Embraccess

Redesigning the Flying Experience for Passengers with Limited Mobility

Mechanical Engineering 310 Final Report

Team Embraer
Rodrigo Monteiro, Clifford Bargar, Maria Barrera, Luiz Durão, Laura Hoinville, Guilherme Kok, Amanda Mota

Mechanical Engineering Design Group
416 Escondido Mall
Stanford University
Stanford, CA 94305-2203
http://me310.stanford.edu
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1 Prelude

1.1 Executive Summary

In a world that is dynamic in almost every aspect, mobility is a necessity. However, for persons that suffer from disabilities, their mobility can be severely limited. Traveling with limited mobility can be a very difficult and burdening task, especially if it involves being within the small confines of an airplane. Passengers that are faced with limited mobility or a disability have a different and often times worse experience than the average passenger throughout the entire flight experience. How can we give all passengers the same experience? Creating a new travel system are essential for giving the same experience to all passengers and to give passengers with limited mobilitythe independence and control they lack today.

Embraer, the Brazilian airline manufacturer, decided to partner with Stanford University and the University of Sao Paulo to solve the problem of improving the entire air travel experience for persons with limited mobility. In collaboration, we started this journey toward a solution through extensive needfinding and benchmarking. The needfinding centered on conducting user interviews for both the disabled passenger and the flight crew, while benchmarking focused on analyzing analogous situations, patents, regulations, and current concepts and solutions in place today.

The research that was conducted during needfinding and benchmarking was instrumental in the approach we are taking toward a solution. The user interviews led us to the four themes we need to address with our solution. These themes are improving customer service, giving the user control and independence, and creating a non-discriminatory solution. The interviews with potential users revealed horror stories that dealt with customer service or the lack thereof. The solution space needs to create an environment that limits or improves the quality of the interactions between the flight crew and the passenger to prevent these horror stories from becoming a reality for future travelers. Independence and control were also instrumental in our findings. The users of our solution want to feel independent and in control of their situation even when they might need assistance. This leads our solution path to one that provides piece of mind to our user. Because wheelchairs often gets damaged when they are handled from the jet way to the cargo hold, wheelchair users are very anxious and spend their flight wondering if their mobility device will make it safely to their destination. Finally, we realized that since passengers with disabilities have a condition that singles them out, we should focus on creating a product that is well designed with the user in mind and that lacks the dehumaninzing aspects that we see in cabin mobility aids today.

These themes were our driving forces for the critical function and critical experience prototypes we created to further explore our problem space. The team created a number of prototypes but really focused on the ones that solved this problem; one being a more incremental fix while the other addressed a more futuristic solutions.

Our vision is to provide the wheelchair user with two products that address the main themes and the biggest painpoints. As mobility inside the cabin is an extremely uncomfortable and unsafe experience today, we want to give passengers a completely redesigned aisle chair that allows for improved customer service as well as increased passenger comfort and support. No longer do passengers need to be carried by airport personnel and risk injury since this redesigned aisle chair will allow the user to move inside the cabin and transfer independently from one seat to the next using either the lateral or frontal transfer options. Having access to a more humane and versatile aisle chair will certainly revolutionize the flying experience for wheelchair users.

Beyond solving mobility inside the cabin, airport logistics concerning wheelchair storage must also be improved. It doesn't matter how delightful the flight experience was if a disabled passenger can't move once they arrive at their destination because their wheelchair is broken. We found that most of the damage to wheelchairs is incurred during the handling process so we have created a platform that allows handlers to manipulate any type of wheelchair, whether it's powered or manual, without having to touch the wheelchair itself. We are also using smart features that know who is responsible for the wheelchair and can detect any signs of mishandling. With this, we aim to reduce the number of damaged wheelchairs and improve the handing experience for airport personnel.

We know that in order to provide wheelchair users with an enjoyable flying experience from beginning to end, our solution must provide them with absolute piece of mind concerning what happens to their mobility device when it is taken away from them and a pleasant cabin experience that makes them feel independent, in control and not singled out. Both improvements are necessary to truly redesigning the flying experience for people with reduced mobility.

1.2 Glossary

80/20: Aluminum T-slotted profiles used for building modular structures.

ADA: Americans with Disabilities Act; one of America's most comprehensive pieces of civil rights legislation that prohibits discrimination against and guarantees people with disabilities have the same opportunities as everyone else to participate in the mainstream of American life.

Aisle Chair: Common assistive device utilized to help individuals with mobility limitations to more easily board airplanes. Aisle chairs are narrower wheelchairs which highlight multiple straps to completely secure the user, and can be rolled down narrow airplane aisles to get the individual to his or her seat.

Airport Personnel: All parties involved in handling the passengers and cargo for a flight including but not limited to: flight attendants, luggage handlers, check-in personnel and other contracted helpers.

ANAC: Agencia Nacional de Aviao Civil Brazilian National Agency of Civil Aviation

ANSYS: ANSYS Mechanical software is a comprehensive finite element analysis tool for structural analysis, including linear, nonlinear and dynamic studies. The engineering simulation product provides a complete set of elements behavior, material models and equation solvers for a wide range of mechanical design problems.

Arduino: A low cost and easy to use microcontroller for rapid prototyping of mechatronic and electrical systems

Assistive Technology: Assistive, adaptive, and rehabilitative devices for people with disabilities; promotes greater independence by enabling people to perform tasks that they were formerly unable to accomplish, or had great difficulty accomplishing.

Benchmarking: A standard by which something can be measured or judged.

Boarding: The process of entering the airplane.

Cabin: The section of an aircraft in which passengers travel.

Cargo Hold: The space in a ship or aircraft for storing cargo such as baggage, shipping containers, animals or mobility devices.

Control: The power to influence or direct either people's behavior or the course of events.

Dark Horse Prototype: A device created during the winter quarter of ME310 that was ruled out in the fall quarter or undiscovered due to being too risky or to difficult to complete; emphasizes creative out-of-the-box thinking and exploring all of the design space for the project.

Disability: A physical or mental condition that limits a person's movements, senses, or activities.

Disembarking: The process of exiting the airplane.

EXPE: The Stanford design fair that is held every year at the beginning of June. During this fair, all ME 310 teams present the work they have done throughout the year and show their final prototype.

FAA: Federal Aviation Administration; United States national aviation authority whose mission is to provide the safest, most efficient aerospace system in the world, oversees all aspects of American civil aviation.

Independence: Freedom from outside control or support.

Jetway: A telescoping corridor that extends from an airport terminal to an aircraft, for the boarding and disembarkation of passengers.

Limited Mobility: Mobility impairment may be caused by a number of factors, such as disease, an accident, or a congenital disorder and may be the result from neuromuscular or orthopedic impairments. It may include conditions such as spinal cord injury, paralysis, muscular dystrophy and cerebral palsy. It may be combined with other problems as well (i.e. brain injury, learning disability, hearing or visual impairment).

Needfinding: Discovering opportunities by recognizing the gaps in the system or the needs.

Non-Discriminatory: Fairness in treating people without prejudice.

Pain Points: A level of difficulty sufficient to motivate someone to seek a solution or an alternative; a problem or difficulty.

Perspective: A particular attitude toward or way of regarding something; a point of view.

Self-Image: The idea one has of one's abilities, appearance, and personality.

Taxiing: The movement of an aircraft on the ground, under its own power.

Transfer: The act of moving a wheelchair user from one chair to another.

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2 Context

2.1 Need Statement

Airlines are always searching for new ways to fit more people on a single flight and increase their profit margin, making the seats in the aircraft smaller and closer. As the seats get smaller, the personal space for a passenger shrinks, making it harder for anyone to move and fit comfortably as shown in Figure 2.1.

Figure 2.1: *With Airlines adding more and more seats to their planes, it is increasingly hard to maneuver around the cabin. [22]*

As global business continues to increase, people are constantly on the go and airports are becoming larger and larger, growing busier each year. The distance from check-in to gate is increasing as more airlines expand terminals. Therefore, it becomes a problem for passengers who have a hard time walking long distances or need assistance with bags or a mobility device. More airport staff are needed to move the passengers with mobility needs, yet often the staff are not trained in handling the mobility devices or the person with disabilities.

Additionally, airlines have limited space in the cabin because of the increased amount of seats, requiring assistive devices to be stored in the cargo hold where they are susceptible to damage. The flying experience today is tailored to a person that has all of his/her mobility, leaving out those who have some impairment that requires additional time. However, 58 million Americans live with a disability, including 5.5 million military veterans, so this is a problem we cannot ignore.

2.2 Problem Statement

The biggest painpoints our users are facing (which are deeply analyzed in appendix A) can be broken down into the following two areas that need to be addressed:

- Mobility inside the Cabin

- Storage and Security of Assistive Devices

The whole process (see Appendix B) was analyzed and we found that the current systems in place today are those required by the FAA and ADA regulations. However, these systems have gaps that need to be addressed in order to improve the passenger experience. The interviews we conducted during Autumn quarter showed the gaps and led to uncovering these two main pain points. Our users want to be able to transfer from their wheelchair to the aisle chair independently and without the interference of others and they especially don't want to be carried over a stranger's shoulder. They also want to know that their wheelchair will be handled with the utmost care and returned to them in working condition with no damage at all.

This is what our user needs and wants addressed in order to have a better flying experience that is more personal, allows for independence and control, and provides them with peace of mind. In addition, the airport staff and flight attendants need to be considered to ensure that they can use the new systems with ease and without an increased time committment by making the solution as intuitive and inclusive into the airport personnel's current tasks as possible.

2.3 Vision Statement

Imagine you are packing for a trip and you pack your most important possession in your carry-on. But when you arrive at the gate, you are required to gate check your bag. You immediately panic. You do not know if the bag will be damaged. What if it gets lost? Put on the wrong flight? Your entire flight is ruined because now all you can think about is what state your bag will be when you arrive, especially since airlines do not have the best reputation concerning luggage handling.

Now imagine if this was your wheelchair. Your legs. Your independence. What if you had no clue how you were going to move now that you no longer have a functional wheelchair? What if your activity in the cabin was limited due to the loss of your chair? For our users, this is a struggle every time they board a plane and have to endure a flight of misery and constant worry. What if we could eliminate this unease, worry and fear by designing a new system that allows the user to know how their wheelchair was handled, to know it was safe, and that it will be there safely when they disembark? What if we could design a way for them to be able to move in the cabin with ease and make the bathroom and other tasks more accessible?

The two systems described in the story above are our vision and focus for the final product. Our users are in need of independence. The current systems that are utilized today on airplanes and in airports require our users to be assisted by airport or airline personnel for any task that requires mobility.The user interviews from fall quarter stressed the importance of independence and the pain points that the lack of independence create in the flying experience. Therefore, the theme of independence was the driving force behind the solution and design space described above.

With independence in mind, we found that mobility inside the cabin and the storage and security of the wheelchair were the two places where independence broke down the most in the flight experience. The pain point of mobility in the cabin is being addressed by redesigning the aisle chair. The new aisle wheelchair will allow for user control during boarding and disembarking, for ease of independent transfer using a sliding seat, and for ease of mobility in the cabin such as using the restroom. The storage and security of the wheelchair will be accomplished with a specialized shipping container that allows for the wheelchair to be strapped or tied down in the jetway in front of the user. The user will be able to supervise the entire process and will receive updates of who is responsible for their chair as the container is loaded into the cargo hold. These two solutions will be bringing independence and control back to our users and creating a more desirable experience.

2.4 Corporate Partner: Embraer

The corporate partner for this design project is Embraer. Since 1969, Embraer has been involved in all aspects of the aviation field. Embraer began with support from the Brazilian government to produce military aircraft in addition to its small passenger planes. Embraer then expanded to agricultural planes and later to commercial planes and business/private jets. Embraer has over 5,000 aircraft operating in over 80 countries. They are the market leader for commercial jets with fewer than 120 seats. Embraer is interested in expanding its commercial market to larger commercial jets, in maintaining some of the best executive jets, and in entering new defense markets.

Corporate Liaison

Luciana Ribeiro Monteiro
Technology Development
Embraer - SJK
Phone: +55 12 3927 8576
luciana.monteiro@embraer.com.br

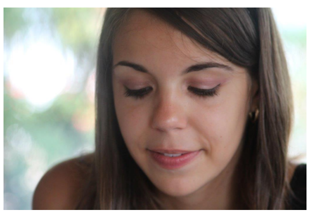
2.5 The Design Team

Our team has a diverse educational, cultural, and social background that encompasses many skill sets and multiple areas of study.

Stanford University

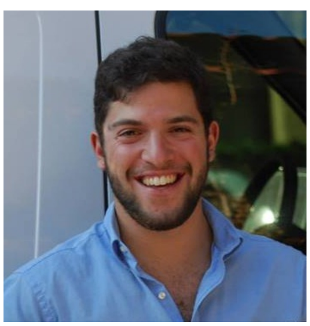
Maria Barrera
Status: Mechanical Engineering Graduate Student
Contact: mariabarrera5491@gmail.com

I was born in Colombia and moved to South Florida with my mom when I was 10. My dad and sister still live in Colombia so I tend to hop back and forth every chance I get. I did my undergraduate at Stanford also in Mechanical Engineering and have developed a deep interest for entrepreneurship during my time here. I run a tutoring company in the area and hope to one day start a company in the aviation sector. I also enjoy traveling, photography and playing with puppies!



Laura Hoinville
Status: Aeronautics and Astronautics Graduate Student
Contact: laurah31@stanford.edu

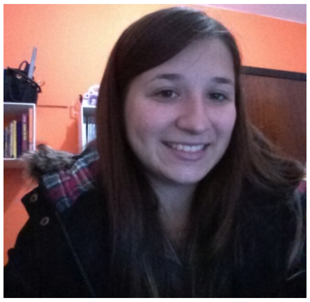
I come from Toulouse, France. I attended ISAE-Supaero (the French Graduate school of Aerospace Engineering) at Toulouse for my undergraduate degree in Aeronautics. I worked at Airbus head quarters in Blagnac, France as an intern last summer and want to make a career in the field of aircraft design. I'm also interested in dance (ballet, modern jazz, contemporary), gymnastics, scuba diving and reading.



Cliff Bargar
Status: Mechanical Engineering Graduate Student
Contact: cbargar@stanford.edu
Website: http://cliffbargar.com

Having spent the first 22 years of my life within a subway ride of Boston, Massachusetts, I decided to drive west and come to Stanford. I'm completing my MSME this spring, focusing on mechatronics, robotics, and controls. I graduated with a BSME from Tufts University, where I double majored in Mechanical Engineering and Mathematics, was an active member of Engineers Without Borders and the Tufts Robotics Club, and ran on the Tufts Cross Country and Track and Field teams. Here at Stanford I'm a Course Assistant for ME218 and a researcher in the CHARM lab as well as an active member of the Stanford Running Club.

University of São Paulo

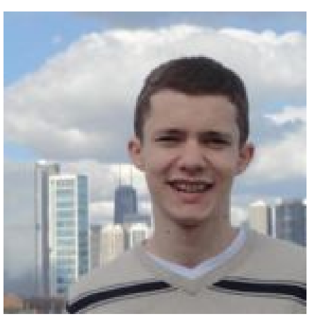


Amanda Mota Almeida
Status: Product Design Undergraduate Student
Contact: amandamotaalmeida@gmail.com

I was born and raised in São Paulo. I'm attending the University of São Paulo for my undergraduate studies in Product and Graphic Design. I have worked in a project with Embraer in the past regarding the design and comfort in the aircraft cabin (2011), I have interned for Staples in São Paulo SP (2012) and I was part of exchange in Portugal last year (2013). My interests include: photography, arts and crafts and reading.

Luiz Durao
Status: Industrial Engineering Undergraduate Student
Contact: luiz.durao@usp.br

I was born and raised in São Paulo city. I attended Colgio Etapa for my High School and it was while participating in the Chemistry and Physics Olympiads that I discovered my taste for the sciences. I'm attending the University of São Paulo for my undergraduate studies in Industrial Engineering. I have interned for GE Oil and Gas at Jandira SP and I have worked since my sophomore year as a teaching assistant for some courses at USP. My interests include soccer, music and movies.



Guilherme Kok
Status: Industrial Engineering Undergraduate Student
Contact:guilhermekok@gmail.com

As a Brazilian and a soccer enthusiast, I grew up in São Paulo and in Baltimore. I've also spent 5 months in Nanaimo (Canada, BC) and 1 year studying at the University of Illinois at Urbana Champaign. I'm currently finishing my undergraduate studies at the University of São Paulo in Brazil, where I study Industrial Engineering. I have interned for a taxi app startup and have done undergrad research concerning the consolidation of the phonographic industry. My interests include playing soccer, hiking, tasting different cuisines and travelling, preferably to remote locations.

Rodrigo Monteiro de Aquino
Status: Computer Engineering Undergraduate Student
Contact: guigonyts@usp.br

I have lived all my life in São Paulo. I am now graduating in Computer Engineering at USP and I also work in a technology development lab at the university. I have worked on several projects developing educational games and other educational interfaces that help children learn with technological devices. I like to play videogames and go to the movie theater. I like science fiction movies and reading adventure books.

2.6 Contributors

Erika Finley
Contact: erikam.finley@gmail.com

I was born and raised in Tennessee. I attended the University of Tennessee at Knoxville for my undergraduate degree in Mechanical Engineering. I participated in a study abroad in Canberra, Australia. I have interned for Tennessee Valley Authority at Browns Ferry Nuclear Plant and for Schlumberger at the Rosharon Design Center. I will be interning at Microsoft this upcoming summer. My interests include baking, reading, photography, and roller coasters.

Robert Karol
Contact: robbiekarol@gmail.com

I grew up in New Jersey through high school. After that, I moved to southern california where I attended the California Institute of Technology majoring in Mechanical Engineering with minors in Aerospace Engineering and Control and Dynamical Systems. I have worked on robotics projects with NASAs Jet Propulsion Laboratory, as well as experiments in high altitude photography and performed research in microgravity.

Riley Shear
Contact: rjshear@gmail.com

Riley is finishing an MS in ME at Stanford University, where he came for graduate study after obtaining a BS in Mechanical Engineering from Arizona State University. He enjoys spending time in the machine shop making things, sailing, and riding his motorcycle.

2.7 TAs

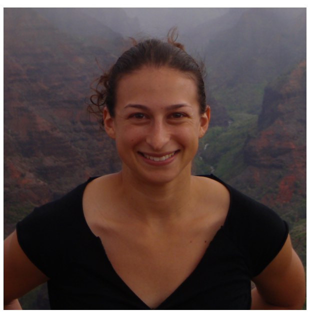
Leandro Key Higuchi Yanaze
Contact: leyanaze@gmail.com

Leandro did is undergrad in architecture and urbanism, specialized in Theory and Practice of Communication, got his Masters in Social Communication and iwas a doctoral student in Electronic Systems at the Polytechnic School of University of So Paulo. Is a researcher at POLI-EDU, a research group that promotes reflection on teaching and learning in/to engineering. He is a professor in the Methodist University of So Paulo.

Maria Alice Gonzales
Contact: camargo.alice@gmail.com

Maria Alice Gonzales, researcher from The Center of Interdisciplinary of Interactive Technology and Poli-Edu, is ungraduated in architecture and urbanism. Shes doing her master degree research at The Polytechnic School of The University of So Paulo. Her research is about engineering learning spaces. She also works as a graphic and set designer.

2.8 Coaches



Shelly Goldberg
Contact: shelly.goldberg@gmail.com

Shelly Goldberg was an ME310 alum from 2005, where her team worked on the EADS AugmenTable. Shelly has been at Apple, Inc. for the past 9 years since leaving Stanford. She is now a Senior Manager in the Mac Product Design group, where she leads a team of mechanical and product design engineers responsible for conceiving, designing, engineering, producing, and sustaining the Mac portables and desktops.

Annika Matta
Contact: annikamatta@gmail.com

Annika Matta is a former ME310 student and course assistant with a background in product and user experience design. As an ME310er she worked with SAP to build the Nib, a tablet with a writing experience reminiscent of paper. She graduated in 2013 and now works as a user interface designer at a consumer software startup in the Bay Area.

3 Design Development

Tasked with creating the future of flying for disabled passengers, we carried out process-centric and product-centric needfinding and benchmarking to understand our design space. The insights garnered from these explorations led us to the following key insights which are detailed further in Appendix C. These insights led us to finally focus on both what happens to the passenger and what happens to his/her wheelchair. The following section is here to show the path our team took to get to this design choice.

3.1 User needfinding

Fall quarter was spent primarily focused on needfinding and benchmarking (see Appendix A) in order to get a firm grasp of the problem we were trying to solving. Given that "re-designing the flying experience for people with reduced mobility" is a huge design space with a great number of possible users, we used our findings to further develop our understanding of the user segment with the biggest need as well as their specific burning need. After looking at countless available products and interviewing a myriad of different users, we decided to focus on wheelchair users as our target user.

Throughout our interviews we heard many horror stories about mobility in the cabin and how it affected how wheelchair users prepare for their flights (i.e. ensuring they won't have to use the restroom), how they choose to situate themselves during flight (i.e. choosing to sit in the window seat so they won't be in anyone's way) or whether they even choose to fly. Our final "experience" prototype for Fall Quarter involved the idea of having seats on rails that would automatically adjust width when a person needed to enter or exit a row. This way, the wheelchair user would have more room to get into their seat and would also be able to choose the seat they wanted because the row would shift when someone else needed to get out, freeing the wheelchair user of the guilt of being in the way. This design addressed painpoints we all encounter while flying (moving in a constrained space) yet would significantly improve the experience for our target user.

When we started Winter Quarter we came in with a brand new prospective on the project given that we had just acquired 3 new team members. In order to get the most out of it, we started the quarter by multiple brainstorming sessions in order to identify what were the elements of the aircraft we could change to most improve the travel experience for a wheelchair user- the user we had decided to focus on.

Through these brainstorming sessions we wanted to understand our design space and its limitations. We also wanted to build a strong relationship with our global partners in Brazil and agreed to meet them on Skype at least once a week and share our common work via a Podio web platform. This helped us keep our teams organized ourselves and aware of the other team's progress and allowed us to tackle and learn about different issues during two big steps in our design development: the dark horse and functional prototypes.

3.2 Dark horse

3.2.1 Introduction

Winter quarter began with the first of three prototyping missions, Dark Horse. Named after the horse racing term, this prototyping mission fosters the unimaginable and impossible; improbable solutions to the presented problem from Embraer. The mission called for the brainstorming of out-of-the-box ideas and the creation of a physical prototype for this seemimngly implausible solutions. The learning that occurs from the mission is more important in comparison to the actual building process and it is intended to guide the team toward their final vision.

3.2.2 Benchmarking

During our interviews and needfinding research, we realized carry-on luggage was a huge concern. Currently, luggage is stored in a very burdensome and unintuitive way and with our prototype we sought out to redesign the carry-on luggage experience. Our users have voiced their concerns about not being able to store/reach their luggage as well as the panic they feel when they are not aware of where their belongings are being stored. Our team looked at a couple of different designs out there that use the vertical space within the airplane in a different manner to accommodate both people and luggage in a more user friendly way.

Figure 3.1: *Design that allows for easier luggage storage for all passengers Source: http://www.gizmag.com/future-of-air-travel-comfortable-seating/17751/*

The design shown in Figure 3.1 displays a cabin layout where consecutive rows of seats are on different levels, allowing passengers to store their luggage behind their tray but under the seat of the person in front of them. This design puts luggage at the ideal height for both standing and sitting passengers as depicted by the image in Figure 3.2, a standard design rule for accessibility and mobility.

Another design solution we explored was actually having two seats on top of each other as shown in Figure 3.3. This design opens up the area under the stairs for luggage storage, which could also include a passengers wheelchair, allowing for a less stressful flying

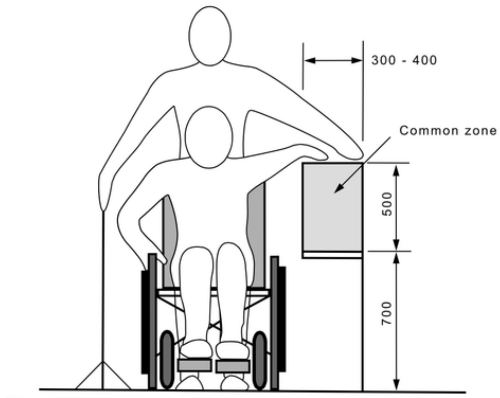


Figure 3.2: *Ideal height for reaching objects for both sitting and standing passengers. Source: https://law.resource.org/pub/nz/ibr/nzs.4121.2001.svg.html*

experience for handicapped users. The bed next to the seat could also be used to provide passengers flying with toddlers with extra room to put them in so that they do not have to sit on their lap throughout the whole flight.

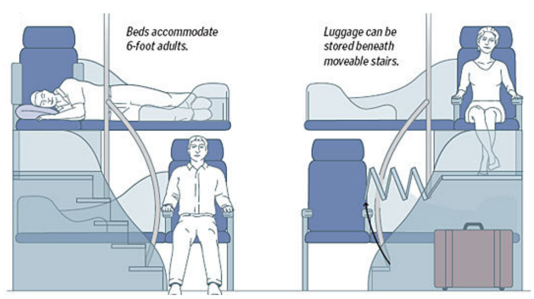


Figure 3.3: *Vertical cabin configuration with luggage storage*

This benchmarking really brought to light the lack on control disabled passengers feel over their belongings. Since they already suffer from mobility constraints, they are not able to fully control where their belongings are stored which causes a huge amount of anxiety. We realized later on that this anxiety was only increased when the object in question wasn't just a bag but rather a mobility device.

Another main concern for our user was the actual transfer process and how they would get from an aisle chair to their seat. We know that today people can use transfer boards, they can be carried by someone else or, if they are strong enough, they can attempt to transfer themselves(although the limited space in the cabin makes this virtually impossible). We found that there are some products on the market utilized in analogous situations that could make the transfer experience better, such as the harness shown in Figure 3.4 or the walker in Figure 3.5. We believed that the walker would be an interesting solution if we were able to add mechanisms that would lower the bar supporting the persons weight to get it closer to the seat and that would swing the blue supports open such that the person would come in contact with the chair. In the end, we decided to opt for a more futuristic vision and decided to widen the airplane aisle and get rid of the transfer all together.

Figure 3.4: *Harness used to get disabled out of the bath.*

Figure 3.5: *Walker that could be adapted to become a better aisle chair.*

3.2.3 Description of the prototype

Currently, people with reduced mobility have to first transfer from their own wheelchair to an uncomfortable and narrow aisle wheelchair. Once boarding starts, the user is brought to his/her seat by a flight attendant or an airline employee and is then transferred to his/her seat, usually by being carried over their shoulders. This process is long, dehumazing and it deprives them from their independence. Since the boarding process is such a pain point for our users, we decided to tackle this problem to improve their experience and give them more independence. Our team thought that if we could enable people with reduced mobility to enter the aircraft with their own wheelchair and then give them the possibility to transfer themselves from their wheelchair to their seat without someone else helping them it would considerably improve their experience.

