changes would still need to be made.

Proposed Budget

The client has provided us with a $500 budget for the semester. Careful planning of purchases and solid bookkeeping should keep the device well within the limits of the proposed budget.

VII. References

[1] Rita.dot.gov. (2017). Data Analysis | Bureau of Transportation Statistics. [online] Available at:
https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/freedom_to_travel/html/data_analysis.html [Accessed 6 Oct. 2017].

[2] US Department of Transportation. (2017). Passengers with Disabilities. [online] Available at:
https://www.transportation.gov/airconsumer/passengers-disabilities [Accessed 8 Oct. 2017].

[3] US Department of Transportation. (2017). 2016 Disability-Related Complaints Received for All Carriers. [online] Available at:
https://www.transportation.gov/airconsumer/2016-disability-related-complaints-received-all-carriers [Accessed 8 Oct. 2017].

[4] (2012, June 29) *Aircraft Boarding Equipment* [Online] Available:
https://www.faa.gov/documentlibrary/media/advisory_circular/150_5220_21c.pdf

[5]*Airplane Aisle Wheelchairs* [Online]. Available
FTP:http://www.1800wheelchair.com/category/wheelchairs-for-airplanes/

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

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

[8] US Department of Transportation. (2017). DOT Fines US Airways for Failure to Provide Wheelchair Assistance to Passengers with Disabilities. [online] Available at:
https://www.transportation.gov/briefing-room/dot-fines-us-airways-failure-provide-wheelchair-assistance-passengers-disabilities [Accessed 12 Dec. 2017].

[9] Martin, H. (2017). These three airlines were fined for passenger rights violations. [online] latimes.com. Available at:
http://www.latimes.com/business/la-fi-airline-fines-20170724-story.html [Accessed 12 Dec. 2017].

[10] Forbes.com. (2017). Forbes Welcome. [online] Available at:
https://www.forbes.com/sites/tanyamohn/2013/11/12/us-airways-fined-1-2-million-for-failure-to

-provide-wheelchair-assistance-to-passengers-with-disabilities/#3dd89651439b [Accessed 12 Dec. 2017].

VIII. Appendices

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
- 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

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].

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

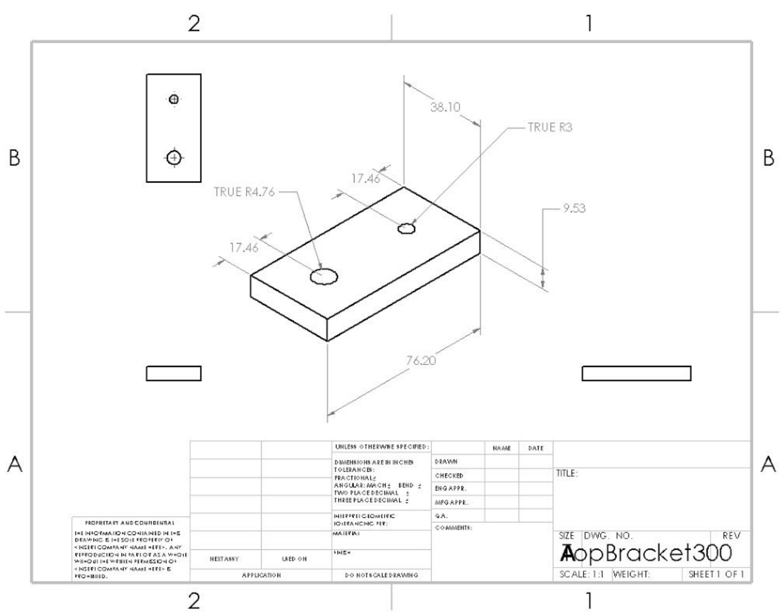
Appendix B. Department of Transportation Disability Complaints

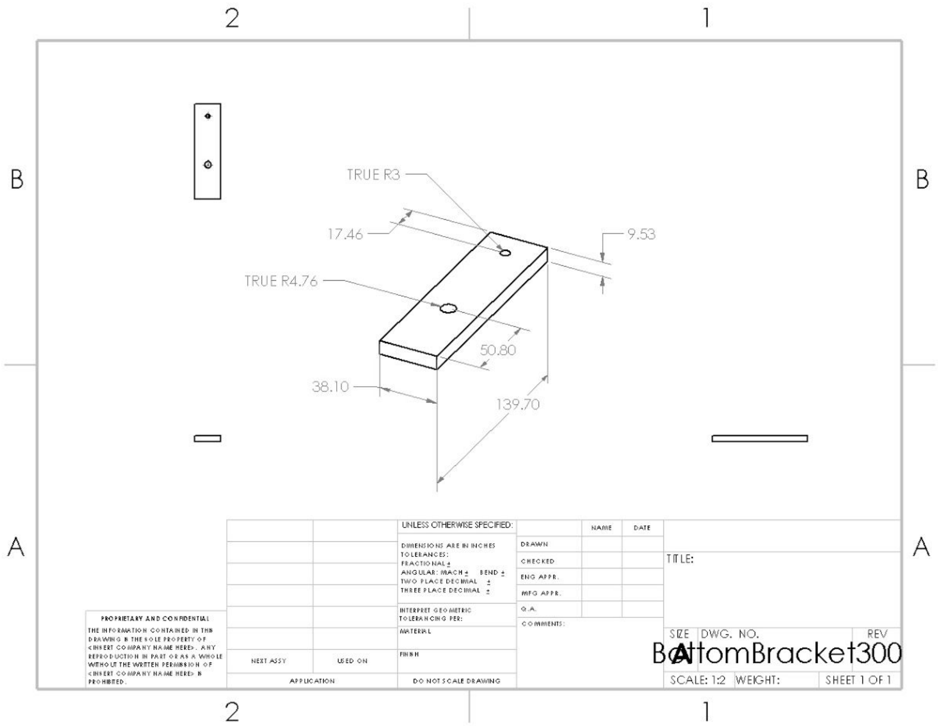
Summary of Disability-Related Complaint Data

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

Appendix C. Locking Mechanism SolidWorks Brackets





Appendix D. Project Budget - Fall 2017

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**