Helping our user access his/her seat :

Our objective was to enable passengers to enter the aircraft with their own wheelchair and to do so we had to figure out a way to make the aisle wider. Initially we did not want to take into account the constraint of keeping the number of seats in the aircraft the same so we imagined a new cabin layout for boarding. The idea was to have the aisle seats on rails so that they could be moved and lined up with the window seats as shown in Figure 3.6 .

Figure 3.6: *Our first new cabin layout for boarding the plane*

With this system, all the seats would be lined up on each side of the plane and the aisle during the boarding process would therefore be three times bigger than during the flight, giving people with reduced mobility the ability to enter the aircraft with their own wheelchair since the average width of a wheelchair (30 as shown in Figure 3.7), would now fit down the bigger aisle.

But we realized that with this system it would be impossible to keep the total number of passengers on board the aircraft the same since the proposed boarding layout required too much space per seat.

Therefore, we thought of a second cabin layout for the boarding process which would also make the aisle wider but in a more reasonable way. We looked at the dimensions of a standard Embraer plane (Figure 3.8) and found out that if we were able to angle the rows

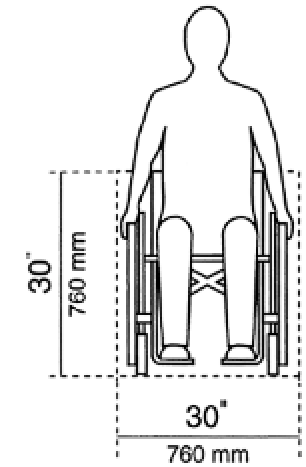


Figure 3.7: *Standard wheelchair dimensions*

by 46.2 (see Figure 3.9) from their current position we could make the aisle wide enough (42.87) to enable our passengers to reach their seats in their own wheelchair while still keeping the total number of seats the same.

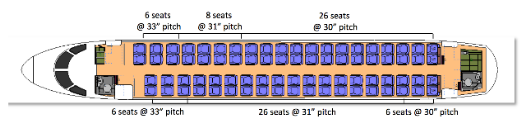


Figure 3.8: *Standard Embraer plane cabin layout*

Our concept was to initially have all of the rows of the plane linked to a mechanism that would rotate the seats before the boarding process, making a wider aisle for passengers. Passengers with reduced mobility who have reached their seats with their own wheelchair would be able to transfer themselves to their plane seats.

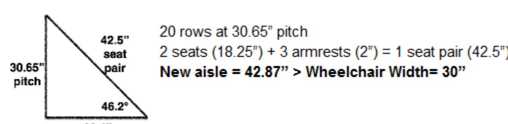


Figure 3.9: *New cabin layout with angled seats for boarding*

Once the passengers are all seated (potentially while the aircraft is taxiing towards the runway) the seats would go back to the standard non-angled cabin configuration for take-off and would remain in that state for the duration of the flight. When the plane stops at the gate and is ready for passengers to disembark, the seats would be angled again and flight attendants would bring passengers with reduced mobility their own wheelchair. This configuration would completely remove the need for an aisle wheelchair.

3.2.4 Learnings

Several classmates and peers were users for this prototype and provided the majority of our learnings. However, some of the learnings came directly from team observations during user testing.

Reconfiguration:

- Our testing revealed that the users were concerned about what would happen to their feet during the transformation of angled seating to the regular configuration and vice versa. Some users suggested the addition of a footrest. But where would the ideal location be? This revelation is very important to our target users because some of them do not have the ability to move their legs out of the way or to move with the chair. This would also mean they would have to manually put their feet on a footrest, and the ideal position of the footrest would need to be designed to help the target users have a better experience.
- A single, continuous rotation mechanism would be better than multiple discrete ones for all passengers. The users commented that the mechanism should be similar to the movement of a car seat because it so slow it is barely felt. In addition, the window seat felt like it experienced less movement partly because the displacement was smaller than for the aisle seat. This is important due to the benchmarking findings of last quarter that showed that the target users preferred the window seat over the aisle seat.
- Passengers would be able to board faster due to a wider aisle that allows for easier maneuvering of the cabin space. The wider aisle would allow for a double line of traffic to head down the aisle instead of one line.
- The wider aisle would allow for a wheelchair to be able to maneuver down the aisle to the seat. The wheelchair would have space on both sides as it moves down the aisle to allow for a comfortable fit. It would be easier for a mobility challenged passenger to get into the aisle seat but they may need a handle to access the window.
- The legroom is the limiting factor with the reconfiguration. When the seats are in the angled arrangement, the window seats have less legroom than in the normal configuration. The angle of the seats would need to be reconfigured to allow for a smaller angle with more legroom but still create a wider aisle with plenty of tolerance for a wheelchair. However, it was noted that it is easier to board and deboard with angled seats. Thus, angled seats would be the preferred configuration for boarding and disembarking from the plane.
- It may be possible to achieve the desired effect by only rotating several of the aisle seats, allowing increased access to those seats specifically.

3.3 Going Back to The Need

Following the wrap up of our prototypes, the team decided to take a step back to figure out if we were truly solving the burning need. We analyzed all of our prototypes up to this point and saw an overarching theme we were trying to address: giving our users their independence back. With independence as our umbrella, our team looked at the whole flying experience piece by piece (see Appendix B), with the purpose of identifying the points at which independence truly breaks down.

We went back to our needfinding from fall quarter, sent surveys to both old and new contacts and carried out more interviews. All of these allowed us to confirm that mobility within the cabin is, in fact, a huge issue. However, this new information also brought to light a burning need we had initially discarded fall quarter - wheelchair storage. Furthermore, both of these needs stem from the same procedure the wheelchair user is forced to go through: that of giving up his/her wheelchair.

The Problem

Imagine you are a wheelchair user. You arrive at your gate, ready to board your plane, and are told you need to hand over your wheelchair for storage in the cargo hold. At this point, you ask yourself two questions:

1. How will you move now that you don't have your mobility device?

2. Will your mobility device arrive safe and sound at your destination?

The following sections will detail the user quotes and research that led us to choosing both of these directions.

Mobility In the Cabin

In order to confirm the need for improving mobility inside the cabin, we asked our contacts to fill out a survey that would give us a better idea of what exactly would be the most helpful for them. The full survey responses can be found in Appendix D.

When asked about the prospect of having an "on demand" powered aisle chair, users were keen on the independence it would provide as it would allow them to "board the plane at [their] own pace and go to the restroom when [they] please." One of our respondants stated that such a device would allow them to "feel like a passenger for a change and not a sack of coffee beans". This quote clearly depicts the struggle users currently go through when they give up their mobility device and along with it, their independence.

Our team assumed that having such a chair would be a great improvement to the experience yet we could not figure out if the chair had to be completely autonomous and show up on demand or if a flight attendant could bring it to the user. What we found is that users would much rather have automated systems than feel the guilt of inconveniencing someone else to do something for them, even if it only meant they had to bring them a chair just like they bring any passenger a drink or snack.

Finally, we decided to delve deeper into the transfer process. One of our interviewees, Scott Rains, had told us about a friend who was injured as he was being transferred from the aisle chair into his airplane seat. The airport personnel did not lift him up high enough and his bottom was hit against the armrest. Given that wheelchair users have thinner and more sensitive skin in this area, this caused him lots of pain and even resulted in 3 weeks spent at the hospital. While injuries are not the norm, it is a very dehumanizing and undignified experience, just as Esther Appleyard-Fox states in her tweet in Figure 3.10.

Wheelchair Storage

Figure 3.10: *Tweet from Esther Appleyard-Fox explaining how she feels when she is transferred when she flies.*

As we were looking for more data to substantiate our claim that mobility in the cabin was, in fact, the problem to solve, we stumbled upon another huge problem. During our interview with Aubrie Lee, a student in Product Design at Stanford University who is also a wheelchair user, she mentioned that while mobility inside the cabin is a problem, it is such a short part of her experience that she hardly remembers it as being painful. Part of this is due to the fact that when she travels with her dad he carries her down the aisle which can be more a comforting bonding moment than dehumanizing. However, she emphasized that"the most emotional part of [her] flying experience is having to give up [her] chair and waiting for them to give it back." For her, giving up her chair is "a huge source of anxiety - as soon as it is out of [her] sight, [she doesn't] know where it is", whether it is going to come back to her unharmed or whether it is even going to make it to her destination.

In order to understand what can happen to a mobility device on during its transfer to the plane and once in flight, we interviewed an Air France employee working at Toulouse-Balgnac airport (France). All the details form this interview are in Appendix E. It shows how airlines handle wheelchairs from the jetway to the cargo hold and gives some insight on the type of damage that can occur.

A study by Trailblazers **??**, a group of disabled campaigners across the UK who tackle social issues affecting young disabled people, shows that 60% of wheelchairs are damaged when traveling with an airline. As David Gillon says in Figure 3.11 below, we must do better.

Figure 3.11: *Tweet from David Gillon on Trailblazers study that shows 60% of wheelchairs are broken in airline travel.*

Stories like the one shown in Figure 3.12 are not uncommon, with wheelchairs ending up like the one in Figure 3.13 due to airport personnel attempting to dismantle it or from the wheelchair moving around in the cargo hold.

There are also instances of the wheelchair not even making it to the destination, just like what happened to Josie shown in Figure 3.14.

Now to put this into perspective, imagine that you are a wheelchair user and you rely on your mobility device for you independence. This wheelchair isn't just an object, it is your legs, your independence, part of who you are. As Aubrie stated my wheelchair"is in limbo between being a physical object and half of me." Now imagine that after your flight, you no longer have the ability to move. This is a HUGE problem for our users, one we need

Figure 3.12: *Anecdote from a Trailblazer that had her wheelchair broken during flight.*

Figure 3.13: *Picture of a broken wheelchair after a flight.*

to focus on.

Through the user interviews, surveys and research depicted above, we have proven to ourselves, our advisors and our users that these are the 2 most compelling needs we need to address for our users and we decided to focus on both for the Functional Prototype.

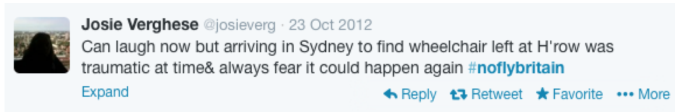


Figure 3.14: *Tweet from Josie Verguese about her experience when her wheelchair did not make it to her destination.*

3.4 Functional Prototype

The final prototyping mission during Winter Quarter was the Functional Prototype in which we had to create a working prototype with system integrations using materials that could be present in a final vision. The functional mission leads the team into the Spring Quarter by aiding in the finalization of the vision and creating an actionable direction. To find the direction and the vision, more needfinding might have to take place to confirm a need and verify the thinking and decisions of the team. The Functional mission serves as the stepping point from iterative prototyping missions to the iterative final product mission.

3.4.1 Wheelchair Storage Benchmarking

Before prototyping our first wheelchair storage device we executed a larger search both for existing wheelchair storage and protection devices as well as methods for securing wheelchairs. We found several relevant patents for protection devices as well as regulations for securement, relating primarily to bus travel.

Securement
The United States Department of Transportation's Federal Motor Carrier Safety Administration publishes a wide array of regulations. Included amongst the regulations governing school bus safety, Federal Motor Vehicle Safety Standards §571.222 [11], are a number of requirements for how wheelchairs must be secured while in transit. The section requires that the wheelchair is secured in four locations, with an additional three point mounting required to secure the student. Similar topics are covered in further regulations, such as Title 49 §38.23 [9]. Figure 3.15 demonstrates the general setup.

Storage
A group at Utah State University performed market research [13] and designed a prototype wheelchair storage container, determining that over 50% of their surveyed users might be or would be interested in their device. A drawing of their box, which provides several securement methods for wheelchairs and other objects, can be seen in Figure 3.16; more information is in US Patent application 12/142,662.[21]

3.4.2 Wheelchair Storage Description

As our last round of needfinding and research had brought to light the importance of wheelchair storage, the Stanford team decided to prototype the first version of what a wheelchair storage device could look like. This first prototype, shown in Figure 3.17, focused on having a rigid floor to distribute the weight of the wheelchair as well as a place to attach

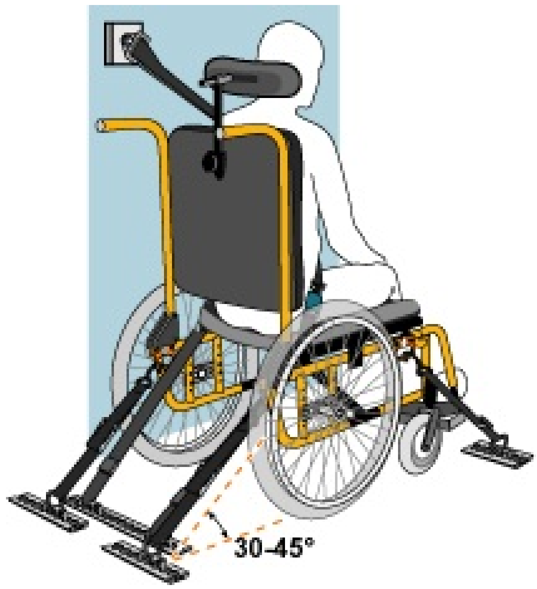


Figure 3.15: *Wheelchair tie-down setup for van travel*

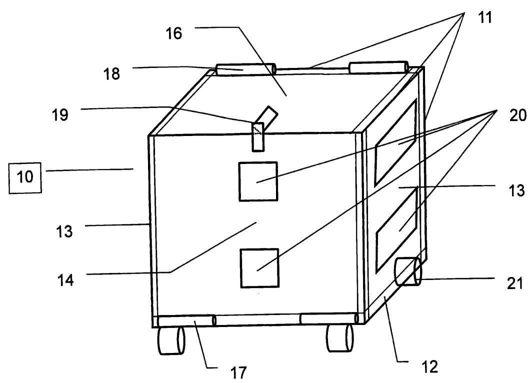


Figure 3.16: *Storage container*

the hooks that would secure the wheelchair down. It had rigid walls that would serve to protect the wheelchair (as if it were a box) that were also hinged at the side so they could be moved out of the way as the handler was tying down the wheelchair. We opted to use the straps and hooks mechanism that people are already familiar with from buses and trains to create a sense of trust and security.

Since many of the stories we encountered about wheelchairs being damaged involved airport personnel attempting to disasemble them or handling them poorly, we wanted the wheelchair owner to be present during the securing process, just like they are on a bus or train. This way, the wheelchair user could help the airport personnel speed up the process by providing information about their specific wheelchair and how it should be secured as well as ensure that the airport personnel is not accidentally mishandling their mobility device. At the end of the securing procedure, the container is to be closed up, giving the

Figure 3.17: *First prototype of wheelchair storage device.*

user satisfaction in knowing that their wheelchair is secure and will arrive safely at their destination.

Because the wheelchair user is present while their wheelchair is secured, we must also enable an easy transfer from their personal wheelchair onto the aisle chair. As shown in the rendering Figure 3.18, right now this is accomplished by bringing the transfer chair close to the passenger's chair that is already secured. This further explains our use of hinged walls and puts a hard constraint on our system- in order for the wheelchair user to be able to easily transfer once their wheelchair is secured, there must be a way to "remove" all walls during securing and "reappear" them once the wheelchair is stored for the wheelchair to be protected.

While there are certain hard constraints that were not met with this protoype, we are keeping them in mind and will insitute them in future iterations. We know the container must protect the wheelchair but also fit through the door to the cargo hold as well as fit inside the cargo hold. It needs to be movable, as the wheelchair storage container must travel from the jetway down into the cargo hold. This product must help the luggage handler create a connection with the wheelchair user and gain empathy for the importance of the mobility device that is in their hands; the more important they know it is, the better they will treat it. Finally, the storage device must be lightweight as this is of utmost importance to Embraer and the airlines they serve.

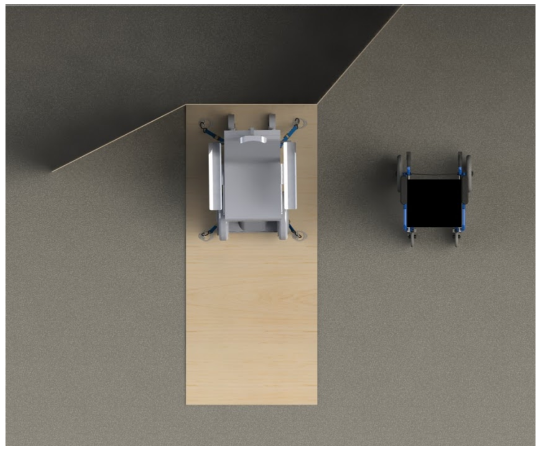


Figure 3.18: *Rendering of wheelchair and aisle chair side by side once wheelchair has been secured.*

3.4.3 Wheelchair Storage Learnings & Next Steps

From our first prototype we were able to learn a myriad of things. Primarily, we realized that using a mechanism that wheelchair users are already familiar with is a huge plus; it provides them with a feeling of trust and security that their wheelchair will not be damaged throughout their flight. Thus, we suceeded at providing the user peace of mind with this device. However, we realized it is pretty difficult to line the chair up in the correct configuration in between the protruding hooks that strap the wheelchair to the platform and thus it would be best to have the hooks be flush against the top of the base so they didn't get in the way of the wheelchair manuevering. We had several users go through the process of securing the wheelchair and found that having simple straps and hooks can be confusing and time consuming. Thus, it is best to have retractable hooks that come out of the base so that the tension is automatically set, making the job of the securer much easier.

For a process that takes place prior to a flight, time efficiency is extremely important. Airport personnel are very crunched for time as they cannot afford to have any process delay the flight and push their schedules back. This means having very clear instructions for both the wheelchair user as to what's expected of them, where to park and how the process will unfold, as well as for the person securing the wheelchair. For the wheelchair user, we are thinking of ways to transfer this imformation prior to their flight, knowing that most disabled passengers keenly do their research before flying. Having a video that shows the whole process would allow the wheelchair user to be prepared to tell the securer exactly what the right attachment points are and how to best secure the wheelchair down. On the other hand, it is important for the securer to know the correct order of the procedure which can be accomplished by numbers next to each hook as shown in Figure 3.19 and simple drawings depicting what's next.

Finally, our user testing confirmed our theory that we would need retractable walls. Not only were they necessary for the user to easily transfer onto the aisle chair but they also made the securing process much easier. The back wall, however, was still rigidly attached. This, we found, was not ideal as it made the two hooks in the back extremely hard to reach.

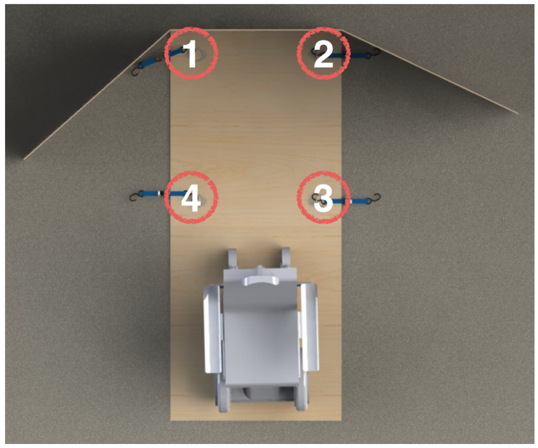


Figure 3.19: *Securing the wheelchair*

With this information in mind, we have been brainstorming different design ideas that would enable for the walls to be completely out of the way during boarding and securing yet would be present during flight to protect the wheelchair from being damaged. We have thought about accordion or telescoping walls as well as having inflatable walls. We really liked the idea of inflatable walls as it provided the wheelchair with protection from damage yet could be blown up to accomodate different types of wheelchair sizes and would be extremely light weight. A preliminary mock up of a possible vision can be seen in Figure 3.20 With this in mind, we began a feasibility study to understand how possible the use of inflatables would be in the application.

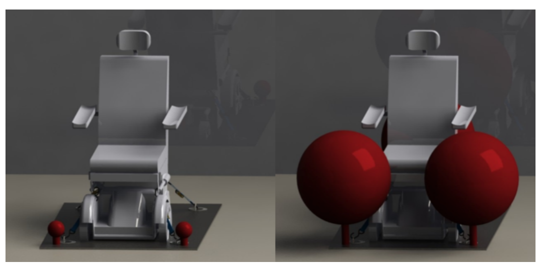


Figure 3.20: *Rendering of a preliminary idea of what an inflatable "wall" could be.*

3.4.3.1 Inflatable Materials

In order to test the feasibility of an inflatable device in the cargo hold there were a few problems that needed to be addressed.

Pressure

The cargo hold of many planes is not pressurized in order to save on costs. One of our goals was to determine if an inflatable device to protect the wheelchair would pose a problem in low pressure situations. Initially we were unsure as to what the pressure in the cargo hold would be, and as such decided to design for the worst case when the pressure is the same inside the cargo hold as outside.

It was important to design for this case as regardless of the pressure in the cargo hold, in any emergency situations where the cabin lost power, we would not want any problems to arise in the cargo hold potentially making the situation worse.

Temperature
A second potential problem with an inflatable device in the cargo hold is that the luggage does not require the same heating and insulation as passengers. While it may not get as cold as the air outside (approximately -40 C) in normal situations, we must design the device to work reliably even in case of an emergency.

Testing
While it may be possible to test the effects of pressure on an inflatable device without taking it into a plane by increasing the pressure inside the inflatable device (since the pressure differential is the most important aspect to test), its much more difficult to test this pressure differential at a realistic temperature on the ground. Instead we decided it would be best to get an inflatable structure up to approximately the height of a plane and determine what failure modes, if any, would be present.

In order to do this we attached a fully blown-up arm flotation device to a weather balloon. This balloon was released in order to take the device into the upper atmosphere where it would experience similar conditions to those of an airplane. While it ignores some effects from the natural plane insulation, its a more extreme environment in all cases so its a good measure of feasibility.

Results
Unfortunately the barometer which was being used as an altimeter for this experiment failed, and as such we were unable to get reliable altitude data on the flight. However by looking at the videos returned from the launch, and given the group's prior experience with weather balloons, a reasonably reliable estimate of 50,000 - 60,000 ft can be estimated for when the flotation device popped,an altitude which is significantly higher than an Embraer jet flies (37,000 ft maximum). We were able to see small water droplets on the larger weather balloon which froze at high altitudes forming ice crystals.

This experiment showed us that an inflatable solution would in fact be feasible if it was something we wanted to pursue.

3.4.3.2 Wheelchair Tracking Concept

We didn't just want to stop at protecting the wheelchair, we also wanted to give the wheelchair user information regarding their wheelchair. We envision a wheelchair tracking system in which each storage container has a unique identifier, such as a QR code, which can be tracked as the container moves from the jetway to the tarmac, into the cargo hold, and then back out again after landing. The identifier can be recognized at a series of checkpoints, which need to consist only of a webcam if a QR code is used. Such a system will provide our users with the peace of mind that their mobility device has not been mistreated or left behind.

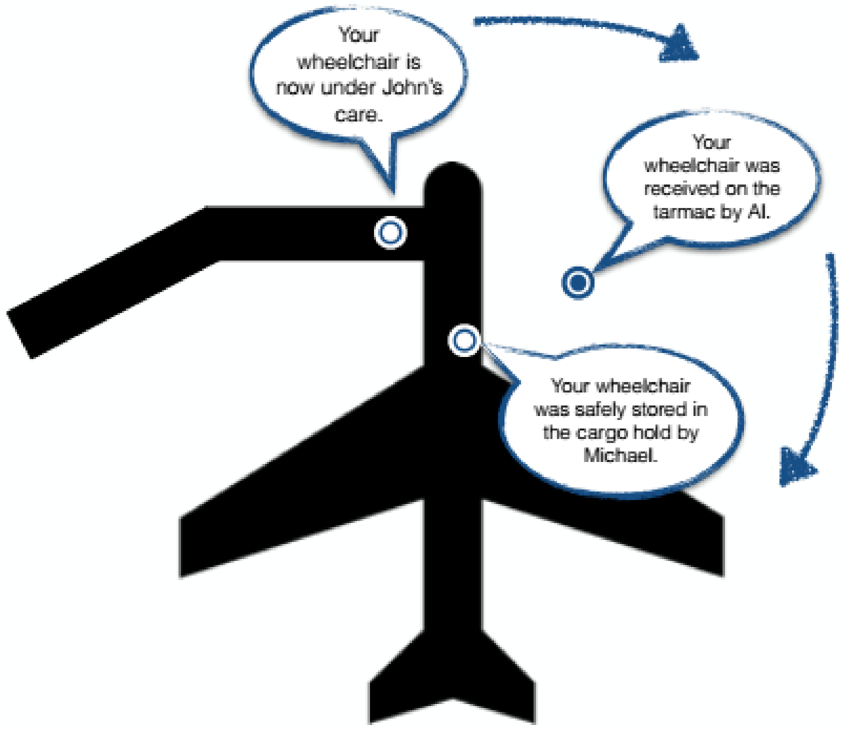


Figure 3.21: *Wheelchair tracking system overview.*

An important aspect of this system is that it can also help develop empathy on the part of the baggage handlers. Wheelchair users will have the opportunity to tip handlers who've done a good job in managing their mobility device, both providing an incentive for doing a better job while also helping form a closer connection between two people who may never meet face to face.

An overview of the system and one potential user interaction are in Figures 3.21 and 3.22.

3.4.4 Transfer mechanism from aisle wheelchair to seat

Once the problem of wheelchair storage storage is addressed, there is still one that needs to be solve: how do disabled passengers reach their seats once their mobility device is stored in the cargo hold?

Our benchmarking and interviews showed us that the transfer is one of the most demeaning moments for the handicapped, so the team focused on making the user more independent while transferring.

Figure 3.22: *One possible minimal interface for user interaction with the tracking system.*

3.4.4.1 Candidates

The team agreed that the prototype should make the transfers inside the airplane so easy that the person on the aisle wheelchair could make the transfer by himself without major efforts. After a brainstorm, the team had two ideas for making this transfer: a sliding seat and a comb mechanism in which a male/female coupling system would allow the user to be transferred. The former mechanism was chosen because it was simpler to build and lighter, as it did not require a motor to lift the user or a counterweight to stabilize the chair. With that in mind, we benchmarked existing mechanisms that were used to make linear transfers. These mechanisms are listed below:

Linear Guide
The rails would be installed on the aisle wheelchair and the seat, while the carriage would be installed on the cushion. The cushion would be able to slide from one seat to the other if the seat and the wheelchair were correctly paired.

The negative aspect of the linear guide is that it would require a milimetric precision when pairing the aisle wheelchair with the seat. We found this to be unrealistic, especially when we took in consideration that the solution would not necessarily be automated.

Conveyor rollers
The mechanism would use the same principles of a conveyor table, where one can move heavy objects by sliding them on top of conveyor rollers. This mechanism would be installed on

Figure 3.23: *Linear guide*

the seat and the aisle wheelchair, allowing the cushion with the user to slide.

Figure 3.24: *Conveyor rollers*

Caster transfer table
The mechanism would work as the previous one, where the cushion would be able to slide from the aisle wheelchair to the seat, but using caster spheres instead of conveyor rollers. These spheres are lighter than the previous solution and as a result were more appropriate for our design.

Unfortunately, for our first prototype, we could not find a supplier that could provide the components in time to build the prototype with an affordable cost, so the mechanism with they conveyor roller was chosen. For the final prototype, the team was finally able to get the caster spheres into the device and implement them.

Based on what was discussed above, for the first version, the team decided to implement the seat with conveyor rollers to enable the sliding movement of the seat (Figure 3.26). With the same mechanism installed on the aisle wheelchair, one would be able to easily transfer oneself laterally from the aisle wheelchair to the seat and vice versa without major efforts.

Figure 3.25: *Ball transfer table*

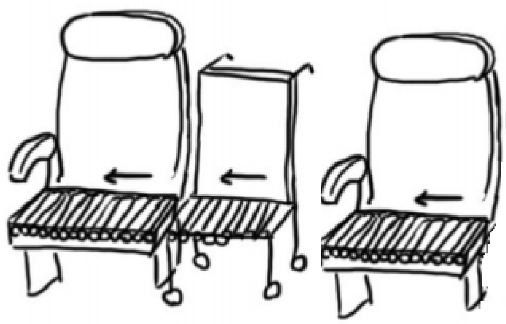


Figure 3.26: *Idea of the mechanism*

3.4.4.2 Building our prototype

In our first attempt to build the prototype (Figure 3.27) the high friction made the sliding movement extremely difficult. The main reason for this failure was that we incorrectly assumed that the aluminum cylinder directly attached to the wooden structure would be enough to make the rolling movement.

Figure 3.27: *First building attempt*

In order to overcome this issue, we added bearings to both ends of the cylinders (Figure 3.28). This solved the friction problem, making the whole mechanism work as we had designed it (Figure 3.29).

Figure 3.28: *Fixing bearings*

Figure 3.29: *Final mechanism*

Next, we tested the sliding mechanism with different types of materials on the cushions base. First we tried adding an adherent surface (rubber) to see how the mechanism would slide. We noticed that it was quite hard to overcome the static friction. Afterwards we tried adding a semi-rigid plastic base. Although the transfer was quite easy, one could feel the cylinders while sliding. As a result, we chose to use a hard flat base under the cushion to make it slide smoothly.

3.4.4.3 Learnings

We tested our mechanism with a number of able-bodied users as we were not yet confident that it was safe enough for a disabled person to use it. We learned alot from these testing sessions and it thanks to these learnings that we were able to create a product that could be safely used by a disabled person.

- The friction between the aluminum cylinder and the wood is too intense for a user to transfer from one seat to another.
- The space between the cushion and the mechanism must be considered to avoid increasing the friction and the looseness of the cushion (due to a rotating movement).

- Cushion must be firm enough so that the user does not feel the cylinders and to allow proper transfer.
- Correct alignment between the aisle chair and the seat is very important.
- Armrest must be retractable.
- It is possible, quite easy and comfortable to make a lateral transfer.
- Understanding how the mechanism will be used is crucial for achieving a user-friendly design. For instance, by simulating how a transfer would be made by an user, we noticed that it made sense to link the latching mechanism with the movement of the armrest. Armrest up, seat unlocked and vice-versa. We had several options for locking the seat, but we insisted in finding one that would be intuitive for the user. This proved to be a good design choice until we realized that users may sometimes want to put the armrest up to get comfortably in their seats and not just because they want to transfer.
- Our conveyor rolling mechanism is not viable because it required too many alterations of the airplane and added too much weight.

3.5 Our vision for the final product

From all the prototypes our team built during winter quarter we decided to combine the two products: the wheelchair platform and the transfer mechanism into one single enhanced experience for passengers with reduced mobility.

Figure 3.30 shows the different steps our user should go through in order to get a much better flying experience than what they have today.

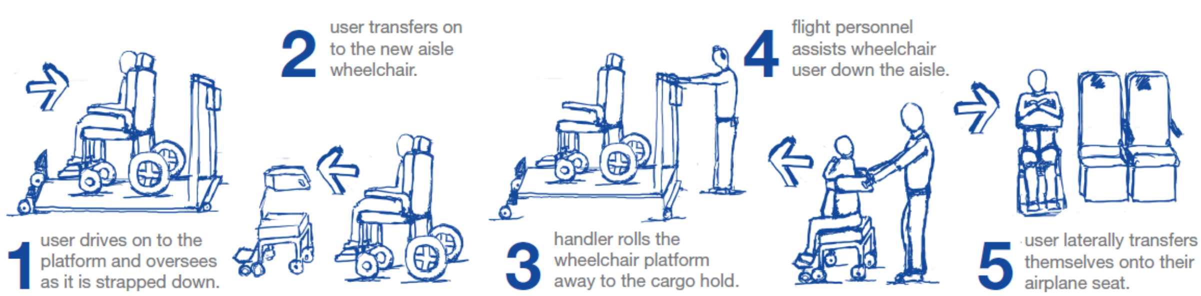


Figure 3.30: *Our vision for the final product*

In order to include the two products (wheelchair platform and transfer mechanism) into the one single experience for the passengers, we realized that our team would also have to completely redesign the aisle wheelchair to enable a smooth transfer from the passengers wheelchair to the airplane seat.

With this vision in mind, our objective for the spring quarter was to build and test with users:

- The wheelchair platform
- The redesigned aisle wheelchair
- The transfer mechanism integrated into an airplane seat

All the design requirements associated with these products are presented in the next section and the design specification section gives many details about the design solutions we implemented for each system.

Unfortunately, due to time constraints, we did not get th opportunity to develop and create a smartphone app that would provide wheelchair users with information about their trip and the way their mobility device is handled by the airline. We instead decided to focus more on the hardware than the software but additional information about what we envisioned for the app can be found in Appendix G.

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4 Design Requirements

The following requirements are based on the problem statement, team brainstorming, user needfinding, and prototypes described in the design development section. Some of this requirements also come from a geometrical and structural analysis of the plane (cabin and cargo hold) that are detailed in Appendix F.

This requirements fall into two categories: Functional and Physical. Functional requirements detail what a design should do, its actions and capabilities. Physical requirements describe the constraints on the manifested system components.

We have divided the functional and physical requirements into two main parts:

- Requirements for the wheelchair platform that will improve wheelchair storage from the jetway to the cargo hold
- Requirements for the transfer mechanism that will enable wheelchair passengers to reach their seats in a more comfortable and independent way

4.1 Functional Requirements

Wheelchair storage device

In order to prevent wheelchairs from being damaged our team wants to design a platform that will enable baggage handlers to move the mobility device from the jetway to the cargo hold. This platform will be composed of four parts:

- A pallet that will support the wheelchair
- A moving mechanism to enable transport from jetway to cargo hold
- Electronics that will identify who is handling the wheelchair and detect mishandling
- A handle that will enable baggage handlers to interact with the platform

The functional requirements for each of this part are in the tables from 4.1 to 4.4.

Requirement	**Metric**	**Rationale**
Support Load	Platform must be able to support a minimum of 450 lb	Platform must support the weight of the power wheelchair and the passenger
Lightweight	Platform weighs less than 60 lbs	Platform must not add substantial weight to the airplane's payload
Wheelchair Climbable	Platform is less than 1.5 inches high	The wheelchair cannot climb on top of the platform if it is too high
Platform Structure	Platform must not deflect more than .5 inches when the wheelchair is on top	Platform must be reinforced in places where it is likely to deform
External wheels	Platform does not use wheelchair wheels for mobility	Handlers often break wheelchairs by trying to shift their gears
Transition from Movable to Stationary	Needs an actuator that activates moving mechanism in less than 20s	Needs to shift from moving to stationary quickly depending on the situation.
Time efficient	Putting the wheelchair on top of the platform and securing it should take less than 5min	Baggage handlers and airport personnel are busy, since they also have to deal with luggage and other passengers
Wheelchair Attachment to Platform	Platform has straps for the wheelchair with placement conforming to transportation regulations: 36 CFR 1192.23, D2	Wheelchair must be rigidly attached to platform using a system that wheelchair users already trust and will provide them with peace of mind
Fatigue	Platform must be able to withstand 5000 cycles	Platform should be replaced sparingly.

Table 4.1: *Functional Requirements for the Platform*

Requirement	Metric	Rationale
Moving Load	Wheels have to support at least 200 pounds	The heaviest power wheelchairs can be up to 200 lbs
Resistant Wheels	Wheels have to withstand and overcome friction forces found in rough terrain	Our system will be used on the tarmac as well as on the jetway
Withstand stationary load	Parts in contact with the floor must be able to support 450 lbs	Person will be driving the wheelchair on to the platform thus it will have to withstand the weight of power wheelchair + person (max 250lbs)

Table 4.2: *Functional Requirements for the Moving Mechanism*

Requirement	Metric	Rationale
Support Load	Handle must be able to move a load of at least 200 lbs without deflecting more than 1in	Handler needs to be assured that the handle can push the required load
Ergonomics	Handle must comply with standards for pushing heavy items	Handler must exert minimal force to move platform along
Electronics Housing	Capability to hold electronics	Handlers need an easy and quick access to the RFID antenna.

Table 4.3: *Functional Requirements for the Platform Handle*

Requirement	**Metric**	**Rationale**
Handler Check-in	Electronics include an RFID antenna that recognizes the RFID tag in their gloves	Handlers' accountability will increase if they know that others are aware that the wheelchair is their responsibility
Instantaneous Feedback	Feedback for successful check in is received within 10 ms	Handler must immediately know when they have successfully checked in so they can continue doing their jobs
Visual Feedback	Electronics includes highly visible LEDs	Visual feedback is easy to spot. Handlers are in a loud environment and are wearing thick gloves so auditory and tactile feedback are out of the question.
Detect Free Fall and Mishandling	Electronics include an accelerometer that is calibrated to detect any acceleration greater than 14 Gs that are shorter than 12.5 ms in duration	Airlines needs to be notified of any falls or hard impacts so they may appropriately prepare and notify the wheelchair user
Wireless Connection	Electronics have embedded wireless communication capabilities	Passengers should know who is handing their wheelchair and airlines should know who is responsible when mishandling occurs so they may take action
Easily Rechargeable	Battery should only need to be charged for 5-6 hours at a time	Battery should be able to get by only being charged during airport down-times (e.g. overnight)

Table 4.4: *Functional Requirements for the Platform Electronics*

Wheelchair transfer mechanism

In order to improve the boarding experience for disabled passengers, our team decided to redesign the aisle wheelchair by making it possible for a wheelchair user to transfer himself from the wheelchair to his seat without needing to be carried by flight attendants. The system that we are designing to give wheelchair users their independence back will be composed of seven parts:

- A chest rest that will equip the aisle wheelchair in order to make its use more comfortable and less degrading for passengers
- A locomotion mechanism that would enable wheelchair users to move through the cabin
- A cushion that will support disabled passengers
- A sliding base that will enable transfer from the aisle wheelchair to the airplane seat without external assistance
- A wheelchair structure that will completely be redesigned to accommodate the sliding base and the chest rest
- A footrest that will enable disabled passengers to have support for their legs
- A new airplane seat that will be adapted to the sliding base

The functional requirements for each of this part are in the tables from 4.5 to 4.10.

Requirement	**Metric**	**Rationale**
Removable from Base	There is a latching mechanism on the sliding base to attach/detach chest rest	The rows must be unobstructed to allow other passengers to exit in an emergency and the chestrest must be available for other passengers that may request the aisle wheelchair.
Adjustable Height	Minimum vertical variation is 6in	It has to be adjustable to people with different body types
User Support	The mechanism shall keep a 150kg sandbag securely positioned during transfers	The mechanism shall provide safety and keep the user erect and attached to the structure
User Comfort	There shall not be contact areas with a pressure above 200 mmHg	We want to avoid bruises or sores on the user's body
Body Support	Rigid structure should withstand a 330lb person leaning on it	It allows the user to feel secure while being transferred
Ergonomic Height	Handles located 30in above ground	Allows assistant to easily push/pull the wheelchair

Table 4.5: *Functional Requirements for the Chest Rest*

Requirement	**Metric**	**Rationale**
Steering Radius	Wheelchair can steer in a 15in radius	Allows for maneuvering inside the tight spaces in the plane
Brakes	Wheelchair does not move more than 5mm after being locked (under normal circumstances).	Allows personnel to securely lock the wheelchair to avoid accidents during transfer

Table 4.6: *Functional Requirements for the Locomotion Mechanism*

Requirement	**Metric**	**Rationale**
Foot Support	Has a support for passengers feet with dimensions of 15in x 6 in	To prevent the feet from being dragged.
Foot Securing	Has a mechanism that keeps the user's feet away from obstacles on the aisle.	To keep the user's feet secure while moving the wheelchair.

Table 4.7: *Functional Requirements for the Footrest*

Requirement	Metric	Rationale
Adjustable	It should be at least 4" tall and the filling/stuffing should be adjustable (different pressure/padding)	Its common for wheelchair users to suffer injuries for seating for long periods of time. Cushion must be adjustable to user to provide them with comfort
Removable	There is a detachable mechanism on the cushion	Allows for proper hygienization and maintenance.

Table 4.8: *Functional Requirements for the Cushion*

Requirement	Metric	Rationale
Non-Aligned Lateral Transfer	Allows a transfer with a gap of 2in and a .4in tolerance between the seat's cushion base and the wheelchair's cushion base	Makes the lateral transfer easier and faster
Independent Transfer	A maximum 50N force will be required for the transfer	Allows for user to independently transfer themselves without the help of others
Secure	Has a latching device that latches it on to the seat and wheelchair	Avoids undesired lateral transfers and consequently accidents.

Table 4.9: *Functional Requirements for the Sliding Base*

Requirement	Metric	Rationale
Maximum Load	Must withstand a 150kg load	Wheelchair must be secure enough to be used by passengers. Due to the restriction of the size of the aisle of the airplane, people that are extremely obese were not considered on this design.
Chair Mobility	Chair has wheels that can move with minimal force	The chair must be able to easily move inside the aircraft.

Table 4.10: *Functional Requirements for the Wheelchair Structure*

4.1.1 Functional Constraints

Wheelchair storage device

- Due to FAA regulations and flight requirements the platform protecting the wheelchair must withstand 3 G's.
- The platform cannot damage the space or items within the space during its operation.
- The electronics will require a power source (battery) to perform some of its functions.
- The battery should satisfy the DOTs Hazardous Materials Regulations (HMR; 49 CFR parts 100-185).
- The entire device needs to be approved as safe for air travel.

Wheelchair transfer mechanism

- Due to FAA regulations and flight requirements every element that goes inside the cabin must withstand 6 G's.
- The redesigned aisle wheelchair must be as safe as the standard aisle wheelchair operated today.
- The new aisle wheelchair has to operate in the constrained space of the airplane aisle.
- In case of turbulence, the wheels of the new aisle wheelchair must be locked.

4.1.2 Functional Assumptions

Wheelchair storage device

- Since the straps that are used to attach the wheelchair to the platform are the same as bus straps, wheelchair users are assumed to already be familiar with them. The use of this mechanism should provide them peace of mind since they already trust it.
- The platform configuration changes (rests on the wheels to be moved or rests on the platform to be stored) will be triggered by baggage handlers acting on an electric jack.
- Baggage handlers will be wearing their gloves with the RFID tag every time they handle a wheelchair and use our platform.

Wheelchair transfer mechanism

- All aisle seats that will be used by wheelchair users must have retractable armrest. It must allow the mechanism to slide without any obstacles in its way.
- The passenger will always be accompanied by a flight attendant to guarantee the safety of the passenger and to pull/push the aisle wheelchair.

- Tetraplegic passengers will always be accompanied by a travel companion/assistant. Because of regulation (ANAC) and their reduced autonomy, tetraplegic users are not allowed to fly alone.

- The airplane seat must withstand 19 G's during takeoff and landing. This is what the FAA requires in order to make sure seats can withstand any type of accident happening during takeoff or landing.

4.1.3 Functional Opportunities

Wheelchair storage device

- Our platform must be intuitive to use. A baggage handler should know how to attach a wheelchair to the platform after a 15 min training.

- Ideally the platform should have a braking system for the wheels to prevent it from moving too fast on a sloped surface. A braking device would allow handlers to have better control of the device.

Wheelchair transfer mechanism

- Although we are designing for a paraplegic user, the transfer mechanism shall also allow a tetraplegic user to be transferred from the aisle wheelchair to his/her seat with assistance. In this case, it should be a more pleasant experience since the assistant would not need to lift the tetraplegic user like they do today.

- The chest rest makes frontal transfer possible. Today, this cannot be done due to the current aisle chair dimensions.

- It reduces the risk and liability associated with transfer because no one has to carry the disabled passenger. The chest rest is here to avoid human contact that can be unpleasant and/or source of accidents.

- The chest rest can facilitate paraplegic passengers using the restroom.

4.2 Physical Requirements

The physical requirements of the system explain the physical appearance and structures chosen for each part of the devices.

Wheelchair storage device

The physical requirements for the wheelchair storage device can be found between Tables 4.11 and 4.13.

Requirement	Metric	Rationale
Non-intrusive RFID Tag	Tag is built into handler's current equipment and cannot be felt when not in use. We have selected to imbed the RFID tag into the gloves	Tag should seamlessly integrate into their current equipment in order to reduce friction
Intuitive Check-in	There is a mark on the appropriate finger that is to be used to check-in	Wheelchair handler needs to knows exactly what finger to use to check-in
Thin Electronics Enclosure	Enclosure thickness cannot be greater than .125in	RFID tag needs to be max .5 away to be recognized by the antenna
Package Modularity	Enclosure can be opened and electronics can be removed and replaced	Electronics need to be removable in case battery power runs out or a component needs to be replaced
Easily Located	Electronics box is stands out because it is bright blue and is located on platform handle	Handler needs to be able to easily find the electronics box in order to check in.
Attachable	Enclosure is attached to the handle	Electronics must travel with the wheelchair platform at all times and be easily accessible by the handler
Lightweight Enclosure	Enclosure does not weigh more than .5 lbs	Every ounce of weight costs the airline money

Table 4.11: *Physical Requirements for the Electronics*

Requirement	Metric	Rationale
Floor Safety	Surface area in contact with the floor is greater than 24in^2	Reduces probability of cabin floor failure
Lightweight	Weighs less than 60lbs	Each extra lb costs money to the airline

Table 4.12: *Physical Requirements for the Platform*

Requirement	**Metric**	**Rationale**
Handle	Platform has an attached handle	Wheelchairs are often broken due to handling mistakes. By providing the handler with a handle independent of the wheelchair that they can use to move the wheelchair from the jetway to the cargo hold, we are reducing the chance of a mishandling accident
Wide Handle	Platform has a 3ft wide attached handle	The wider handle allows for the handler to place his/her arms farther apart and exert more force to move the wheelchair.
Handle Height	Handle is at a height of 4 ft 6 in above the ground	Handle is at a height where the average person can exert the most amount of force with least amount of effort according to the Center for Occupational Health and Safety

Table 4.13: *Physical Requirements for the Handle*

Wheelchair transfer mechanism

The physical requirements for the wheelchair transfer mechanism can be found between Tables 4.14 and 4.17.

Requirement	Metric	Rationale
Inclusive Design	Clean design that does not dehumanize passenger	Inconspicuous design improves user experience.
Ergonomic	Adapted to average user size and body shapes	Incites people to use it because it looks well designed and comfortable

Table 4.14: *Physical Requirements for the Chest Rest*

Requirement	Metric	Rationale
Retractable Handles	Handles retract at least 15cm	Allows for the lateral movement of the system and avoids handles getting stuck on the seat's backrest

Table 4.15: *Physical Requirements for the Locomotion Mechanism*

Requirement	Metric	Rationale
User Comfort	Has a special cushion that protects user from hard edges on mechanism	Avoid injuries in contact with rigid surfaces and mechanism.

Table 4.16: *Physical Requirements for the Cushion*

Requirement	Metric	Rationale
Attachable Chest Rest	Has a latching mechanism	Chest rest must be easily secured and removed

Table 4.17: *Physical Requirements for the Sliding Base*

4.2.1 Physical Constraints

Wheelchair storage device

- The wheelchair load (more than 600 lbs for the heaviest wheelchairs) must be distributed over a minimum surface area of 8 in^2 otherwise the stress experienced by the cargo hold floor will be too high and the floor may collapse. (All the details explaining how we got the 8in^2 figure are shown in appendix F).

- For the RFID identification system, the distance between the antenna and the tag must be as small as possible. The outer plastic surface covering the RFID antenna must be less than .125".

Wheelchair transfer mechanism

- The width of the aisle (19.75" in Embraer jets E175) limits the size of the aisle wheelchair.

- The new aisle wheelchair must be less than or equal to current aisle wheelchairs which weigh approximately 35 lbs.

4.2.2 Physical Assumptions

Wheelchair storage device

- If a ramp is used for the wheelchair to get on the platform, it has to be removed once used otherwise it would take too much space in the cargo hold.

Wheelchair transfer mechanism

- We assume that the average wheelchair passenger using our transfer mechanism will have an average weight of 180 lbs.

- If disabled passengers have the opportunity to use the new redesigned aisle wheelchair to go to the restroom, we assume that this restroom is accessible and must have lateral grab bars.

4.2.3 Physical Opportunities

Wheelchair storage device

- The handle that enables baggage handlers to move the platform should be ergonomic. They should be covered by an ergonomic sleeve made of material such as silicon in order to increase comfort of pushing the platform around.

Wheelchair transfer mechanism

- Wheelchair transfer from the passenger's wheelchair to the new aisle wheelchair will happen once the passenger has driven his/her mobility device on top of the platform. This way, baggage handlers do not manipulate the wheelchair at all. They only touch the platform. This should provide peace of mind to our user.

- Wheelchair users that are overweight should feel more comfortable in our redesigned aisle wheelchair because there is more support on the sides.

5 Design Description

5.1 Wheelchair Storage

5.1.1 The platform

As explained in the design requirements, our platform had to be able to support the weight of a very heavy power wheelchair while at the same time being as lightweight as possible. For this reason, we decided to make the main parts of our platform out of aluminum. In the future, we can imagine a platform constructed out of composite material that would increase the strength and decrease the weight. However, for our proof of concept, aluminum turned out to be a great material choice.

Indeed, this material is very resistant, it has a yield stress of 240 MPa and it is very light with a density of 2.7 g/cm3. In terms of feasibility, it was also relatively easy to find the aluminum we needed at a reasonable price. We purchased a 0.125in thick flat plate of aluminum with the following dimensions- 36x50. These dimensions are slightly larger than what is considered to be the minimum amount of area for securing a wheelchair according Federal Motor Vehicle Safety Standard 222. We also ordered 80/20 made to create the structure, reinforce the main frame and make the handle of the platform.

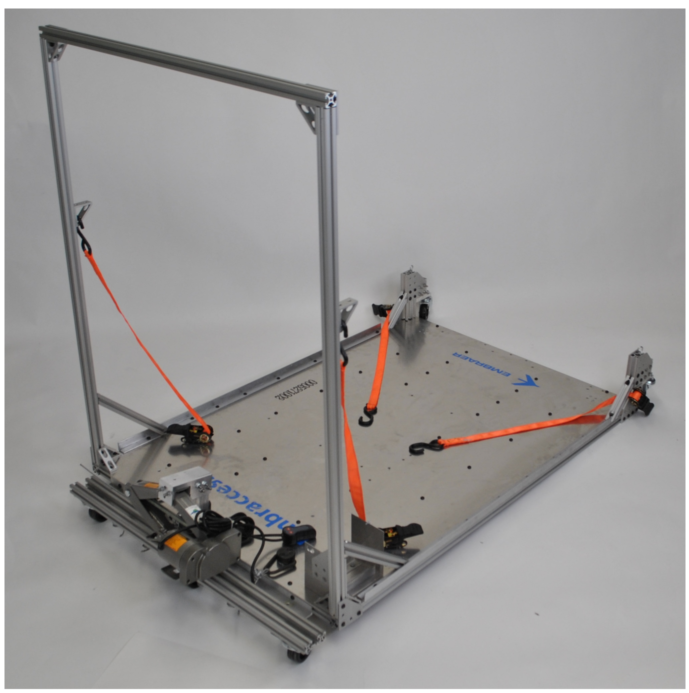

Figure 5.1: *The platform we designed using aluminum*

As we were analyzing and simulating the effects of the wheelchair load with ANSYS, we realized we needed to add a frame under the aluminum plate because the flat plate would bend if the load applied exceeded 300lbs. As shown in figure 5.2 the ANSYS analysis which was carried out for a 400 pound load applied at four contact points (each one simulating a wheel) shows a lot of bending. The maximum deflection in this case was 2.6 inches, a deflection that is no longer negligible.

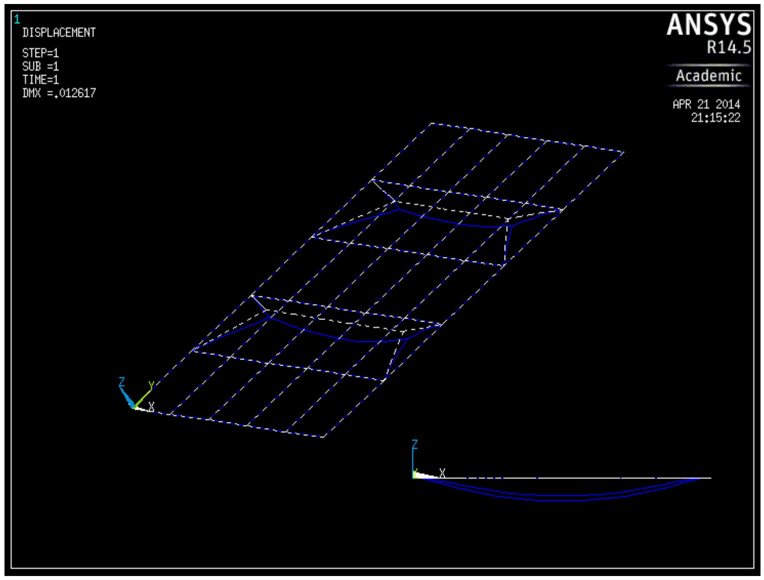

Figure 5.2: *ANSYS analysis of the platform aluminum plate*

For this reason, we chose to increase the stiffness of the plate by adding an 80/20 bar along the sides of the platform and three additional 80/20 bars in the middle. This was enough to decrease the bending of the aluminum and did not add much weight (roughly 20 pounds)

Because we needed to raise and lower the platform (see moving mechanism section for more details), we decided to add extra stiffness on the edges by adding an aluminum angled bar on each side as shown in figure 5.3.

Figure 5.3 also shows another feature we added to the main part of the platform: the straps. As explained previously, we needed to secure the wheelchair once it was on top of the platform. We decided to use straps found in public transportation today because our users are already familiar with them and they trust them. We did not add any other protection device because through our needfinding we were able to infer that wheelchairs mainly get damaged when travelling from the jet way to the cargo hold. Indeed, wheelchairs are the last item put inside the cargo hold and the first one taken out, so it is unlike that baggage handlers throw bags on top of it and airline employees generally use nets inside the cargo hold to make sure heavy items remain static. For this reason, we chose to only use the straps to tie down the wheelchair and did not add other protection device. We could imagine that a next version of our prototype could have inflatable or other material to protect the wheelchair.

The last main feature of the platform is the handle. As you can see from Figure 5.1, we made it out of the aluminum 80/20. We designed it such that baggage handlers were pushing the platform and not pulling it since this would enable them to look at the wheelchair while

Figure 5.3: *The angled bar and the straps we added to the platform*

moving the whole system. To determine the optimal height of the handle our team did some research on ergonomics of dollies and pallet jack. We found out that according to the Center for Occupational Health and Safety the ideal height was 44 inches from the ground as shown in Figure 5.4. This is the appropriate placement for an average adult who is 5 feet 8 inches to use his/her arms to push something heavy while minimizing the effort required to do so. In the future, we could improve the ergonomics of this handle by adding a silicon sleeve to the section that is in contact with handlers hands, giving them further information on where exactly they should push and providing them with a more comfortable way to do so.

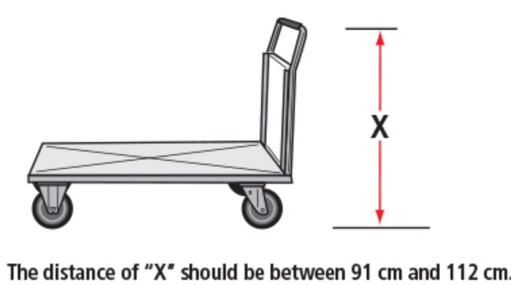

Figure 5.4: *Platform height*

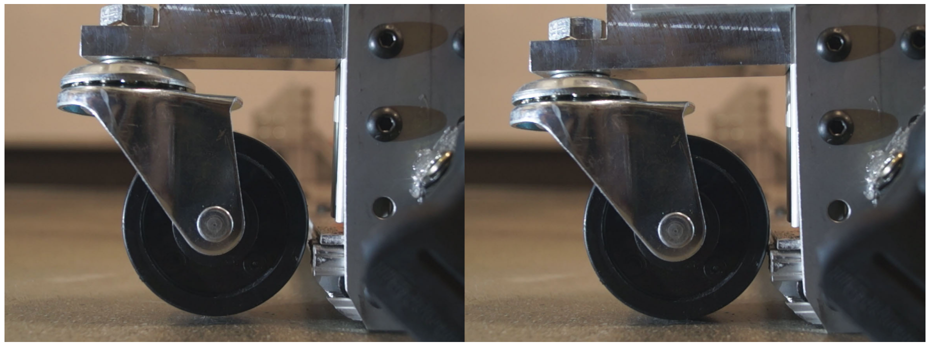

Figure 5.5: *Front wheels disengaged (left) and engaged (right)*

5.1.2 The moving mechanism

The platform's moving mechanism was made up of two main components - the front wheels, which are permanently fixed to the platform but not always in contact with the ground, and the rear wheels, which are permanently in contact with the ground but are at a variable height relative to the platform.

By raising and lowering the platform relative to the rear wheels the platform is effectively rotated, engaging and or disengaging the front wheels, as shown in Figure 5.5. This process is enabled by an electric jack, controlled by the user, which is attached on top of the rear wheels and is responsible for modulating the platform's height. The rear of the platform is shown in Figure 5.6 while the process is shown in Figure 5.8. Several parts had to be custom designed and manufactured from stock aluminum using both the manual and CNC mills in the Product Realization Lab. These consisted of two pairs of the front mounting bracket Figure 5.9 and one each of the rear mounting assembly: Figure 5.10, Figure 5.11, and Figure 5.12. For added stability there are also four steel cable wires running between the platform and the 80/20 support structure underneath the rear wheels.

The jack is actuated by pressing two buttons on the electronics box attached to the handle - one for raising the platform and one for lowering. When lowered, the platform effectively distributes the weight of the wheelchair and secures it safely in place. Raising the platform allows for easy manuevering by a single handler.

5.1.3 The electronics

The electronics subsystem consists of an Arduino Uno along with a Sparkfun RFID board, an ADXL345 accelerometer, and an XBee radio for communications. The software on the Arduino, available in the appendix, allows for keeping track of who's handling the platform by scanning RFID tags embedded in gloves (demonstrated in Figure 5.13). LEDs inside of the box light up and illuminate the translucent acrylic, notifying handlers of a successfull tag-in. Additionally, the accelerometer is capable of detecting when the wheelchair is excessively bumped or goes into freefall, both of which are potential indicators of mishandling.

This is relayed wirelessly through the XBee radio boards and displayed in an interface programmed with Processing, shown in Figure 5.14.

The electronics box is powered by a 9 volt switching regulator which is in turn powered

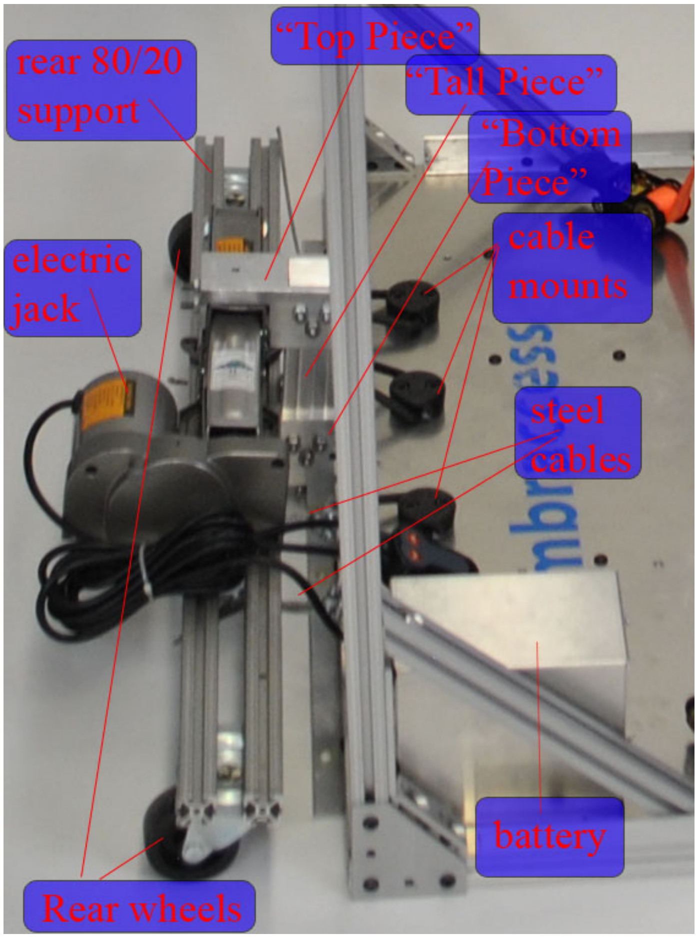

Figure 5.6: *Rear of platform, with jack*

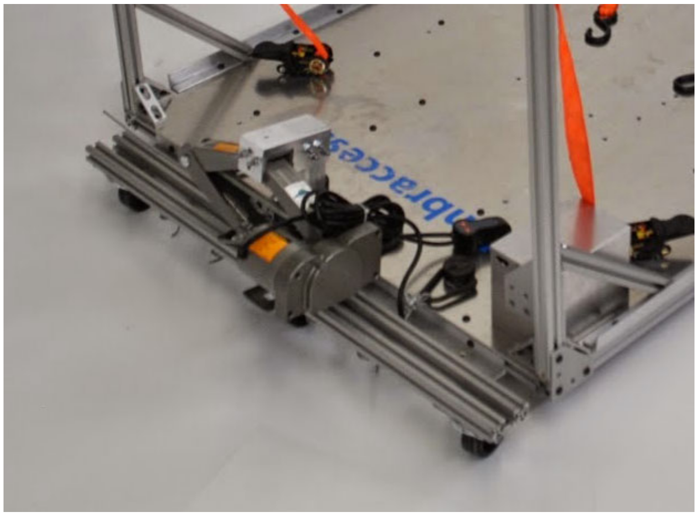

Figure 5.7: *Another view of the rear of the platform*

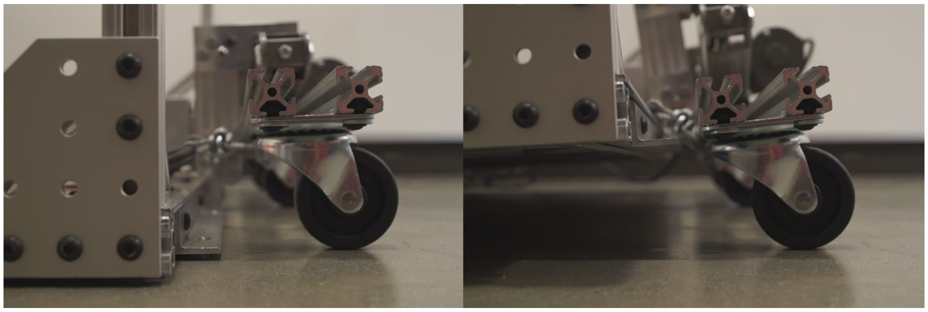

Figure 5.8: *The platform lowered and raised with respect to the rear wheels*

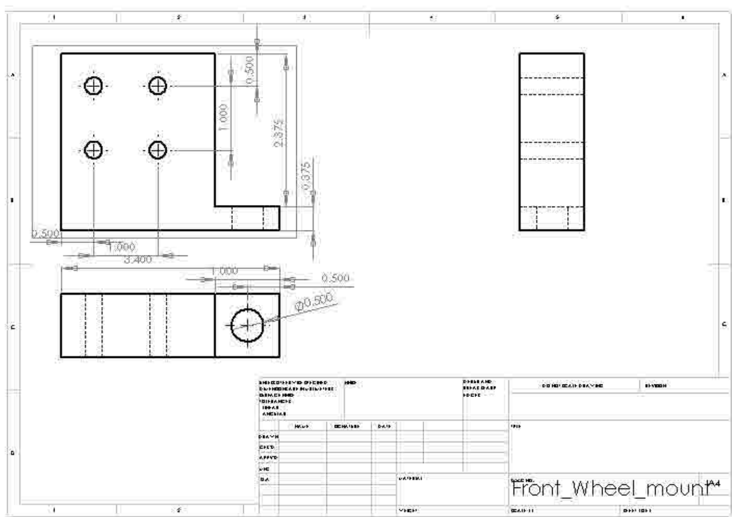

Figure 5.9: *The bracket mounted to the front of the platform for attaching the front casters*

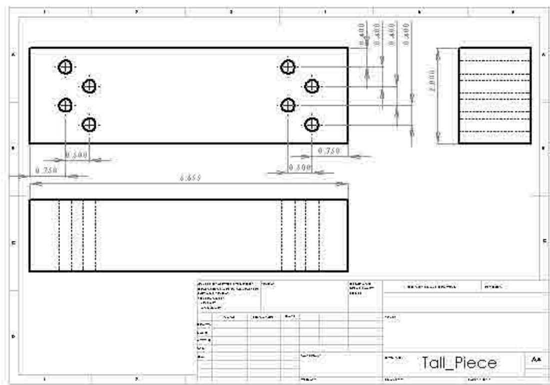

Figure 5.10: *The piece bridging the bracket attached to the rear of the platform and the bracket attached to the jack*

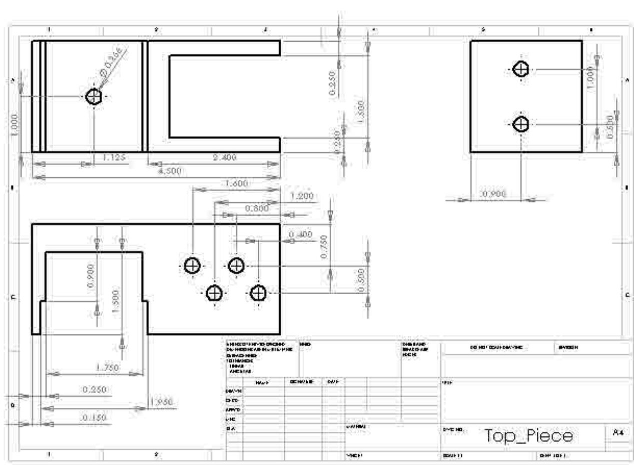

Figure 5.11: *The bracket for attaching to the electric jack*

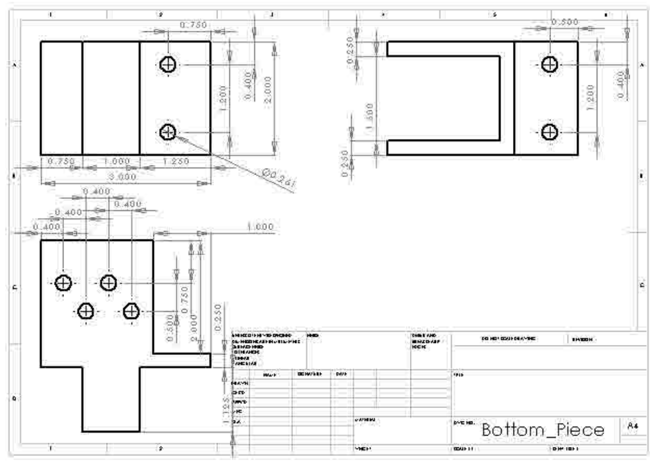

Figure 5.12: *The bracket for attaching to the rear of the platform*

by the battery attached to the base of the platform. The battery (non-spillable lead acid) is also used to power the electric jack, which runs off of a 12 volt supply.

5.2 Embraccess Aisle Wheelchair

Users today suffer as they have to perform uncomfortable and unsafe transfers between their wheelchair, the aisle wheelchair and the airplane seat (e.g. while boarding or disembarking, or to use the restroom). Redesigning the accessibility of an airplane is therefore critical to improving the overall experience for wheelchair users. By doing this, both airlines and airplane manufacturers can improve their brand image and profitability by reassuring the company's commitment to social values, by reducing the time spent on the ground and by gaining entry to new markets.

By focusing on the enhancement of the current aisle wheelchair, we developed a product that improves the users independence, comfort and safety. Furthermore, it benefits those who handle the aisle chair by reducing the time and effort spent during transfers.

The following sections explain in detail the design of the Embraccess Aisle Wheelchair:

5.2.1 The Big Picture

The Embraccess Aisle Wheelchair is unique because of its innovative front rest and sliding mechanism that allows users to be supported by and to rest comfortably on the chair and transfer easily from their wheelchair to the aisle wheelchair and finally to an adapted airplane seat. The main parts of this product are shown in Figure 5.16.

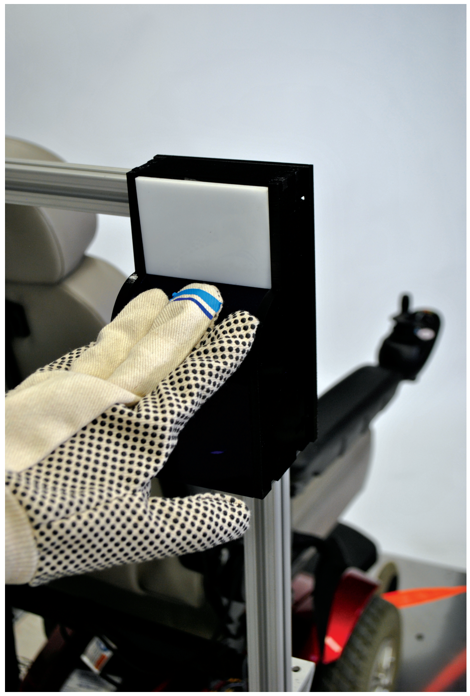

Figure 5.13: *An RFID-enabled glove and an earlier prototype of the electronics box*

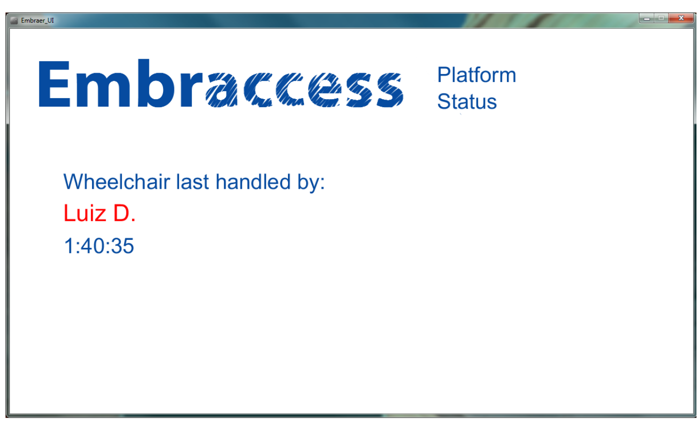

Figure 5.14: *Processing interface showing most recent handler*

Figure 5.15: *Processing interface indicating that the wheelchair was bumped*

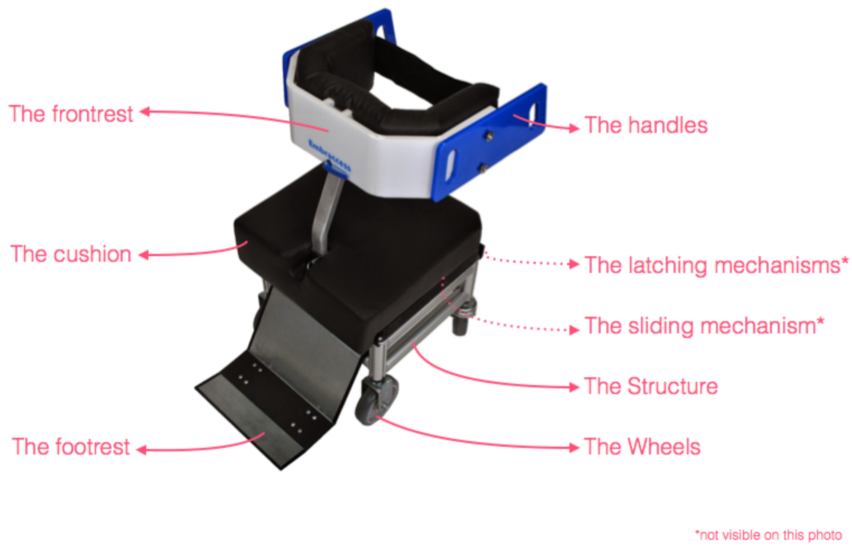

Figure 5.16: *The Embraccess Aisle Wheelchair*

5.2.2 The Cushion

The cushion used in this product was especially designed for wheelchair users to provide them the support they need for sitting during prolonged periods of time (i.e.the flight's duration). It contains a high density flame retardant foam, coated with synthetic leather, that provides both comfort and meets the airplanes safety requirements. For the next generation of this wheelchair, we recommend substituting this cushion with an air cushion which can provide a higher level of adjustable pressure relief by constantly shifting to the user's body movement.

5.2.3 The Structure

Aluminum was chosen as the main material used in wheelchairs structure.This is because aluminum provides the structure the product needs without substantially increasing the weight. Rounded aluminum profiles were used to make the base of the chair, while a thin sheet of aluminum was used to provide a plain surface for the transfer casters to slide on.

5.2.4 The Wheels

In order to minimize weight and ease the movement of the wheelchair, two 6” lockable polyurethane swivel caster wheels were used on the rear part of the wheelchair and two 6” fixed caster wheels were used on the front. This arrangement of the casters allows the wheelchair to be locked by the flight attendant and also guarantees maneuverability in confined spaces.

5.2.5 The Footrest

The footrest, shown in Figure 5.17, is made up of by a thin bent aluminum sheet attached to two 2” swivel caster wheels that provide the user comfort and safety while transferring through the aisle. The angle of the footrest and the rough adherent surface guarantee that the user’s feet do not slip off, providing comfort and security to them.

Figure 5.17: *The footrest*

5.2.6 The Sliding Mechanism

The sliding mechanism, shown in Figure 5.18, consists of .35in diameter spheres positioned under a wooden base that supports both the cushion and the frontrest housing. The equidistant position of the spheres under the base were defined to allow a smooth transfer and guarantee the contact of the spheres at all times during the transfer. A gap of up to 3.1in may be overcome because of the positioning of the casters. For the next generation of this aisle chair, we suggest that the base should consist of a different material such as aeronautical aluminium to optimize the weight of the mechanism as a whole.

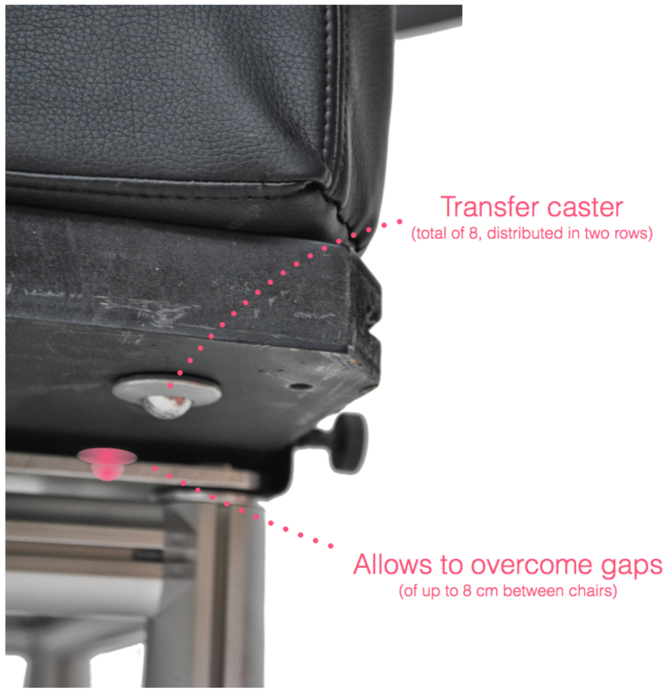

Figure 5.18: *The sliding mechanism*

5.2.7 The Latching Mechanism

The latching mechanisms were developed to allow for an intuitive and safe design. One of the module, show in Figure 5.19, consists of two pins, one at each side of the sliding base that prevents the cushion from sliding laterally. To unlock the latching mechanism, one simply has to pull and turn the pin that is closer to the airplane seat. The other module consists of two static aluminum profiles, located in front and behind the cushion base, that guarantee that the chair does not move forward or backward independently of the rest of the chair. Lastly, a removable pin locks the frontrest to the sliding base as can be seen in Figure 5.20. For the next generation of this aisle wheelchair, we suggest that the sliding latching mechanism should be linked to a mechanism that detects when both aisle wheelchair and airplane seat are properly aligned, thus improving the transfer and the user's sense of independence.

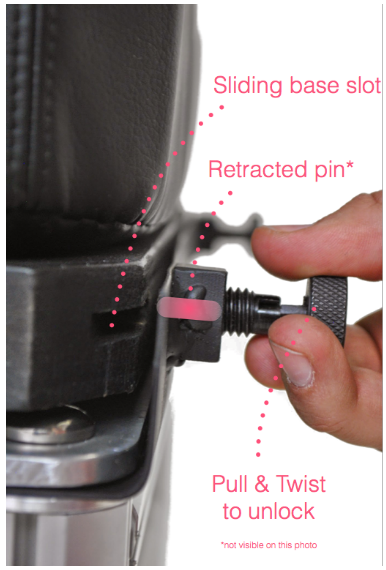

Figure 5.19: *A close up of the latching mechanism*

Figure 5.20: *Diagram of whole latching mechanism*

5.2.8 The Frontrest (Chestrest)

The frontrest, shown in Figure 5.21, was conceived so that it would provide support for the user while he is being laterally transferred. Its unique design allows the user to make a frontal transfer from his wheelchair to the aisle wheelchair and perhaps a backward transfer from the aisle wheelchair to the airplane's toilet seat (this still has to be tested). The U-Shaped support combined with the cushion and back strap provide the users with increased support and comfort, allowing them to move around the aisle and make lateral transfers easily and safely. The quick release latch located right below the Embraccess logo allows for the height of the front rest to be adjusted, making it flexible for different types of users.

Furthermore, the rigid mast made of aluminum securely attaches the front rest to the sliding cushion base. Lastly, the vertical and horizontal slots on the U-Shaped Support allows the handles to be adjusted (see "The Handles" for more details).

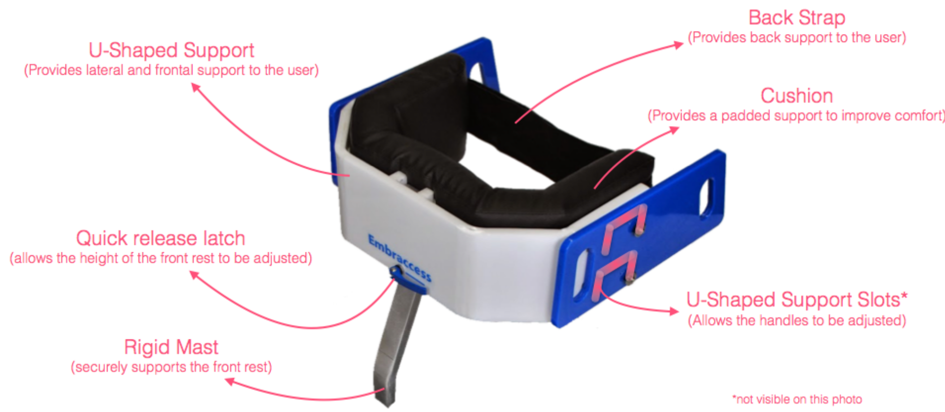

Figure 5.21: *Diagram of the Frontrest*

5.2.9 The Handles

The handles, shown in Figure 5.22, are made of two acrylic parts that can be adjusted to allow the people maneuvering the wheelchair to pull or push it from both the rear and front of the aisle wheelchair. This is extremely important in confined spaces like airplanes because one cannot reach the other side of the wheelchair. In the future, the handles would be made of lighter materials. Nevertheless due to budget and fabrication limitations, this heavier plastic was used.

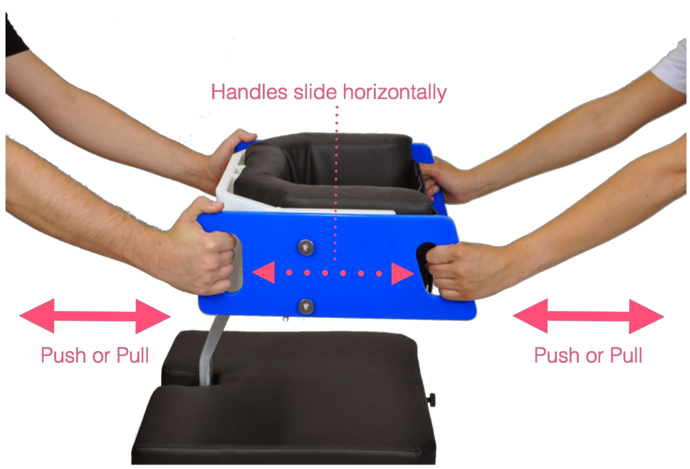

Figure 5.22: *The adjustable handles*

5.2.10 The Optional Seat Belt

An optional seat belt was added to our design that securely maintains the user's legs positioned away from obstacles while being transferred through the aisle. This seatbelt is only required for users whose legs spread involuntarily.

5.2.11 Others

The Beasy Board This transfer board shown in Figure 5.23 eases the frontal/backward transfer between the user's wheelchair and the aisle wheelchair by reducing the friction and eliminating the gap between the two chairs.

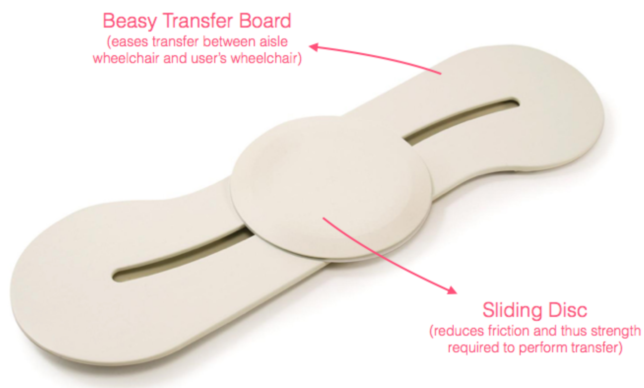

Figure 5.23: *The Beasy Board*

The Airplane Seat A simple adaptation of the airplane's seat, shown in Figure 5.24, was made in order to demonstrate the concept of our project. A redesigned aisle seat would be required in order to make the Embraccess Aisle Wheelchair work flawlessly, as it requires a planar surface for the casters to slide and retractable armrests that do not obstruct the transfer path.

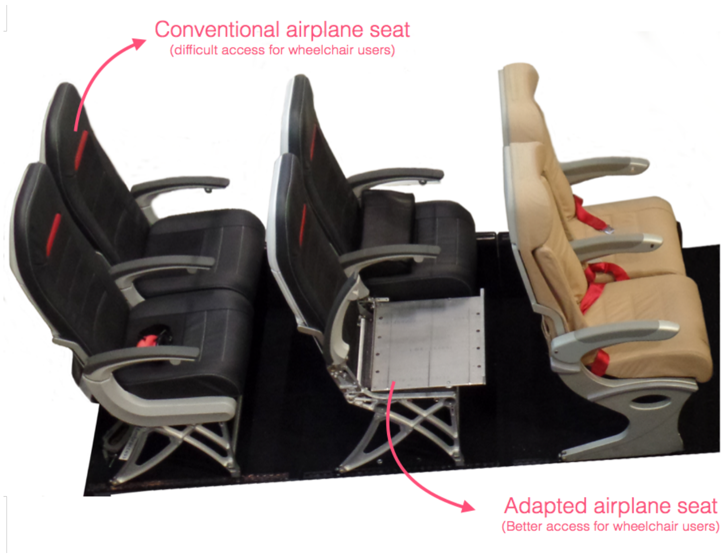

Figure 5.24: *The Airplane Seat*

5.3 User feedback about the whole experience

6 Project Management

6.1 Deliverables and milestones

Our experience from fall and winter quarter supports our notion that a detailed forward-thinking plan is necessary for creating high quality work. Taking this experience into account we decided to meet together at the beginning of each week during spring quarter to explicitly plan our actions for that week. In order to deduce what had to be done each week we filled out a calendar starting at the date of EXPE and worked our way backwards to the beginning of spring quarter. Allowing for ample spillover time should any one goal have unexpected challenges, we assigned deadlines which, if followed, would ensure that we would have a well finished prototype for EXPE.
At each weekly meeting, we would recap what we had accomplished in the previous week to ensure everyone in the group was aware of what everyone else was doing and to boost team morale by showing the progress we were making. Though not a perfect system, we found that these weekly planning meetings were the best method for ensuring that our team stayed informed and on track for EXPE.
Below is a recap of the main milestones and deliverables that led us towards the final prototype that we presented at EXPE.

	Date	Delivrables and Milestone
Fall quarter	October 29 - November 8	Benchmarking and research
	November 9 - December 3	Needfinding and user interviews
	December 4 - December 8	Autumn presentations
Winter quarter	January 1 - January 27	Dark Horse prototype (3 iterations)
	January 28 - February 13	Funky fink-tional prototype (1 iteration)
	Febrauary 14 - March 6	Functional prototype (2 iterations)
	March 7 - March 12	Winter presentations
Spring quarter	April 1 - April 15	Hunting plan and integration of the first subsystem (electronics)
	April 16- April 24	Manufacturing plan
	April 24 - May 15	Penultimate integration
	May 16 - May 30	Preparation for EXPE --> Finalize prototype and booth
	May 30 - June 5	Poster and brochure for our product
	June 5 - June 10	Final presentations and final documentation

Figure 6.1: *Deliverables and Milestones for the whole project*

6.2 EXPE Booth

For the Stanford Design Experience, or "EXPE," on June 5th, 2014, our group was given the wall of the atrium, as shown in Figure 6.2. Our planned layout is shown in Figure 6.3.

We wanted to do our best to capture the full experience of our prototypes while also allowing as many people as possible to be able to see our work. To accomplish this, we

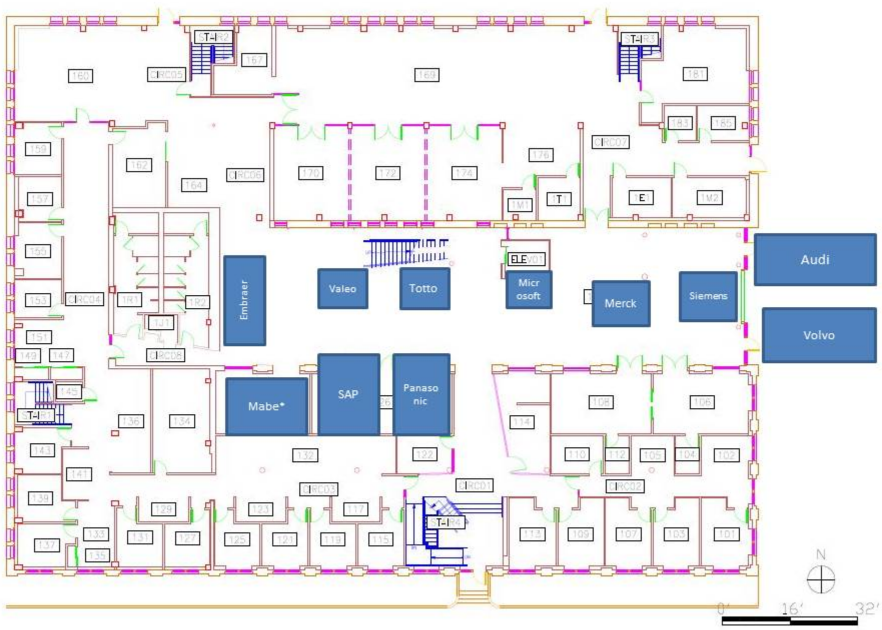

Figure 6.2: *The layout of building 550 for EXPE*

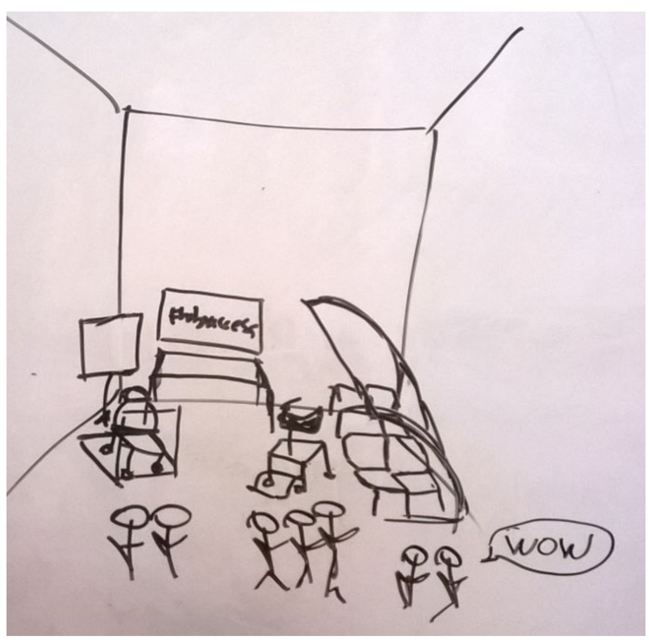

Figure 6.3: *The layout of our EXPE booth*

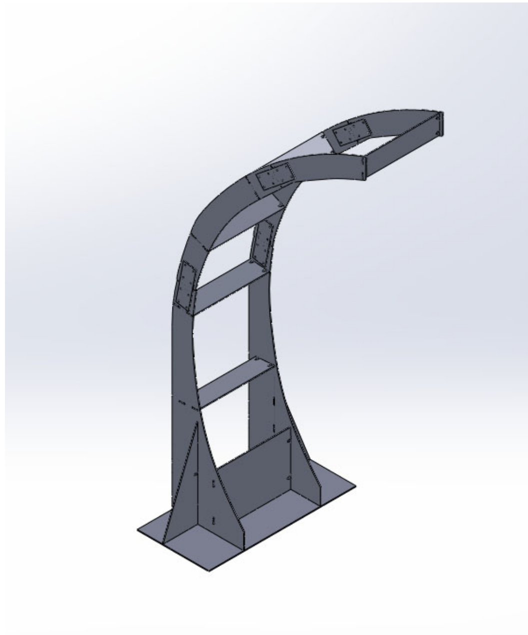

Figure 6.4: *Solidworks model of fuselage piece*

developed half of an airplane cabin with a see-through fuselage - this enabled us to maximize the experience in the available space while both feeling like an aircraft cabin and allowing other EXPE attendees to see our process. The see-through fuselage was made up of laser-cut acrylic; an image of the Solidworks assembly is in Figure 6.4. We were also very lucky to receive three sets of airplane seats on loan from Zodiac for our EXPE set up. The resulting booth is shown in Figures 6.5, 6.7, and **??**.

6.3 Distributed team management

Over the past three quarters ,the seven of us have learned a lot of lessons about how to work together as a distributed team and how to take advantage of our diverse talents. Our diverse backgrounds (two mechanical engineers, one aerospace engineer, one product designer, two industrial engineers and one electrical engineer) allowed each of us to shine in various ways. During winter and spring quarter we challenged each other to take on something outside of our individual comfort zones, a challenge that brought with it some successes and some failures

In order to ensure successful cooperation within the whole team, we decided to set a weekly meeting for the Winter and Spring quarters with our global partners. We found it was a very useful update on what each entity of the team had worked on during the week. It was also a valuable safety net when the schedule started to get very busy. In addition to these regular meetings, we also shared our documentation and our work on a Podio platform as well as on Google Drive. It enabled us to share content and react almost immediately to our peers ideas. When discussions were required between individuals who

Figure 6.5: *Preliminary booth set up*

Figure 6.6: *Side view of the booth*

Figure 6.7: *The team at EXPE*

were collaborating, we used Skype as an informal and easy way to share ideas.

We believed that another attribute of our success as a team is the relationship that we built during the Stanfords team visit to USP in March. The social connection and a good understanding allowed us to feel comfortable both to tease each other and to throw out crazy ideas which challenged the group.

6.4 Project Budget

6.4.1 Stanford Budget

The Stanford team's budget and spring expenses are shown in Appendix H.

6.4.2 USP Budget

6.5 Reflection and Goals

6.5.1 Stanford Team

6.5.1.1 Clifford Bargar

6.5.1.2 Maria Barrera

I first decided I wanted to take ME310 when I went to EXPE last year. I saw all of these production-quality prototypes in booths that looked so professional and, frankly, I was blown away. I knew then that I needed to be a part of this experience. It wasn't until midway through Fall Quarter, however, that I truly began to see the challenges that would unfold as our project moved forward.

They say the team is the most important part in a group project. Based on my experience, I could not agree more. Our team here at Stanford broke down a couple of times - ME310 is not a class that should be taken lightly and it is simply too much for some to handle. This obviously affected our progress as it was extremely hard to move forward when there were so many unresolved team issues. We were extremely lucky that our colleagues at USP were extremely passionate and hardworking, despite being a part of ME310 for the first time and not really knowing what the class would entail. They have been an amazing driving force for this team and I believe we, the Stanford team, owe a lot of our success to the USP students and their supportive teaching team.

We stated earlier that one of the things that we attribute to our success is the team bonding that occurred while the Stanford team was visiting USP. I wonder if we had done this earlier, or maybe taken the time to forge those types of relationship with the Stanford team early on, if our team troubles would have been less intense. This team experience is one I will never forget and will carry with me throughout my professional career. While I definitely believed I gained and refined ME-related skills, the most rewarding part of this class by far has been learning how to be a better team player and better leader. I know I still have a lot to improve but I am grateful for the opportunity to develop these skills in the confines of such an amazing class.

I also could not be prouder of our EXPE booth- we killed it :)

6.5.1.3 Laura Hoinville

This project was a great experience. I must admit it took me some time to understand what the expectations both from the class and from our users were. ME 310 was my first product design class and it made me realize how important it is to understand who your user is and how to put yourself in their shoes to make sure you your solution addresses their real problems. This project was a great opportunity to merge my engineering skills (Im from an aerospace engineering background) with empathy and understanding of the needs and issues of people we were designing for.

I know a lot of aircraft design because this is the field where Id like to start my career, but anytime I was taught about it, it was mainly in terms of aircraft performance and never in terms of peoples need. I think this project enabled me to see aircraft design from the users point of view instead of the aircraft manufacturers point of view and for me this was extremely valuable.// Since I come from France it was actually the first time that I had the opportunity to work with both American and Brazilian people and this cultural diversity was also a great source of enrichment.

But beyond this, this project now means a lot to me. I got the opportunity to talk to disabled people and understand how painful it is for them to travel. They care a lot about our project because they see it as a way to improve their experience and I did not want to disappoint them. They deserve the right to enjoy their flights the way we do and for this reason Im very excited to see what Embraer will do with our prototype and our work and I hope this will contribute in making the flying experience more enjoyable for people with reduced mobility.

6.5.2 USP Team

6.5.2.1 Luiz Durao

When the project started 9 months ago, I was concerned about the direction we would take and the impact on the users' live we could create if we used our ideas correctly. As the time went by and we got closer to our user, I realized that their current experience is really bad and that really motivated to work toward a product that could truly be useful for people with reduced mobility. With that in mind, we developed a complex needfinding analysis, which made me see how difficult the life of people with reduced mobility truly is and how few solutions exists in this field. As the innovation process went by, I realized the importance of the teamwork and the importance of this brainstorming technique that opened our minds to problems that we, by ourselves, could not have thought about. The development of the dark horse prototype helped us consider an idea that was previously discarded by the group. For me, this was important as it gave new insights to the final product and helped push us along by showing us that we cant design for all groups of people with reduced mobility since they have particular problems that increase the difficulty of universal design. Both functional and funktional prototypes were important in showing me that we had a direction to follow and that we were working hard to solve some important problems for our users. The EXPE preparation was intense and surprisingly, showed me my ability to work under pressure. The results were great and I really enjoyed the feedback we got from our booth. As for working with an the international team, I must admit it was a bit of challenge at first to develop a good rhythm, but once we started working together we got a great result.

6.5.2.2 Guilherme Kok

A magnificent eight-month project has come to an end with the delivery of a final prototype/product that greatly exceeded my initial expectations. But more important than the outcome of the project is the bumpy path that took us here.

First of all, neither my colleagues nor I had any experience in prototyping, so we had to overcome the initial fear of getting our hands dirty. This took us some time (maybe even more than we could afford at the time), but as time passed by our rate of learning increased drastically. For me this was significant because I had almost no prior experience in prototyping and now Im capable to work with wood, metals and other materials (although I recognize that there is still a lot of room for improvement!). Furthermore I have become more skillful in finding and dealing with suppliers, which has been proved to be a daunting task, especially in Brazil. Second this was a great opportunity for me to design a product using a user driven framework. Creating empathy with our target users motivated me to strive to find a solution that would make a difference in their lives. This in turn allowed me to inspire my colleagues to keep trying and thinking of innovative ideas to deal with the problems that emerged each day. Although we kept an eye on our users throughout the development of the project, we failed to perform an adequate number of tests with them. The reason for this is that we did not feel our initial prototypes were secure enough to be used by them. As a result our final prototype had design flaws that could have been corrected earlier in the process. In the future, I will police myself to involve the user more frequently in the development process. Third, I regret not being able to work more closely with the Stanford team, but the truth is we never understood completely the internal problems they were facing throughout the project. I am sure we would have had a better outcome if we had converged our efforts to one project and collaborated more frequently. I do recognize that there was a substantial improvement in our relationship after Stanford visited us in Brazil, but unfortunately it was already too late (late March) for any significant changes.

All in all I am delighted and honored to have worked on this project and I am truly grateful to all of those who gave me the opportunity to work on this project including Embraer, the teaching team at Stanford and USP, Amanda, Cliff, Erika, Laura, Luiz, Maria, Robbie and Rodrigo.

6.5.2.3 Rodrigo Monteiro

At the the beginning of the project I thought it would be really difficult to develop a solution that could be satisfactory to our user's needs. But after talking to potential users and going through numerous brainstorm sessions with the team, I was convinced that we would be able build a solution that could make the flight experience better for disabled passengers.

Building the prototype was challenging, expecially since we didn't have much experience buying tools and materials. But we managed to work through the limitations of materials and knowledge to build our final prototype.

It was great to see people's positive reaction to our prototype at EXPE. It was especially rewarding when Jose Luis Naranjo, who had advised and helped our team during the project, tested our redesigned aisle wheelchair.

Overall, the experiences that I acquired from this project is invaluable, and I'm happy that the result was well received.

6.5.2.4 Amanda Mota

The project began with a challenge: working within a restrictive environment such as the plane with a user who needs extra care. The search for how to improve our user's experience was a pleasant challenge to overcome. We saw a wide range of possibilities over the 9 months and it was very satisfying to see the different tests and prototypes.

All these months of work contributed to learning how airplanes and airline operate, as well as learning about seating, comfort and truly understanding the needs of our user. There was also a lot of group work, understanding of different areas of knowledge, and learning how to effectively use design to communicate. Finally, I was happy that able to improve my English.

The ultimate experience of working the last two weeks at Stanford was especially unforgettable. The preceding EXPE work made me work in a new environment with greater integration between the group and learning to deal with pressure of delivery and final presentation. As a final result my expectations were exceeded by what we delivered. We received great feedback from people who saw our project and that to me was very satisyinf; it made me proud and happy.

7 Acknowledgement

TTeam Eduardo Maria Alicia Zodiac Embraer Anika Shelly Erika Robbie

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A Appendix - Flying experience from A to Z

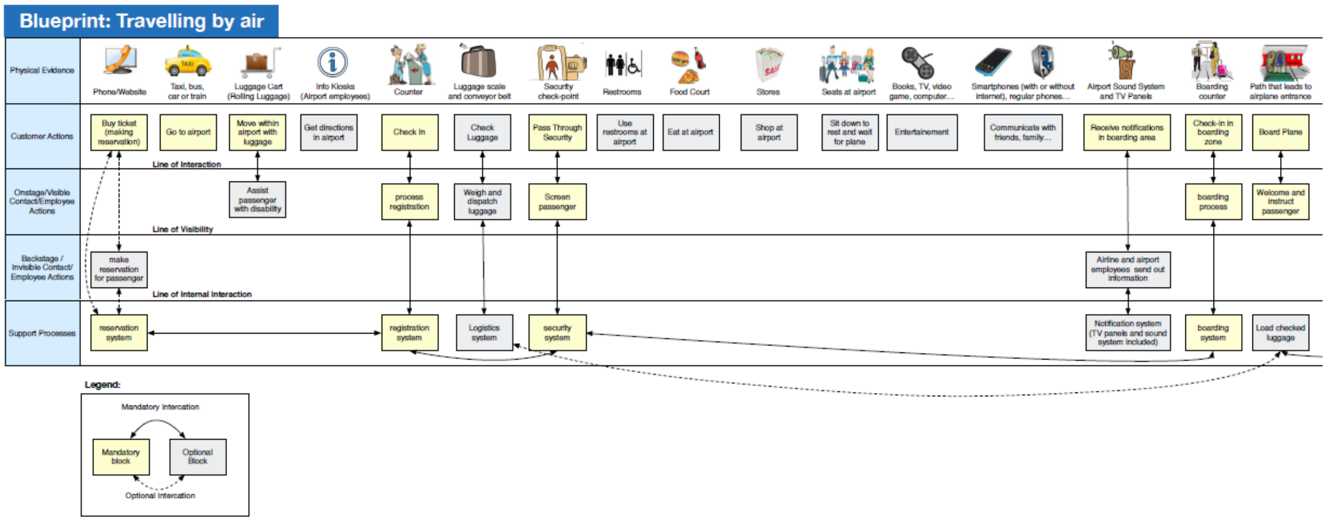


Figure A.1: *Blue Print - Flying experience from A to Z (part 1 of 2)*

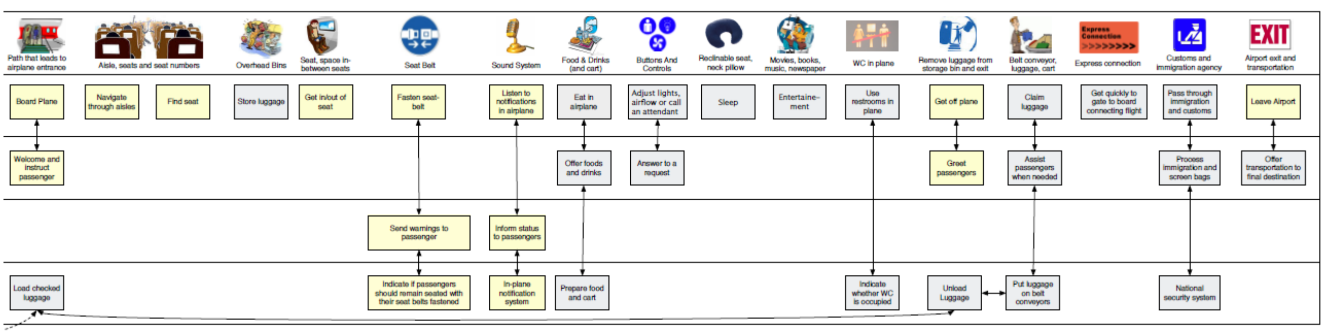


Figure A.2: *Blue Print - Flying experience from A to Z (part 2 of 2)*

B Appendix - Additional Design Development

B.1 Dark horse

B.1.1 Dark Horse Version 1

B.1.1.1 Benchmarking

Our vision for what we wanted to accomplish with our Dark Horse prototype led us to examine different possible cabin configurations and other ways to use the space inside the cabin without current seat constraints. Our team brainstormed a number of different activities that could take place during flight, shown in Figure B.1, which would enable passengers to have a much more personalized and enjoyable experience.

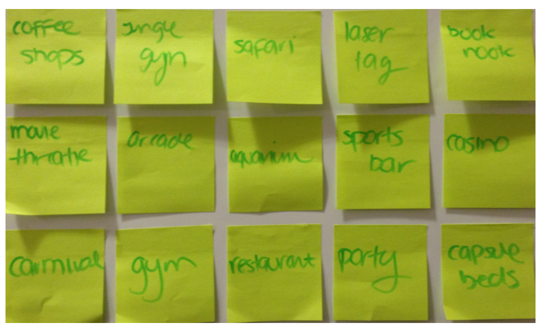


Figure B.1: *Possible ideas for a new cabin configuration*

Our goal for the first Dark Horse Prototype was to find ways to make flying an enjoyable activity, not just another form of transportation. While many passengers find that getting to and around the airport, going through security, and waiting for a flight to board can be a waste of time and a draining activity, people are willing to pay to stand in line at theme parks for hours on end just to get on a fun ride for a few minutes or camp out outside of stores just to get the new iPhone. We believe that if we could make the flying experience a better one, passengers would be less bothered by the less-than-pleasant activities leading up to it.

We realized that a redesigned cabin would need to be more accessible but could also have different sections explicitly to harness our users varied needs and reasons for flying. Flying tends to be a time for rest for many and because of this we researched what others had done to convert the cabin from a sitting room only configuration to a more sleep-friendly space. One of the proxies we looked at were the pod hotels in Japan, shown in Figure B.2, where people sleep in fairly compact space-efficient pods. Similar pods could be designed for use in an airplane cabin, reappropriating room typically used for seating to sleeping spaces.

Figure B.2: *Current pod hotel layout in Japan. Source: http://montaraventures.com/blog/2008/06/08/pod-hotel/*

There are a number of possible airplane configurations for converting the whole airplane into beds. This could be done by utilizing the vertical space available in the cabin, as shown in Figures B.3 and B.3.

Figure B.3: *Example of cabin layout that integrates both chairs and beds and does not decrease the total number of seats. Source: http://www.gizmag.com/future-of-air-travel-comfortable-seating/17751/*

These configurations make the flying experience much more comfortable while at the same time enabling selective seats to be much more accessible than others. These configurations would allow our users to easily get in and out of their seats without facing the problems they face today.

Our team also explored the possibility of sleeping while standing as opposed to laying down and found that there are several design firms that have been exploring vertical seating arrangements like the one shown in Figure B.5. These designs have received a lot of backlash due to their perceived disregard for passenger comfort despite the fact that they may actually be better for our health.

We know that many of our users travel for work purposes so we also considered what the best places to comfortably do work are and found that many preferred coffee shops to their offices. Our team also thought about having a gym integrated during the flight, transforming that seemingly lost flight time into a productive workout. Finally, we looked

Figure B.4: *Example of cabin layout with built in beds. Source: http://www.aviationinsurors.com/chair.html*

Figure B.5: *Vertical seating being designed for airplane chairs. Source: http://www.dailymail.co.uk/news/article-1215081/Packed-like-sardines-New-aircraft-design-plans-seat-passengers-face-face.html*

at different products available for creating a more accessible experience, including handles, conveyor belts and revolving doors. From all of this research, we created our first Dark Horse prototypes.

B.1.1.2 Description of the prototype

In order to make our users think about the present and not only their future destination we wanted to build a flexible and dynamic cabin layout enabling a more customized flight experience for everyone, especially handicapped passengers.

We made the assumption that when passengers buy their tickets, they will have to go through a questionnaire asking them for their preferred activity during the flight. According to their answers they will be placed in the appropriate section of the plane and have the opportunity to do what they really want to do during the flight. If the passengers have special needs due to physical handicaps, we wanted each of our different sections to address these issues and improve the experience not only for everyone, but in particular for those with reduced mobility.

Our team decided to focus on the design of 5 main sections and built a dynamic scale model for each one:

B.1.1.3 Sleeping Area

We wanted our user to be able to rest and relax so we thought of different types of beds or resting pods as mentioned in the benchmarking section. However, when we tried to prototype them and build our scale model we found at that it was quite hard to keep the number of seats the same. In order to not violate this constraint, our team decided to explore solutions that require a very limited space. As such, we designed our sleeping section with foldable seats which can be unfolded to become a bed as shown on the next picture.

Figure B.6: *Plane section dedicated to sleep and relaxation with two configurations: take-off/landing (left) and cruise (right)*

We also studied the possibility of using hammocks but the available space in the cabin was not sufficient to make it work.

Family Area

When talking about passengers with reduced mobility people generally picture wheelchair users and passengers with other physical handicaps, but in a sense, families with young children and pregnant women also have reduced mobility compared to the average passenger. In order to address their specific needs our team designed an entire section of the plane to be the family compartment.

We designed this section to be flexible and easily adaptable to family needs. If parents want to sit close to their children and look after them they can get rid of the armrests and convert their row of seats into a sort of bench allowing the family to stay together during the flight. In order to make it easier for parents, children and pregnant women to move through this area we coupled our idea of a bench with the design of a retractable table that can be folded and unfolded between two consecutive rows of seats facing each other. When the table is unfolded it is then easier for people on the benches to access the aisle as shown on the following pictures.

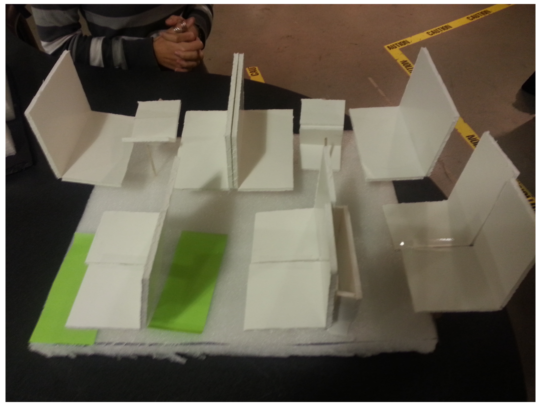


Figure B.7: *Plane section dedicated to family with two configurations: take-off/landing (left) and cruise (right)*

We also considered the fact that the family section of the plane could be sound proof in order to prevent disturbances to the sleeping compartment and concentrate the noise of children playing together in one single area.

Gym Area

When our team brainstormed about what people would like to do during their flight we thought that being able to move your limbs and stretch was a big issue, especially for people with blood circulation problems. In order to solve that we thought that having convertible seats that can be turned into yoga mats or that can be used as gym accessories could improve our users experience. We imagined a cabin layout that is standard for takeoff and landing but that can be turned into a gym area during the cruise, as displayed in the figures below.

People with reduced mobility sometimes need to do physical therapy (PT) exercises to avoid blood circulation issues. However, handicapped people can rarely do their PT exercises alone so its possible that flight attends could be trained specifically to assist these passengers.

We also took into account the fact that people are often thirsty due to perspiration when they are physically active so we thought about a system of individual straws that would be available in each passengers space allowing to drink water whenever they want without having to call the flight attendants or move across the cabin. This idea can also be extended to all the sections and all the passengers allowing them to feel more in control and more independent.

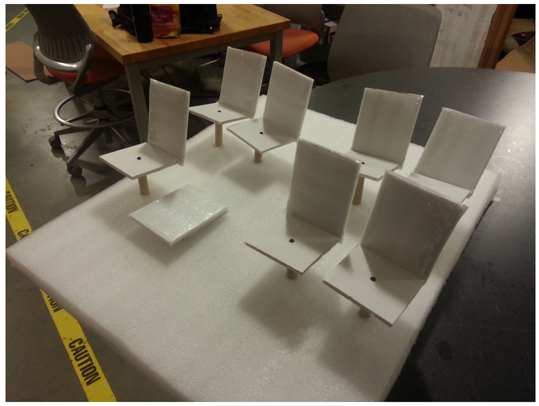


Figure B.8: *Plane section dedicated to sports and physical training with two configurations: take-off/landing (left) and cruise (right)*

Book Nook

Since a lot of people, including those with reduced mobility, travel by plane for professional reasons our team wanted to design a plane section that imitates the cosy atmosphere of a coffee shop where people feel relaxed and comfortable while working. To do so we imagined convertible seats that can be turned into couches and provide better support for people with reduced mobility.

Figure B.9: *Plane section dedicated to work in a cosy atmosphere with two configurations: take-off/landing (left) and cruise (right)*

We also thought that having a round table with one or two flight attendants in the center providing drinks was a good way to have them closer to passengers requiring more attention and assistance.

Ease of Access - Carousel

We decided to fully dedicate the last plane section we designed to people with reduced mobility. In the previous sections we addressed their issues by trying to improve everyone experience so that handicapped people would not feel segregated, but for this last section we focused specifically on their needs and expectations. Our team found out that boarding and disembarking from the plane and moving in/out of their seats were the biggest issues for passengers with reduced mobility. In order to improve this part of their flight experience, our team decided to get rid of the current cabin layout where seats are lined up.

We wanted to explore a different configuration where the seats are part of a carousel system that rotates so that any time a passenger enters the aircraft the seat right in front of them is empty. This would limit the distance people have to cover to get to their seat and should make it easier for them to move in/out of their seat since there is no obstacle in front of them as shown in the following pictures.

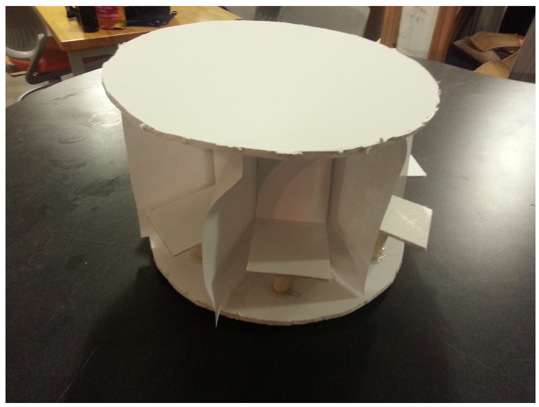


Figure B.10: *Plane section dedicated to people who need easily accessible seats*

We also thought that one of the seats from the carousel could be removed from the circle, making the center of the system accessible. If the central part of the carousel can be accessed then it could be used as a place where wheelchairs or other equipment could be stored.

B.1.1.4 Learnings

1. The following learnings came as a result of team discussions, analysis, and feedback from the teaching team.

2. It is difficult to reconfigure the cabin without losing seats. However, to maximize profit airlines do not want to lose any seats, making it important to maintain the same number.

3. The number of possible cabin configurations increase with the implementation of dynamic seats. Dynamic seats will allow for movement of cabin sections to meet the demands of each passenger.

4. Personalizing the flight would improve the experience for all passengers, not just disabled passengers. Many passengers compare the boarding and flight experience to the herding of cattle. By allowing passengers to choose their prefered cabin surrounding

or configuration, they play a role in their experience and have more control over their situation.

5. Flight attendants may be able to play different roles in the passengers experiences. They would be able to cater more toward what a passenger wants instead of performing a wide range of services for all passengers who might not need or want a certain service.

6. Every cabin configuration that can be implemented needs to have accessible features to fit the wide range of users our project encompasses. The new cabin configurations cannot neglect our target user and should not make them feel singled out.

B.1.2 Dark Horse Version 2

B.1.2.1 Benchmarking

Our learnings from version 1 inspired us to continue to explore changing the cabin layout while also putting additional emphasis into the boarding process. We realized that if we could make the seats more accessible, we would be able to alleviate some of the pain brought on by the transfer process into todays chairs. We looked at cabin configurations like the one in Figure B.11 where the seats face toward the inside of the cabin as opposed to the front. By having the seat face the passenger, it would be much easier to get in without having to worry about climbing over armrests or other passengers.

Figure B.11: *Vertical seating being designed for airplane chairs. Source: http://www.dailymail.co.uk/news/article-1215081/Packed-like-sardines-New-aircraft-design-plans-seat-passengers-face-face.html*

The team researched this further and found that seats are configured to be faced either toward the front or back for safety reasons relating to the forces that passengers could experience during flight. Having seats face inward could subject passengers to excessive lateral forces. Additionally, from the public reception of the configuration shown in Figure B.11, we found that passengers would not feel comfortable directly facing other passengers. Thus, we looked at different types of boarding mechanisms that would enable a simpler boarding experience but that would also retain the safety level found in airplanes today.

B.1.2.2 Description of the prototype

In order to solve the problems faced by mobility challenged passengers we tried to radically change the boarding experience for everyone. To this end, our team decided to further investigate carousel concept developed in dark horse version 1 and push it to the extreme.

In order to go as far as possible with this concept we decided to:

- Rethink the whole boarding process from the gate to the seat by creating a carousel inspired by a conveyor belt system through the entire plane.
- Design for an extreme case: a person with no mobility, i.e. a passenger without the use of any limbs. It made our mission more challenging but we thought it could be a good way to make sure we do not overestimate what a people with reduced mobility can or cannot do. In order to reach our goal, we brought a new persona: a mannequin filled with sand to mimic the weight of a real person.

We wanted our new persona to go through all the steps of the brand new boarding process we imagined:

- Waiting in line at the airport gate where position in the line is determined by seat number. This will facilitate the boarding process since people will have to board in the order defined by the cabin layout. Those in the aft of the plane would go first.
- While waiting, our new persona would be transferred to an airport chair that will then facilitate the transfer to the seat.
- When boarding starts, our persona will use a transfer mechanism located in the front of the cabin to reach his or her seat. Here are different options we modeled:
- The **hammock**-type transfer involves a seat that is detachable and can be moved from one chair to another using a lift
- The **comb** seat involves two separate pieces which have interlocking teeth; one can be lifted up, bringing the passenger with it, then installed on another chair
- Once our user is seated, his seat will then be moved via the carousel/conveyor belt to its standard position as shown on the next drawing.

B.1.2.3 Learnings

The learnings for this iteration of darkhorse resulted from team discussions, user suggestions and feedback, observations of the user persona, and teaching team feedback.

- The transfer mechanism to move the user into the airplane chair is still a problem that needs to be addressed. The user has to be able to make it from the waiting lounge to the airplane seat with the feelings of control, comfort and stability.
- The experience prototype of boarding did not include a mechanism to deal with luggage. The process of storing and carrying luggage needs to be addressed within the prototype to represent the entire experience.
- Communication is key to allow our users to feel comfort, safe, and stable within the new process. The process needs to be communicated effectively and sufficiently to allow for our users to have a better experience and to feel as if this process is better than the previous boarding process.

Figure B.12: *Hammock transfer to enable people to go from the airport chair to their seat*

- Users want to be able to worry and stress less about getting to their seats and finding a place for their luggage. The new boarding process would allow the users to use the boarding time on a more enjoyable pastime.
- The users have to exert less effort with this boarding process because boarding is automated and does not require the need to locate their seats and maneuver the aisle.
- Our user was concerned with bumping into objects or other seats or hitting the wall during movement. The boarding process needs to be done in such a way that the users and passengers feel safe and secure with the movement and with process as a whole. Lateral accelerations need to be considered to create a smooth ride and efficient boarding process.
- Sensors would need to be implemented into a functional prototype or a mechanical prototype to simulate the actual boarding process by having the interim stops to board new passengers. Sensors would also need to be implemented into the process to prevent collisions or accidents in the case of a malfunction.

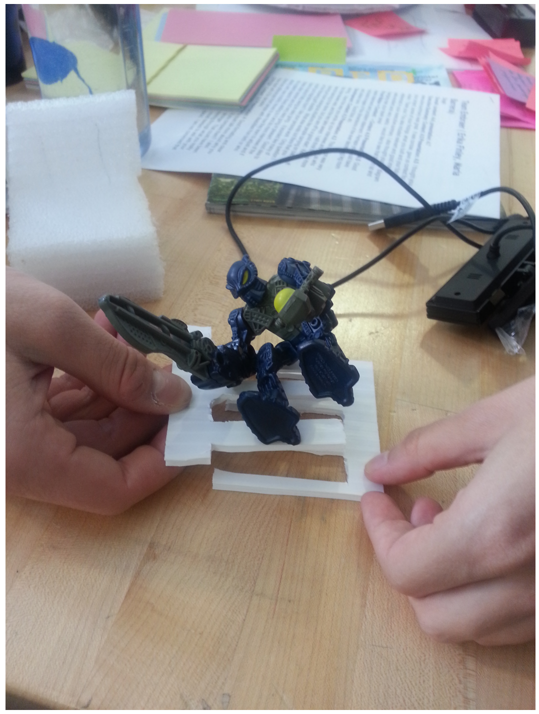


Figure B.13: *Comb seats that would facilitate the transfer from the airport chair to the seat*

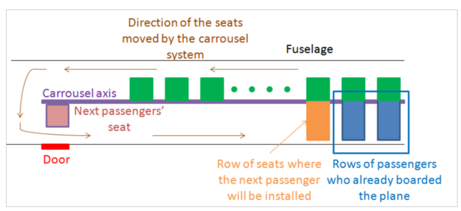


Figure B.14: *Carousel system conveying the seats from the entrance of the plane to their appropriate location*

B.1.3 USP Dark Horse Prototype

B.1.3.1 Ideation

Before starting our brainstorming sessions, we focused on defining the most critical issues based on our need finding research. As a result we emphasized the following three issues:

Broken Wheelchair
This is one of the most notorious issues faced by wheelchair users. To understand the dimension of this problem, Channel 4 made an interview with a wheelchair and pointed out that his wheelchair had been damaged on four out of eight flights he took. This is quite critical, especially when we take in that wheelchairs represent independence outside the plane for them and that this mishandling causes a great deal of anxiety on them during the flight.

Figure B.15: *Broken wheelchair - Unknown user*

Small Pitch
The small space between rows of seats is not a novelty to anybody who has already been on a commercial airplane. For people with reduced mobility the small pitch represents an increase of ones limitation and a growing feeling that one is bothering other people. One feels like a sardine in a can, unable to get in/out of ones seat.

Figure B.16: *Characterization of the small pitch [4]*

Inaccessible WCs
The inaccessibility of lavatories is another important issue that people with reduced mobility travelling on airplanes have to face. As our field research showed, people with reduced mobility take extreme measures to avoid going to the airplane lavatory because they are so tiny that they most of the times arent able to transfer themselves to the toiled seat and enjoy some privacy while inside it. As a result, users feel dependent on others.

B.1.3.2 Dark Horse Candidates

The following Dark Horse ideas were generated during our brainstorming sessions:

Mobile restroom
The basic idea here is having a portable lavatory that can move closer to the user eliminating the difficult process of walking to the W.C., providing the user with autonomy. Nevertheless, as we thought further on the idea and asked other people about their impressions, we noticed that it was highly controversial because it would be very difficult to deal with hygiene, privacy and odors. Any failure on the mechanism would be catastrophic.

Modular Boarding
It consists of a mechanism similar to one of a rollercoaster. For this idea the group discussed two different forms to operate. On the first one, the plane would be just an exoskeleton receiving all the seats together; on the second one, each seat would individually be transferred from the boarding area to the interior of the plane. This solution eliminates the space constraint issue by allowing passengers to board outside of the plane and at the same time makes the boarding/exiting process faster. However, this solution would require changes in airports and increase of the airplanes weight. Lastly, because this solution would have a similar mechanism as our CFP, we discarded it as it would generate less significant insights.

Rotating Access Seats for WCs
It is a rotating seat on the lavatorys wall to aid reduced mobility passengers to access the W.C. It provides maneuver space for the user to be transferred to the lavatory without increasing its size and improves privacy by allowing wheelchair users to close the door. It is a universal solution because it does not segregate a lavatory for specific users. On the other hand, this idea would increase weight and we still did not know how the user would react while using the mechanism. This idea was chosen to be the Dark Horse project.

B.1.3.3 Benchmarking

Our vision for what we wanted to accomplish with our Dark Horse prototype led us to examine different types of lavatory both accessible or not and being part of an airplane or not. Considering this aspects we achieve the following research:
Current Airplane Lavatory
By studying the current W.C. we were able to recognize the most critical aspects of the

imperfections of the lavatory such as the space to maneuver and, related to that, the lack of privacy once it is necessary to let the door open for the aisle chair.

Figure B.17: *Current toilet on the airplane [23]*

Accessible lavatory
By analyzing an accessible non-airplane lavatory we were able to understand the needs, concerning the bathroom, of people with reduced mobility and get to know the adaptations that exists nowadays.

Figure B.18: *Accessible lavatory [1]*

It is possible to observe the bars on the right side of the toilet and also on its back, used to facilitate the transfer in and out the seat; the adapted flush that allows the user to flush while seated on his wheelchair; and at least but not last, the adapted toilet that allows male users to urinate while seated on their wheelchair.
Regulation for accessible lavatory design
Also concerning the accessible toilet, it is important to understand the regulation that covers the construction of an adapted lavatory. In Brazil, this is the ABNT (Brazilian association of technical standards in the Portuguese acronym) 9050 of 2004.

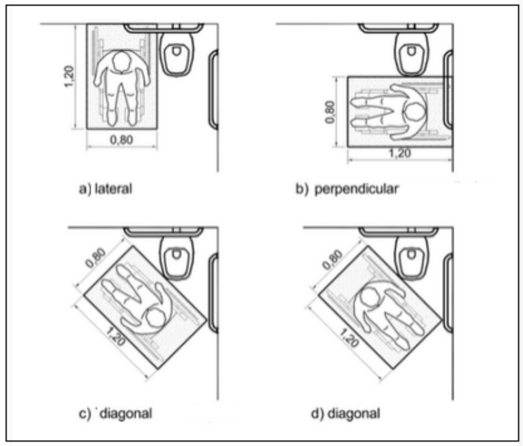


Figure B.19: *Regulation for accessible lavatory design*

It is possible to understand from this regulation the current transfer process and the space required by the users to have their independence.

Lavatory of the Boing 787 Dreamliner
The Dreamliner features two wheelchair-accessible lavatories, each with significant advancements. The 56-inch longitudinal lavatory repositions the entryway door and toilet to provide extra usable space and makes it easier for passengers to reach and use the facilities. A 56-inch by 57-inch convertible lavatory includes a movable center wall that allows two separate lavatories to become one large, wheelchair-accessible facility. Other wheelchair-accessible lavatory improvements include an additional toilet-flush button on the sink cabinet and a fold-down assist bar to aid independent transfers. [3]

Dual pivot expandable lavatory
The lavatory may be positioned close to the doorway area of the airplane, and is provided with a primary and a secondary pivotable module. Each module is pivotally attached to a stationary assembly conventionally affixed to the ceiling and floor of the airplane. During take-off and landing both modules are locked, by means of a locking system, in a stowed position within the stationary assembly. During routine flight, the locking system is unlocked and both modules are pivoted into a deployed position within the doorway area. A flight attendant's seat may be affixed to the exterior of the primary module. If the seat is used, an additional support foot is affixed to the primary module to accommodate the additional loading on the lavatory.[19]

Aircraft lavatory for a person with reduced mobility
An aircraft lavatory includes first and third walls extending inwardly from a second wall and a fourth wall connecting the first wall to the third wall. A countertop extends along a portion of the first wall. A sink is disposed in the countertop. The countertop defines an under-countertop recess free from obstructions. A toilet is disposed adjacent to both the second wall and the third wall and defines a toilet axis bisecting the toilet. A door

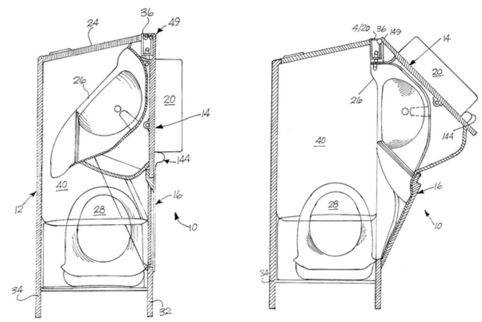


Figure B.20: *Dual pivot expandable lavatory*

extends along at least a portion of the third wall. An access axis is defined that is disposed at an access angle with respect to the toilet axis. When a person in a wheelchair enters the lavatory area along the access axis, the countertop recess accommodates at least a portion of the person's body.[20]

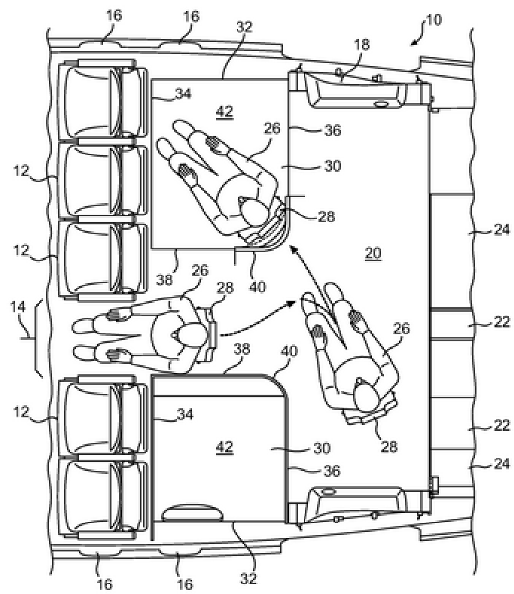


Figure B.21: *Aircraft lavatory for a person with reduced mobility*

We also looked for a couple of support mechanisms for the users foot. We decided to take this direction considering users feedback from the previous prototype.

Wheelchair support
The wheelchair support was considered as a part of the benchmarking research once it is already used for our target group.

Figure B.22: *Utilitary wheelchair foot support*

B.1.3.4 Building our prototype

Version 1.0

The first prototype of our dark horse idea was a paper one to provide the correct vision of our product and give insights for the real scale one. In order to do that we use simple materials as paper, matchstick, clay and glue as show on B.23.

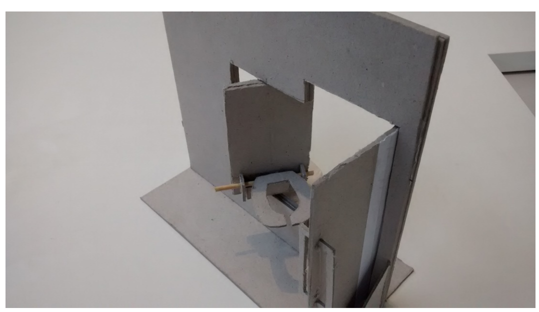


Figure B.23: *Dark horse version 1.0*

Version 2.0

On this version of the Dark Horse we managed to make a real scale prototype to try to understand how users would react with this product and at the same time identify possible design failures and how we could improve it.

Our quest started by searching for materials that could bear the weight of a human being and also that could allow the turning mechanism to exist. A 30mm fiberboard proved to be strong enough for our needs, while the pivotable hinge provided us with the rotational movement we needed. Other than that, we used a retractable hinge to simulate the flight crews retractable seat.

After that we cut the fiberboard, built the prototype and tested it with some people from outside the design group, but that did not have mobility issues because our prototype was huge and heavy, it couldnt be easy transported and because our campus has not many wheelchair users, we were not able to test it with our actual target users.

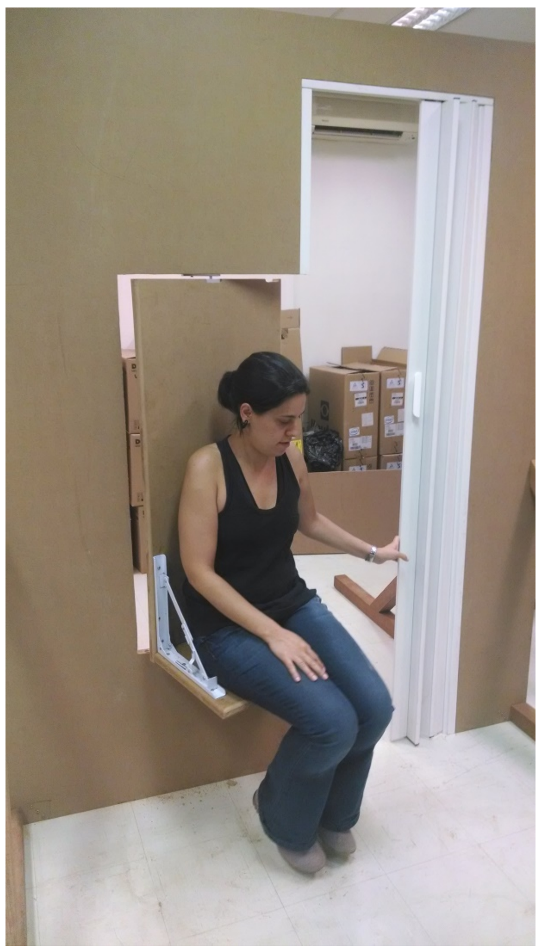


Figure B.24: *Testing with people from outside the group*

Version 3.0

On this version we tried to build a more complex turning mechanism that would provide greater independence for our user. Besides that we managed to create a mechanism for the feet and tested with some people outside the group with no mobility issues and asked for the opinion of one potential user. First, we printed a couple of gears and tried to create a turning mechanism and then we designed the feet mechanism and tested it with more people.

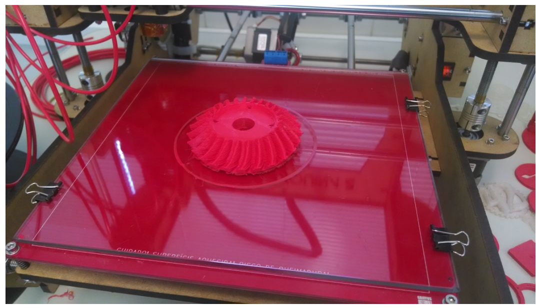


Figure B.25: *Printed gear*

B.1.3.5 Learnings and Feedback

Here are the things we learned :

- Privacy and autonomy are of utmost importance for our users.
- The way that the user removes his pants needs to be thought.
- Rotating mechanism does not necessarily have to be motorized. It could be just a mechanic system, avoiding thus the increase in energy consumption and weight;
- The gap between the rotating wall and the structure wall must be sealed;
- Having the right tools can make the prototyping process much faster;
- The footrest has to allow a smooth transfer. Rotating wheels do not comply with this requirement.
- Because of the friction of the wheels, the force needed to rotate the chair increases considerably. A better solution would include a floating adjustable footrest.
- The footrest angle must be adjusted so as to provide comfort for the user.
- The current airplane lavatories do not have enough space to accommodate the rotating toilet seat.
- Hygiene must be taken into consideration as you are exposing the airplane to potential pathogenic agents when the wall is rotated.

Here is the feedback we got from our users :

- Our interviewee Cid Torquatto told us that he would actually use the solution and that it is a great way to encourage reduced mobility people use the bathroom on airplanes
- The seat must have more depth and be wider, because the way it is now it feels like one could fall from it
- Rotation mechanism is safer using a manual solution rather than an automatic one

B.2 Funky Prototype

The conclusion of Dark Horse brought the team to the beginning of the Funk-tional prototyping mission. This mission called for the creation of a functional system that could be integrated using funky materials such as duct tape, foam core, etc. The system needed have enough functionality such that it could would answer critical questions by being tested in real time.

While our team was brainstorming about the first version of the funktional prototype, the first issue that we immediately had to deal with was defining the boundaries of our system. We wanted to make our user feel more in control of his/her environment but at the same time we realized that the word environment had a very extensive meaning that we needed to define more accurately. In order to do so, we defined our system at first as everything that happens between the departure airport gate (see Appendix B).

We thus identified three main issues :

- Boarding/Deboarding the plane, which we tried to address with our dark horse prototype.
- Moving through the cabin space is a huge issue, especially if passengers with reduced mobility want to use the lavatories.
- Feeling comfortable in your seat. This the big issue we decided to address for the funktional prototype. We decided to focus on the armrest because we saw it as a way to make people feel more comfortable in their seats as well as make it easy for them to access their seat but also as a place to centralize the controls (fan, light, flight attendant call, etc.)

B.2.1 Benchmarking

The Dark Horse mission focused on the reconfiguration of the cabin to meet the passengers' needs. For Funky, we decided to focus on how the user controls their immediate environment in the airplane and how that can be defined. We decided to create a subsystem of the airplane chair that consisted of the seat, the TV screen in front of the passenger, the overhead bin above the head of the passenger, and the armrest on both sides.

B.2.1.1 Version 1: Controlling the Environment

Version 1 focused on controlling the environment by changing the methods in which the passenger can use the controls or buttons at their seats. Today, the passenger has to reach above his head on the overhead bin compartment to call the flight attendant, to change the air flow and direction, or to turn on or off the light. This is not an ideal arrangement for our users since some of them do not have the upper body strength that is needed to lift themselves up to touch the buttons. We decided that we needed to bring the controls down to them and make them easier to reach and more accessible. The controls should be an assistive technology, not another aspect of the flying experience that makes our users dependent on other passengers.

We first envisioned the controls being placed upon the armrest through buttons, scroll bars, track pads, and other mechanisms. We looked into what is being done within the business classes on most flights. Since we are focused on the economy class, we thought that if a solution is aready present in the business class, we could just integrate that same solution into the economy class. B.26 and B.27 show examples of controls on the armrests. The first set of controls is used to control the position and the firmness/softness of the seat. We thought about integrating something similar and giving our user the ability to change these aspects of their seat given that different disabilities have different support needs. However, we focused on having the basic controls of the lights, the air conditioning, the flight attendant button for our design.

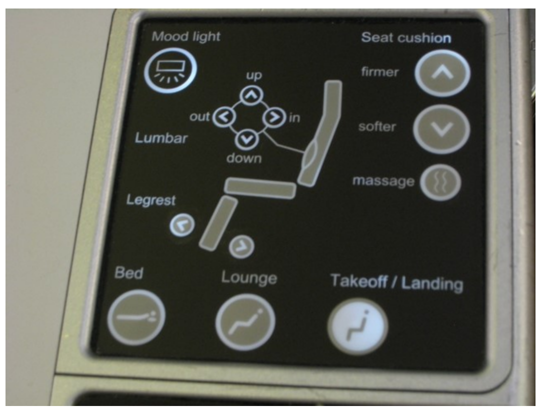


Figure B.26: *Example of current controls on the armrest in a Business Class seat. [5]*

B.28 shows a hinged armrest in which a remote control lies within the armrest compartment. We thought about incorporating a hinged cover onto the armrest with controls, not a remote, underneath in order to protect the controls from being hit on accident during flight. We worried, however, that this would make buttons less accessible to users and they would feel that they shouldn't press them as often since they aren't in direct contact with them at all times.

The use of individual TV screens on airplanes is increasing due to the demand of entertainment. We considered the use of the TV screen as another method of reaching the controls or making the controls accessible. Some TV screens have a remote associated

Figure B.27: *Example of current controls on the armrest in a Business Class seat. [17]*

Figure B.28: *Hinged Armrest that could be incorporated with Control Interface. [18]*

with them while others have a touchscreen. The primary interface we focused on was the touchscreen. B.29 shows a TV screen with a remote in the economy section of an airplane. B.30 below shows a touchscreen TV on an airplane in premium economy class. We also brainstormed one step further and considered what it would be like if the user could use their own electronic device (iPad, tablet, or phone) to manipulate the controls.

Figure B.29: *TV screen with remote on an airplane. [15]*

Figure B.30: *Touchscreen TV on an airplane. [8]*

B.2.1.2 Version 2: Controlling the Environment with a New Armrest and Controls

Version 1 on Funky showed us that there were more areas that needed to be improved within our design subsystem. We decided that we would further develop the controls but also look into ways to redesign the armrest. Why did the armrest have to be like it is? Can it move up and down another way? Can we design something with the same functionality but to be more accessible and more comfortable?

We looked into armrest in all sorts of transportations mediums. We needed to know what had already been done, what could be integrated together, and what we needed to design to surpass the shortcomings. B.31 below shows an armrest unit being split into two so that both persons have an armrest and it can be moved front to back by sliding on the mount to adjust to the desired arm position. This is currently being used in automobiles.

We wanted to design the armrest so that it would not be in the way during transfer from the wheelchair into the airplane chair. One method of doing this is shown below in B.32. The armrest are part of the lounger and then pop out when the lounger changes positions. We wanted to integrate a similar concept into the airplane chair but knew that we would have to consider a way that was slightly more complex than the mechanism below due to the fact that economy seats do not lay down or recline enough for this mechanism to be

Figure B.31: *Split Armrests that can move relative to each other.[7]*

feasibly implemented.

Figure B.32: *Lounger with Built-In Armrests [10]*

Another method of moving the armrest out of the path of transfer would be to have them hydraulically move in the horizontal or vertical plane. B.33 below shows armrests on a dental chair that can be hydraulically moved for personal preference and to allow easier transfer to the seat. Similar technology to the hydraulic movement is the lifting and lowering of an office chair using air pressure and a piston.

For a more futuristic armrest, we looked into design concepts and luxury seating. B.34 below shows a design concept for an airplane chair and business space. The chair has armrests that come from the front and could be lifted and lowered from under the seat. These armrests allow for a wide range of lifting and lowering mechanisms as well as more flexibility with controls that could allow the weight of the controls to be beneath the cabin.

Massage chairs were the luxurious chairs that we considered. B.35 below displays an armrest that has the controls on the top and a spot for your arm inside a protective C-shaped area. This design allows for the comfort of knowing which armrest is yours and not bumping or touching the other person beside you. It also has the controls easily accessible without the fear of accidentally hitting them and signaling for the flight attendant or cranking the volume up to an uncomfortable setting.

Figure B.33: *Dental Chair With Hydraulic Armrests to Position where desired. [6]*

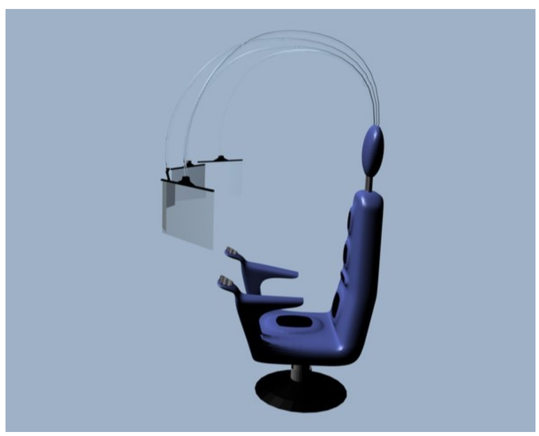


Figure B.34: *Armrests Located on the Front of the Seat. [12]*

The final area we researched was the armrest aids for persons with limited mobility or senior adults. One such device is shown below in B.36. This device allows for the user to be aided in seating on the toilet and raising from the toilet. This device would be applicable for both the chair armrest situation as well as the airplane bathroom accessibility situation. The mechanism for this device follows an arc trajectory during use. This arc trajectory aids passengers that have limited mobility and difficulty seating and standing by allowing them to have a device that moves in a path similar to their mass center. This armrest would be useful for limited mobility passengers that could walk short distances and are not confined to a wheelchair.

Figure B.35: *The luxurious armrest of a massager with controls and a designated arm place. [16]*

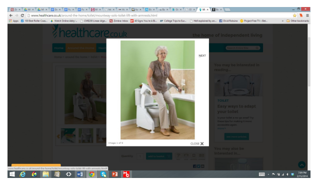


Figure B.36: *Lifting and Lowering Armrest Mechanism for the Elderly. [14]*

B.2.2 Description of the prototype

B.2.2.1 Controls

Funky allowed us to create different interfaces for interacting with the cabin controls in order to examine the level of independence and control a person with reduced mobility experiences with each. After speaking to our users, we know that reaching the controls on the ceiling can be very hard, especially if a passenger does not have much upper body strength. Thus, we wanted to find a way to bring the controls to them and minimizing the effort exerted into changing their cabin environment. Our team focused on 4 main areas for inputs shown in Figure B.37: buttons on the armrest, GUI on screen, GUI on personal device and automated controls. On the backend, we had an Arduino controlling the lights, the fan and the flight attendant light.

B.2.2.2 Buttons on armrest

Since passengers are already accustomed to using buttons to change their environment or summon the flight attendant, we decided to bring these buttons closer to them and test the type of input that was more intuitive to the desired output. The final iteration is shown in Figure B.38. The location of these inputs is key- we want them to be readily accessible when the user needs them but invisible enough such that the user does not accidentally press them.

After testing different locations for each button, we decided that all of them should be placed on the side of the armrest (so they are not accidentally triggered) with markings on the top of the armrest so it is easy to determine the function of each. However, the flight attendant button was actually to remain on the top of the armrest except inserted into an inlet so that once would intentionally have to go into a lower plane to press the button. We

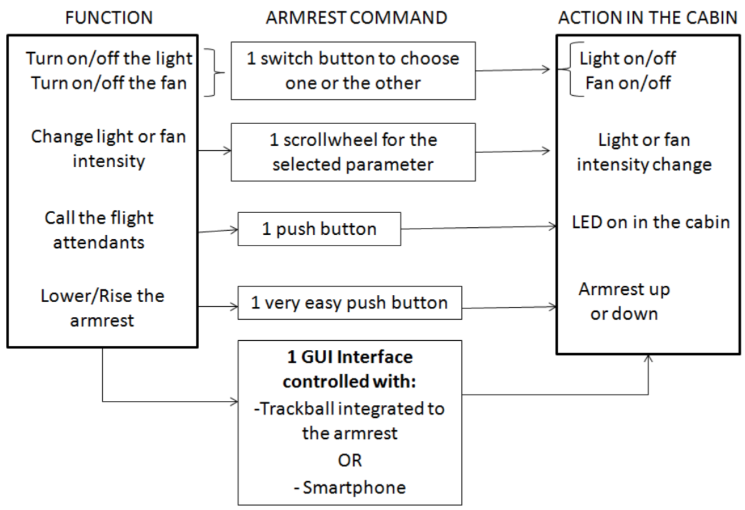


Figure B.37: *Architecture of the system we wanted to build to offer a centralized and better control of the environment to our user*

Figure B.38: *Prototyped armrest with integrated buttons*

tested buttons for both the fan and the lights but realized that it was more intuitive to use a potentiometer to control both of these functions, especially so the user could control the intensity of both. A switch would toggle between fan and light functionality, much like how you choose your right or left rear view mirror to be adjusted in your car.

While the set up for all the inputs was designed on the armrest, there were unfortunately technical complications we did not foresee and were thus unable to fully test out this prototype.

B.2.2.3 GUI on Screen and Device

In order to test whether users were more comfortable with a Graphic User Interface (GUI) as opposed to physical buttons, we created a GUI on MATLAB, loaded it on to a table and connected this to our Arduino. The GUI, shown in Figure B.39, has the ability to control the lights, the fan, and the flight attendant call button.

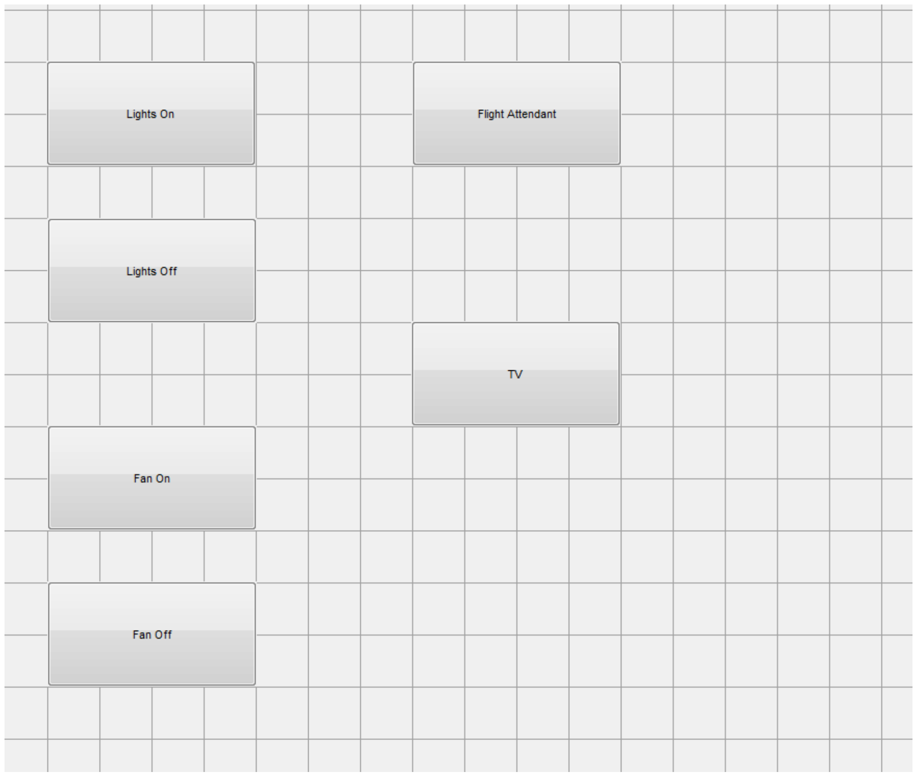


Figure B.39: *GUI that controls the lights, fan and flight attendant call button.*

This GUI was utilized two test two different scenarios, having the ability to control the GUI as if it was placed on the seatback of the seat in front of you with both touch and with the trackball shown in Figure B.40 as well as having the user controlling it with their hands as if they were using your own device.

B.2.2.4 Automated Controls

After exploring different inputs a user could trigger to control their environment, our team decided to take a step back and go back to the basics. Why does a user want to turn their light on? Why do they want their fan off? It seemed to us that there are specific needs a user is trying to satisfy when changing these aspects of their environment, so what if the cabin could anticipate these needs and change the cabin for them? Would they still feel in control and independent?

We decided to test out our hypothesis by assuming that people want to turn on the lights when they want to read. Therefore, if a passenger brings out a book, the light should

Figure B.40: *Trackball used to control GUI on seatback of seat in front of you.*

automatically turn on. We tested this by using an image detection algorithm in MATLAB that would use the camera to detect if a certain color was present and would then trigger a command to turn the light on. We then got a light blue book and used this program to turn the lights on when the book appeared and off when the book disappeared. While this is not incredibly reliable or robust at the moment, we envisioned that if the cabin could sense when you had paper, or text or even your hands in a certain reading position, the light would turn on. Similarly, we could imagine using different types of remote or tactile temperature sensors to control the fan.

B.2.2.5 Armrest

After our research into different types of armrests we decided to prototype one we hadn't seen - an armrest that can collapse downwards into the space between two seats. There were several reasons for pursuing this design, including that the controls would still be reachable and that the user could raise and lower the armrest without having to twist their body.

Our prototype, shown in Figure B.41, was constructed primarily from an Ikea Alrik swivel chair, which provided the mechanism for linear actuation. We sawed off the sides of the seat, using what remained as the physical armrest. Because the chair is designed for a person to sit on we also added springs to make it easier to lower the armrest without applying as much force.

B.2.3 Learnings

Funky version 1 taught us that it is very important to define our goals and our vision before trying to build anything. We took time to precisely define what problems we wanted to tackle and it allowed us to get a very nice result for the second version of our prototype.

Figure B.41: *Funky armrest prototype*

Version 2 of the funky prototype was the direct evolution of version 1 since we decided to keep focusing on the controls and to bring this idea and concept as far as we could. Since we had designed different devices to control the user's environment (buttons on the armrest, trackball, smartphone/tablet app,...) we wanted to know which one was the best for a disabled passenger and we asked one of them to come and test our prototypes.

We invited Jos Luis Naranjo Montoya, a 28 year old T6-complete paraplegic to share our vision with him and to get user's feedback about our version 2 funky prototype which was made of two parts : the armrest and the mechanism we designed to make it lower and raise, and the controls of the environment that we wanted initially to centralize in the armrest.

B.2.3.1 User's feedback about the armrest mechanism we designed:

When we decided to redesign the armrest and the mechanism that makes it lower and raise, we identified two main functions for the armrest: rest the passenger's arm and divide the space. But while testing our mechanism with Jos we realized that we had neglected one very important function of the armrest : being used as a handle by people with reduced mobility. Indeed, disabled people often use the armrest as a handle for support when they get in the cabin and shift in their seat. Therefore the armrest has to be reliable since our user relies on it to support his/her weight, and this is obviously something we learnt from Jos and that made us change our design priorities concerning the armrest.

Another important point we also learned from Jos was about the location of the armrest. It needs to be flush with the seats when it is lowered otherwise it doesn't make getting into the seats that much easier. This can seem to be in contradiction with the previous point since on the one hand our user uses the armrest as a handle but on the other hand he does not want it to be an obstacle between him and his seat. In fact, ideally our user would like to have the aisle armrest flush with the seat but the other armrest up to use it as a handle. For our user the two armrest are not equal and this way of thinking opened for us a whole new design space.

B.2.3.2 User's feedback about the control systems we designed:

- Buttons in the armrest: Potentially problematic as limited mobility users prefer to have something to hold on to that is sturdy when they move themselves. However, buttons are a good way to access quickly a function (light or fan) and could be used as a redundant system or a complement of a fully automated system that could happen to fail.
- Trackball to control a GUI that is on the screen in front of the passengers: the trackball itself is clumsy to use and requires a lot of precision from the user. This is not ideal for quadriplegic users who only have partial sensitivity in their fingers. For them it is more intuitive to tap on a touchscreen or a tablet.
- Touchscreen which could be a smartphone/tablet belonging either to the passenger or the airline: It seems that holding the device is not as easy as expected and our user would prefer to have it in front of them where the normal screen in the plane is. But in this case, the use of the screen requires the passenger to lean forward to touch it which may be hard for someone who does not have a lot of core strength due to his/her handicap.
- Cabin anticipating the user's need: we were not able to test our concept of a thermal camera which, by analysing the passenger's body temperature, can turn the fan on and off if the passenger is hot or cold. However, we were able to test our idea of a webcam detecting the presence of a book and sending the right information to turn the light on. Jos really liked this idea. He did not see it as an assistive technology that makes him lose his independence but really as an assistive technology that makes him independent from the others. He does not need to ask someone to turn the light on for him, the cabin has anticipated his need and the gesture that causes the light to turn on comes from him directly so he does not feel it as a loss of control on his environment. However, he mentioned that it would probably need redundant controls since autonomous systems have too many cases to work perfectly in and people would not trust it.

C Appendix - User survey

Initial Report

Last Modified: 02/20/2014

1. How uncomfortable does the narrow aisle make your experience?

#	Answer	Bar	Response	%
1	Very uncomfortable		1	100%
2	Somewhat uncomfortable		0	0%
3	It doesn't affect my comfort level		0	0%
	Total		1	

2. What are the biggest pain points concerning the current aisle chair? How do you think we can improve your experience?

Text Response
It's cramped and has to be pushed by flight attendants. Doing away with the aisle chair all together would be ideal, such that a personal wheelchair can be used instead. This would require more space at least in the foward section of the plane (bathroom and first few rows). Currently, I've found that Southwest Airlines has provided for the most conformtable boarding experience, where the spacious walkways at the forward end of many of their planes allow for me to board the plane with my wheelchair and transfer to the first row of seats.

3. How do you think having an 'on demand' powered aisle wheelchair would improve your experience?

Text Response
It seems like a neat concept that would allow me to board the plane at my own pace and go to the restroom when I please. Reliability, safety, and stability would be a concern and I would need to see adequate safety precautions taken in the design.

4. If the aisle chair were powered, i.e. you did not have to be pushed by someone else or push yourself, would you rather have the aisle chair come autonomously to you upon calling it or would you rather have the aisle chair be brought to you by the flight attendant? Remember this is not about you being in the chair or your experience in the chair; it is about how the chair gets to your seat.

#	Answer	Bar	Response	%
1	Autonomous		1	100%
2	Flight attendant		0	0%
	Total		1	

5. Please explain why you chose autonomous vs. brought by the flight attendant and how it would improve your experience. Would having the flight attendant bring

you the aisle chair significantly impact your experience?

Text Response
Autonomous is better because I feel I am in control of when the seat is summoned, rather than have to call the flight attendant and wait for them to available to help.

6. The proposed 'on-demand' powered aisle wheelchair will include sensors for detecting obstacles and guides ensuring a straight path of travel. Are there any other issues you can think of that we should address?

Text Response
I'd be concerned about the chair stopping should anything get caught along the way (i.e. clothing article getting stuck on adjacent arm rest, paralyized limb flopping to the side). Also, I would expect the chair to be stable/secure/strong enough to support any type of pushing, tugging, leaning, or wait-bearing on the chair while transfering in/out of the chair.

7. What do you think about the concept of a wider aisle allowing you to enter the plane with your own wheelchair? Is this preferable to having a powered aisle chair?

Text Response
This would be the best option. Using one's own wheelchair is always better because one is already familiar/comfortable with transfering in/out of it as well as operating it. It would also be great if I could access the restroom from my seat using my own wheelchair.

8. How uncomfortable would it be to enter from the front of the plane and be power-driven backwards (facing the front of the plane) to your seat- not being able to see where you are going but knowing there are sensors and rails to guide the chair?

#	Answer	Bar	Response	%
1	Very uncomfortable		0	0%
2	Somewhat uncomfortable		0	0%
3	It wouldn't affect my comfort level		1	100%
4	It would be comfortable		0	0%
	Total		1	

9. Are you more likely to trust a human pushing you while you face backwards or an automated system with rails and sensors? Why?

Text Response
From a trust perspective, I'd select the human, simply because a human can quickly recognize when something goes wrong and react accordingly.

10. In the previous questions, your travel companions would probably have to be boarded from the front of the plane so if you are boarding from the back there might be a small period of time that you are separated, how important is this to you and why?

Text Response
Accessible design shouldn't only be about giving access to someone with limited mobility but also about how inclusive the design makes everyone feel. Being separated from one's group makes the experience rather uncomfortable because it shines an even brighter light on the fact that one has to do things differently as wheelchair user. The objective in accessible design should be to allow a wheelchair user to experience their surroundings as autonomously as possible and as similar to non-wheelchair users as possible.

11. Would you be comfortable using a standing wheelchair or some other sort of device that provides skeletal support to keep you in an upright position instead of sitting down? Please explain.

Text Response
I personally would, provided the appropriate safety precautions are taken.

12. Do you have any other thoughts regarding moving inside the cabin you would like to share with us?

Text Response
Thanks for all of your hard work! -Jose Luis Naranjo

13. Do you typically travel with a carry-on luggage or do you check-in your luggage?

#	Answer	Bar	Response	%
1	Carry-on		1	100%
2	Check-in		0	0%
	Total		1	

14. Do you bring a personal item or do you bring both a personal item and a bag?

#	Answer	Bar	Response	%
1	Personal item		0	0%
2	Carry-on luggage & personal item		1	100%
3	Click to write Choice 3		0	0%
	Total		1	

15. Where do you prefer to stow your carry-ons?

Text Response
Under seat (backpack), that way I can access it when I please w/o depending on anyone else

16. Do you typically access your carry-ons during the flight?

#	Answer	Bar	Response	%
1	Yes		1	100%
2	No		0	0%
	Total		1	

17. Any additional pain points/ stories concerning luggage you would like to share with us?

This question was not answered by the respondent.

18. For those of you that have removable armrests/handles on your wheelchairs, do you trust them to support your weight during a transfer?

#	Answer	Bar	Response	%
1	Yes		1	100%
2	No		0	0%
	Total		1	

19. Do you find them easy to remove in an efficient and quick manner?

#	Answer	Bar	Response	%
1	Yes		1	100%
2	No		0	0%
	Total		1	

20. Is there a specific mechanism that you prefer for your removable parts of

your wheelchair over other mechanisms you have had in the past? Feel free to describe it or upload a picture below.

This question was not answered by the respondent.

21. Describe your mechanism

This question was not answered by the respondent.

22. Any other thoughts concerning handles/support mechanisms you would like to share with us?

This question was not answered by the respondent.

23. Thank you for taking the time to fill out this survey, we really appreciate it. Your responses will be invaluable to helping us improve the flying experience for wheelchair users. Please provide your email if you would like to be contacted for updates and follow up questions.

Text Response
jl.naranjomontoya@gmail.com

Initial Report

Last Modified: 02/20/2014

1. How uncomfortable does the narrow aisle make your experience?

#	Answer	Bar	Response	%
1	Very uncomfortable		1	100%
2	Somewhat uncomfortable		0	0%
3	It doesn't affect my comfort level		0	0%
	Total		1	

2. What are the biggest pain points concerning the current aisle chair? How do you think we can improve your experience?

Text Response
Uncomfortable shape; requires being strapped in, which is very uncomfortable, especially when they ask me to lean back (due to the shape of my body and back, I can't lean back that chair); requires 2 people to operate, makes me feel like I have to either tip them both or tip neither of them. To improve the experience, would be nice if I didn't have to go down an aisle (sit at the front).

3. How do you think having an 'on demand' powered aisle wheelchair would improve your experience?

Text Response
Might let me get on and off the plane more quickly.

4. If the aisle chair were powered, i.e. you did not have to be pushed by someone else or push yourself, would you rather have the aisle chair come autonomously to you upon calling it or would you rather have the aisle chair be brought to you by the flight attendant? Remember this is not about you being in the chair or your experience in the chair; it is about how the chair gets to your seat.

#	Answer	Bar	Response	%
1	Autonomous		1	100%
2	Flight attendant		0	0%
	Total		1	

5. Please explain why you chose autonomous vs. brought by the flight attendant and how it would improve your experience. Would having the flight attendant bring you the aisle chair significantly impact your experience?

Text Response
Independence means not having to rely on a person to do something for us. Having a flight attendant bring the chair might discourage me from using it, because I don't want to bother the flight attendant.

6. The proposed 'on-demand' powered aisle wheelchair will include sensors for detecting obstacles and guides ensuring a straight path of travel. Are there any other issues you can think of that we should address?

Text Response
Detecting an obstacle doesn't mean being able to move the obstacle out of the way. My biggest concern would be hitting or annoying other passengers.

7. What do you think about the concept of a wider aisle allowing you to enter the plane with your own wheelchair? Is this preferable to having a powered aisle chair?

Text Response
Yes, being able to enter with my own wheelchair would be preferable by far. I'm accustomed to transferring to and from my own chair, and I can operate it on my own.

8. How uncomfortable would it be to enter from the front of the plane and be power-driven backwards (facing the front of the plane) to your seat- not being able to see where you are going but knowing there are sensors and rails to guide the chair?

#	Answer	Bar	Response	%
1	Very uncomfortable		1	100%
2	Somewhat uncomfortable		0	0%
3	It wouldn't affect my comfort level		0	0%
4	It would be comfortable		0	0%
	Total		1	

9. Are you more likely to trust a human pushing you while you face backwards or an automated system with rails and sensors? Why?

Text Response
Human. Humans have a sense of responsibility, and therefore guilt and blame; they don't want to mess up because then they'll be at fault.

10. In the previous questions, your travel companions would probably have to be boarded from the front of the plane so if you are boarding from the back there might be a small period of time that you are separated, how important is this to you and why?

Text Response
I'd much rather not be separated because my travel companion (usually my mom or dad) often advocates for me, or backs up what I say. Far too often, people don't listen to me.

11. Would you be comfortable using a standing wheelchair or some other sort of device that provides skeletal support to keep you in an upright position instead of sitting down? Please explain.

Text Response
Uh.........I guess.......................I haven't found a standing wheelchair that works for me due to my unique body shape, but if you could make it work, I'd try it. That sounds like a more difficult solution than just having a sitting chair.

12. Do you have any other thoughts regarding moving inside the cabin you would like to share with us?

Text Response
Even on long flights, I never move around the cabin except to board and disembark. How do I go to the bathroom, you might ask? I don't. I dehydrate myself before the flight so that I'll be able to hold it the whole way, no matter how many hours it might take (including more than 10 hours).

13. Do you typically travel with a carry-on luggage or do you check-in your luggage?

#	Answer	Bar	Response	%
1	Carry-on		1	100%
2	Check-in		0	0%
	Total		1	

14. Do you bring a personal item or do you bring both a personal item and a bag?

#	Answer	Bar	Response	%
1	Personal item		0	0%
2	Carry-on luggage & personal item		1	100%
3	Click to write Choice 3		0	0%
	Total		1	

15. Where do you prefer to stow your carry-ons?

Text Response
On my lap, hung on my knee, or below the seat in front of me if they don't let me carry it on my lap or knee.

16. Do you typically access your carry-ons during the flight?

#	Answer	Bar	Response	%
1	Yes		1	100%
2	No		0	0%
	Total		1	

17. Any additional pain points/ stories concerning luggage you would like to share with us?

Text Response
It's difficult to find somewhere to put my glasses when I want to sleep.

18. For those of you that have removable armrests/handles on your wheelchairs, do you trust them to support your weight during a transfer?

#	Answer	Bar	Response	%
1	Yes		1	100%
2	No		0	0%
	Total		1	

19. Do you find them easy to remove in an efficient and quick manner?

#	Answer	Bar	Response	%
1	Yes		0	0%
2	No		1	100%
	Total		1	

20. Is there a specific mechanism that you prefer for your removable parts of your wheelchair over other mechanisms you have had in the past? Feel free to describe it or upload a picture below.

This question was not answered by the respondent.

21. Describe your mechanism

Text Response
For my scooter, the arm rotates upwards from a hinge at the back. This isn't ideal, because it's hard to reach it once it's back there. For my power chair, the control rotates sideways out of the way through a double-jointed mechanism. The armrests stay in place, though.

22. Any other thoughts concerning handles/support mechanisms you would like to share with us?

Text Response
I like to lean on them, so it's important that they're squishy and they aren't abrasive.

23. Thank you for taking the time to fill out this survey, we really appreciate it. Your responses will be invaluable to helping us improve the flying experience for wheelchair users. Please provide your email if you would like to be contacted for updates and follow up questions.

Text Response
aubrie@stanford.edu

Initial Report

Last Modified: 02/20/2014

1. How uncomfortable does the narrow aisle make your experience?

#	Answer	Bar	Response	%
1	Very uncomfortable		1	100%
2	Somewhat uncomfortable		0	0%
3	It doesn't affect my comfort level		0	0%
	Total		1	

2. What are the biggest pain points concerning the current aisle chair? How do you think we can improve your experience?

Text Response
Lack of safety: Nobody has ever taken notice of the simple physics of torque in an independent transfer from a manual chair to an aisle chair. It is obvious in the design (the front wheels do not lock and thus the force of transferring causes them to swing the aisle chair away from the wheelchair leaving the person transferring holding an Iron Cross. It is obvious in staff behavior (clueless) that they are not trained to deal with this even though they observe it regularly (One person places their foot blocking the aisle chair caster wheel from rotating. Another blocks the wheelchair's.)

3. How do you think having an 'on demand' powered aisle wheelchair would improve your experience?

Text Response
I would feel like a passenger for a change and not a sack of coffee beans.

4. If the aisle chair were powered, i.e. you did not have to be pushed by someone else or push yourself, would you rather have the aisle chair come autonomously to you upon calling it or would you rather have the aisle chair be brought to you by the flight attendant? Remember this is not about you being in the chair or your experience in the chair; it is about how the chair gets to your seat.

#	Answer	Bar	Response	%
1	Autonomous		0	0%
2	Flight attendant		0	0%
	Total		0	

5. Please explain why you chose autonomous vs. brought by the flight attendant and how it would improve your experience. Would having the flight attendant bring you the aisle chair significantly impact your experience?

Text Response
Autonomous would be my preference but then where would my personal chair go? I'f have to push it anywhere I went.

6. The proposed 'on-demand' powered aisle wheelchair will include sensors for detecting obstacles and guides ensuring a straight path of travel. Are there any other issues you can think of that we should address?

Text Response
It should have a call button to airport security is the power fails. Airport security and not the subcontractors who help you with wheelchairs because they would just ignore you. They are overworked as it is.

7. What do you think about the concept of a wider aisle allowing you to enter the plane with your own wheelchair? Is this preferable to having a powered aisle chair?

Text Response
Actually, an aisle chair is better because otherwise I'd need to lift over my real wheels rather than slide straight across into the airplane seat.

8. How uncomfortable would it be to enter from the front of the plane and be power-driven backwards (facing the front of the plane) to your seat- not being able to see where you are going but knowing there are sensors and rails to guide the chair?

#	Answer	Bar	Response	%
1	Very uncomfortable		0	0%
2	Somewhat uncomfortable		0	0%
3	It wouldn't affect my comfort level		0	0%
4	It would be comfortable		1	100%
	Total		1	

9. Are you more likely to trust a human pushing you while you face backwards or an automated system with rails and sensors? Why?

Text Response
Because my cell phones understand as much English as some of the people I have had help me!

10. In the previous questions, your travel companions would probably have to be boarded from the front of the plane so if you are boarding from the back there might be a small period of time that you are separated, how important is this to you

and why?

Text Response
There is no reason why we should not be boarded together.

11. Would you be comfortable using a standing wheelchair or some other sort of device that provides skeletal support to keep you in an upright position instead of sitting down? Please explain.

Text Response
Sure, I use one at home for exercise so the technology doesn't bother me but I would never trust the folks who currently do this sort of work with my safety in a standing position.

12. Do you have any other thoughts regarding moving inside the cabin you would like to share with us?

Text Response
there is still the issue of getting to the bathroom in-flight

13. Do you typically travel with a carry-on luggage or do you check-in your luggage?

#	Answer	Bar	Response	%
1	Carry-on		0	0%
2	Check-in		1	100%
	Total		1	

14. Do you bring a personal item or do you bring both a personal item and a bag?

#	Answer	Bar	Response	%
1	Personal item		0	0%
2	Carry-on luggage & personal item		1	100%
3	Click to write Choice 3		0	0%
	Total		1	

15. Where do you prefer to stow your carry-ons?

Text Response
doesn't matter

16. Do you typically access your carry-ons during the flight?

#	Answer	Bar	Response	%
1	Yes		0	0%
2	No		1	100%
	Total		1	

17. Any additional pain points/ stories concerning luggage you would like to share with us?

This question was not answered by the respondent.

18. For those of you that have removable armrests/handles on your wheelchairs, do you trust them to support your weight during a transfer?

#	Answer	Bar	Response	%
1	Yes		1	100%
2	No		0	0%
	Total		1	

19. Do you find them easy to remove in an efficient and quick manner?

#	Answer	Bar	Response	%
1	Yes		1	100%
2	No		0	0%
	Total		1	

20. Is there a specific mechanism that you prefer for your removable parts of your wheelchair over other mechanisms you have had in the past? Feel free to describe it or upload a picture below.

This question was not answered by the respondent.

21. Describe your mechanism

This question was not answered by the respondent.

22. Any other thoughts concerning handles/support mechanisms you would like to share with us?

This question was not answered by the respondent.

23. Thank you for taking the time to fill out this survey, we really appreciate it. Your responses will be invaluable to helping us improve the flying experience for wheelchair users. Please provide your email if you would like to be contacted for updates and follow up questions.

Text Response
Poorly phrased question mismatches with a required field "Please provide your email IF...

D Appendix - Interviews regarding baggage handling

D.1 Claude Monteils, Air France

In order to understand what can happen to a wheelchair during this long period of time that includes transfer to the tarmac, loading in the cargo hold, and flight disturbances, we interviewed Claude Monteils, an Air France employee at Toulouse-Blagnac TLS Airport (France). Claude is responsible of the cargo hold management of the short range aircraft of Air Frances fleet at TLS and accepted to answer our questions about the way wheelchairs are handled and stored in the cargo hold.

Figure D.1: *Claude Monteils - Air France employee at Toulouse airport (France)*

D.1.1 General procedure for wheelchair storage

The type of wheelchair the passengers are equipped with really makes a difference in the way the airline will handle it:

- For a light wheelchair, that is to say a non powered wheelchair, the forces applied on the floor per square meter is very low. Therefore, these wheelchairs do not require any particular attention. They have the same status as a piece of luggage and are taken from the jet way to a conveyor belt that puts them into the cargo hold in the end so that once the aircraft has landed the wheelchairs are the first things that come out of the cargo hold. There is no box or protection or anything to protect this type of wheelchairs.
- For a heavy wheelchair (mostly powered wheelchairs), the problem is very different. First the wheelchair has to be able to enter the cargo hold (smaller than the door

which is always the case for A320, B737 and bigger planes but Claude was not able to confirm this on smaller Embraer jets). Depending on the weight of the wheelchair, the force per square meter can be higher than what the cargo hold floor can stand. Since the contact area between the floor and the wheelchair is small (seeD.2) but the weight is high, it causes lots of issues. The only way for Air France passengers to make sure their heavy powered wheelchair can go to the cargo hold and be protected from all sorts of damage is to follow a very specific and long procedure.

Figure D.2: *Contact area between the wheelchair and the cargo hold floor: its causes an important stress on the aircraft structure*

D.1.2 Specific procedure for heavy powered wheelchair which are stored in the cargo hold

First, they have to tell Air France in advance that they are travelling with a heavy powered wheelchair and they have to give all the characteristics of their chair in advance. Usually, once they initiate the procedure, an Air France employee has to contact them to ask for more information and details. The problem is that most of the time disabled passengers with powered wheelchairs do not mention it at all until check in or even boarding and when the airline finds out that they have to deal with a heavier than what the cargo hold floor can stand powered wheelchair, most of the time because they are afraid of being sued for denying a reduced mobility passenger the right to have his/her wheelchair in the cargo hold, they have to find a solution in a hurry and most of the time its not an optimal solution. They systematically use a sort of fake floor or wooden plates to distribute the load of the wheelchair and thus decrease the number of Newtons per square meters, even if the wheelchair happen to be light enough because they dont have time to analyze it. In order to make sure the wheelchair will remain on this support they use ropes to tie it and they usually store it in a section of the cargo hold that is not dedicated to containers. The reason for it is that most of the time in such sections you have several nets to deter the objects from sliding and bumping (where as in the container compartment everything is already enclosed in boxes so no need to use nets). However, when disabled passengers told in advance the airline about their powered wheelchair and sent in advance all the information to handle properly the wheelchair, things happens in a much better way. The personnel in charge of the cargo hold management can analyze whether the chair will require a fake floor to distribute its load or not, if so they usually try to adapt a container to shelter the wheelchair. As a consequence, when passengers leave their wheelchair at the jet way, the wheelchair directly goes to an adapted container and usually the airline employees use a lift instead of a conveyor belt to put the container in the cargo hold. The only inconvenience is that its a little bit longer to bring the wheelchair back to his/her owner once the plane has arrived at destination.

D.1.3 Impacts on the center of gravity of the plane due to the presence of a heavy wheelchair in the cargo hold

Before putting a wheelchair in the cargo hold the person in charge of the position of the center of gravity is notified the weight of the wheelchair (there is a weight measurement of everything that goes on a conveyor belt on a lift used for containers). Knowing the weight they use a computer to determine the best position for the wheelchair inside the cargo hold in order to make sure the center of gravity of the plane will remain stable during the flight.

However, it is necessary to have several powered wheelchairs on board (e.g. a team of handicapped athletes travelling altogether for a competition) to have a significant impact on the center of gravity of the plane, but in this case the airline generally knows a long time before the flight that they will have to deal with several power wheelchairs and they arrange everything in advance. Once the wheelchair is on board the pilot is notified with the following information: the type of battery, in which compartment the chair was stored (front or rear, left or right), how heavy it is, etc. Since the pilot knows the chair is on board, why not the passenger? In fact nobody thinks about reassuring the passenger about his/her wheelchair, but it could be a good thing to do.

D.1.4 Responsibilities of the airline employees

In terms of responsibilities the airline employees have regarding wheelchair storage in the cargo hold, if the storage is arranged in advance there are several check-in points where each employee has to sign a document to testify that all the safety rules are respected so if something gets broken they are able to tell where and why. Most of the time for Air France when storage is arranged in advance, the wheelchairs are not damaged. If they are damaged it often happens in the cargo hold itself where no human operator can control it, but its rare. However, when storage is not arranged in advance, or when disabled people only have a non powered wheelchair that is considered as a piece of luggage, there are no check-in points during the whole storage process. There are surveillance cameras on the tarmac for safety reasons but most of the time the plane, catering, fuel truck, etc hide the employees and they are free to do whatever they want with the wheelchair. If they break it nobody will blame them since nobody will know.

D.2 Brandon Witta, Delta Airlines

We were able to get in touch with Brandon Witta, a Ramp Agent for Delta Airlines at Hartsfield Jackson International Airport in Atlanta, Georgia. He answered a series of questions for us over email.

"All the information below is of the Atlanta operation. Each station has a similar operation but what makes ATL so different is the heavy flight schedule. I don't know the flights per day in ATL but I do know that Hartsfield-Jackson has been the busiest airport in the world since 2000. "

- What are the biggest constraints in the job? What are you most concerned about?

  "Since the operation moves so quickly I think time is the biggest constraint. The size of the operation also makes communication key amounst the ground crews, dispatch, and towers. Here are some other constraints; flights changing gates, on the ground gate changes, destination changes, bags missing flights, connecting bags to their connecting flights, travel times, unload times, loading times, # of handlers per gate, # of drivers per offload....I was in a meeting with one of the station managers last week and one concern he is focusing on this year was minimizing the number of bags missing their connecting flights, since more people are flying delta now more than ever it's hard to compinsate using the same staffing. He is focusing on connecting flights 35-45 minutes out. We run into problems during the offload since it takes 10-30 minutes to offload depending on the number of bags and type of aircraft. Anyways..note that electrical wheel chairs are never transported on the bag tugs, they are gate checked and given back to the customer upon arrival..however standard wheelchairs are commonly checked luggage and can be transported via tug."

- What type of information (if any) do you get about specific wheelchairs before you handle them?

  "The only information we get is the weight, which gives us an idea if it's a standard or an electrical wheelchair. Standard wheelchairs as well as electrical wheelchairs have similar designs so we handle them both the same."

- How do you receive the information?

  "Everything loaded on the plane is scanned and uploaded to a ramp worksheet that we process before a plane departs and arrives. It shows all the details of weight and balance. For example; # of bags and their position, pounds of freight, valet bags, wheel chairs, strollers, live animals, dangerous goods, dry ice, and total pounds in each bin."

- How would you like to receive the information? How can it be improved?

  "Recieving the ramp worksheet is simple. "

- How long would you spend handling a wheelchair? How long does it take?

  "Typically a standard manual wheelchair takes 3 to 5 minutes to get to the jet bridge after a plane is parked. However electrical wheelchairs could take up to 10 minutes since some weigh up to 600 pounds! If they are too heavy to handle we use the elevator for transportation. "

- How many handlers typically handle a wheelchair? How is information shared between them?

  "1 handler per standard wheelchair since they are light. For electrical wheelchairs there are 2 to 4 handlers depending how heavy it is."

- Is there a specific training module for handling wheelchairs?

  "Yes. We have annual training that covers the loading procedures for every piece that can possibly be loaded. This training covers lifting techniques to protect us from injury."

- What kind of device is used to move a wheelchair from the jetway to the cargo hold?

  "We typically use the closest elevator to the gate if the wheelchair is too heavy, which we do a lot. If not, we carry it up to the jet way or down to the bin, might take 3 to 10 minutes. But since disabled passengers are the first ones on the airplane and last ones off the airplane, their wheelchairs should be handled properly."

- What would improve your luggage handling techniques (e.g. better tools, instructions, more time, etc.)?

  "TIME and more staffing would definitely make things less stressful."

E Appendix - Characteristics of Embraer jet E175

E.1 Analysis of aircraft dimensions

Dimensions for the seats: Here are the characteristic dimensions of the seats of an Embraer jet E175 in economy class:

Figure E.1: *Seats of a typical Embraer E175 in economy class*

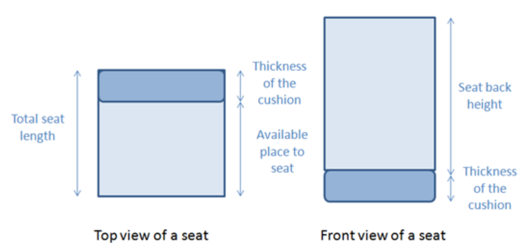


Figure E.2: *Characteristics of the seat*

Dimensions of the fuselage: In order to determine what are the constraints of our design space we wanted to have a precise map of the aircraft fuselage and its available space for passengers. Here are the characteristic dimensions of the fuselage of an Embraer jet E175.

Dimensions of the luggage compartment inside the cabin: To take advantage of the available space inside the cabin our team wanted to analyze the volume and the

Dimensions for the seat		
Element of the seat	**cm**	**inches**
Seat width	46	18.25
Seat height	42	16.53
Total seat length	51	20.08
Back height	71	28
Armrest width	5.1	2
Armrest length	51	20.08
Width of 2 seats + 3 armrest	107.3	42.25
Seat pitch	81.3	32
Leg room	30.3	11.93
Thickness of the cushion	10.5	4.13
Available place to seat	46x40.5	18.25x15.95

Figure E.3: *Table presenting all of the dimensions that define an airplane seat*

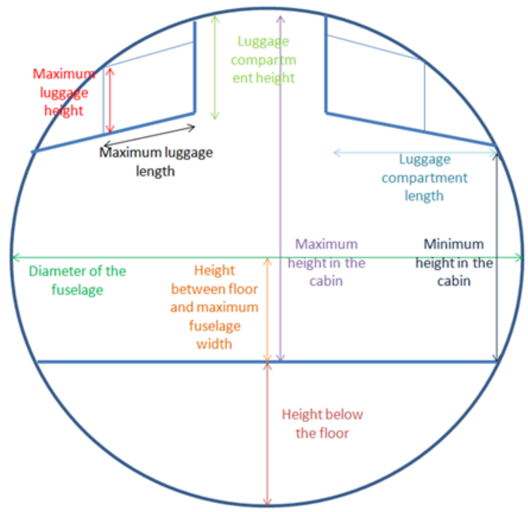


Figure E.4: *Characteristic dimensions of the fuselage of an Embraer jet E175*

Dimensions of the fuselage		
Element of the fuselage	**cm**	**inches**
Diameter	274	108
Height below the floor (cargo hold not circular)	136	53.5
Height between floor and max fuselage width	70.58	27.8
Maximum height in the cabin	200	78.74
Minimum height in the cabin	145	57.1
Aisle width	50	19.75
Thickness of the floor	11	4.33

Figure E.5: *Table presenting all of the dimensions of the fuselage of an Embraer jet E175*

space dedicated to carry-on luggage. All of the dimensions of the luggage compartment are represented on E.5 and their values are presented in E.6.

From the previous analysis we noticed that only 52% of the luggage compartment is actually dedicated to carry-on storage. This is because the remaining 48% are dedicated to wires, light and air conditioned systems.

Dimensions of the luggage compartment		
Element of the fuselage	**cm**	**inches**
Maximum luggage height	32	12.6
Maximum luggage length	50	19.68
Luggage compartment height	52	20.47
Luggage compartment length	74.7	29.4
Size of luggage compartment for 2 seats (orthogonal to my drawing)	81.3	32
Dimensions of the luggage space (not the box, just the empty space)	32x50x81.3	12.6x19.68x32
Volume of luggage compartment for 2 seats (m3/feet3)	0.25	8.91
Effective volume of luggage for 2 passengers (m3/feet3)	0.13	4.6
Efficiency of the storage compartment	52%	52%

Figure E.6: *Table presenting all the dimensions of the fuselage of an Embraer jet E175*

E.2 Analysis of the cargo hold structure

Characteristics of the material used for the cargo hold floor In order to protect the passengers wheelchairs from damages, our team decided to design a structure that would enclose the wheelchair while stored in the cargo hold. In order to understand what are the constraints the will have to deal with during our design process we decided to analyze both the geometric and structural constraints caused by the aircraft structure.

Geometric constraints due the cargo hold shape:

On E.7 we can see that the geometry of the cargo hold is an important limitation for our design since the semi elliptical shape considerably reduces the volume and height available for storage.

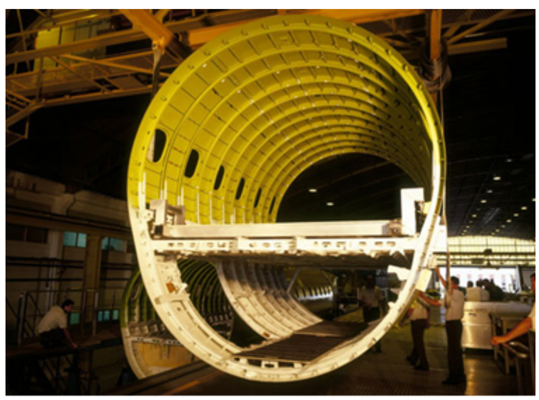


Figure E.7: *Structure of an Embraer jet E170 [2]*

In order to make sure that the product we want to design to protect the wheelchair is adapted to the cargo hold dimensions we looked at two elements:

- The cargo hold characteristic dimensions that are shown on E.8
- The characteristic dimensions of one of the biggest powered wheelchair that is available on the market (E.9). Its dimensions are shown on E.10.

By comparing the wheelchair dimensions to the cargo hold dimensions, we noticed that the headrest has to be remove otherwise the wheelchair is too high to fit the cargo hold. Fortunately, most of the heavy powered wheelchairs are equipped with removable parts in order to minimize the size and weight of the wheelchair while this latter is transported from one place to another.

Aircraft element from the cargo hold	Dimension
Front door height	39.6" / 100 cm
Front door width	35.4" / 90 cm
Aft door height	38.9" / 99 cm
Aft door height	34.3" / 87 cm
Maximum height in the cargo hold	53.5" / 136.4 cm
Maximum width available for maximum height	32.3" / 82 cm

Figure E.8: *Cargo hold characteristic dimensions*

Figure E.9: *One of the heaviest powered wheelchair of the market designed for obese disabled people (https://www.shermanoaksmedical.com/M94_p/m94-invacare.htm)*

Wheelchair element	Dimension
Weight	290 lbs / 131.54 kg
Drive wheels width (2 wheels)	3" / 7.62 cm
Casters width (4 wheels)	2" / 5.08 cm
Minimum area of box in contact with the floor	8 inch^2 / 51.61 cm^2
Wheelchair height (including headrest)	57" / 144.78 cm
Wheelchair height without headrest	48" / 121.92 cm
Wheelchair width (including armrest)	28" / 71.12 cm
Wheelchair length (including footrest)	36" / 91.44 cm

Figure E.10: *Table presenting all the dimensions of the wheelchair*

One the headrest is removed this wheelchair can be stored in the cargo hold. Its width is lower than the doors width so it can enter the cargo hold. Even if the height of the wheelchair is higher than the cargo hold doors height, by tilting the wheelchair airline employees are able to make it go inside the cargo hold.

To conclude about the geometric constraints of the cargo hold, given that the biggest wheelchairs can be stored inside the cargo hold of an Embraer jet, the only restriction we really need to take into account is the clearance between the product we will design to protect the structure and the size of the door. For instance, if we decide to use inflatable material to protect the wheelchair, we may have to blow it up inside the cargo hold and not outside in order to make sure the package size will still be smaller than the door size.

Structural constraints due the cargo hold structure:

As previously mentioned when our team interviewed the Air France employee in charge of cargo hold management, wheelchairs can be very heavy and the contact area with the cargo floor is very small. This can generate stress that the cargo hold floor will not be able to withstand. In order to design a product that will protect the wheelchair inside the cargo hold, our team needed to analyze the stress limitations of the cargo hold floor to take them into account in our design process.

Hexcel is a US company that provides aircraft manufacturers with composite material (beams and panels) used in the cargo hold floor structure. On their website (www.hexcel.com) we were able to get the technical data sheet of Fiberlam, the material that is used for the cargo hold structure of Embraer jet C-28-1386 Type II MEP 15-031.

From these data, here are the calculations made to determine the maximum pounds per square inch the cargo hold floor can withstand. Knowing that there are different types of elements below the floor, we calculated the maximum load for each type of beam and its main failure mode and chose the most sensitive value as our limitation. On E.11 we can see the three different types of beam that constitute the cargo hold structure:

- The long beams that come across the entire fuselage. Because they are very long they are very sensitive to bending and flexural failure.
- The short beams that are very close to the fuselage skin and are designed to withstand traction and compression force. They are not very resistant to shear forces since they are not suppose to experience them a lot.
- The floor panels that are sensitive to flatwise compression.

itemize

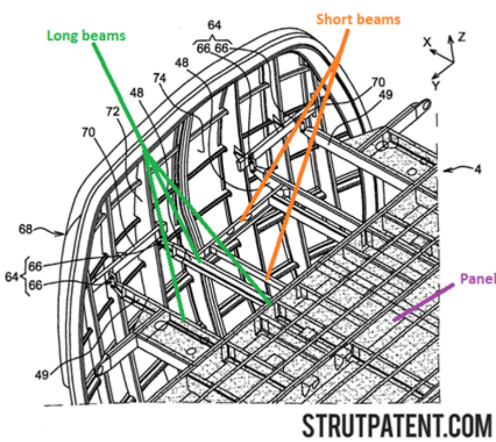


Figure E.11: *Different types of elements that constitute the cargo hold structure from http://www.strutpatent.com/patent/07338013/floor-for-aircraft*

The average skin stress can be determined with the following equation: Skin stress :

$$\sigma_s = \frac{P.s}{8.(h-t).wt}$$

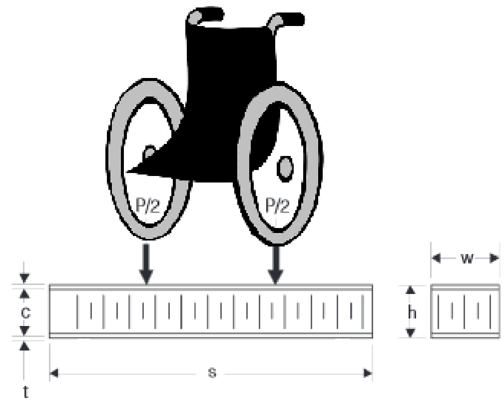


Figure E.12: *Key parameters for the structural analysis of the cargo hold floor stress*

s = beam span (2489 inches / 980 cm)
P = total applied load on the surface of the beam (distributed or punctual)
t = skin thickness (0.015 inches / 0.038 cm)
w = width of panel (24.4 inches / 9.6 cm)
h = panel thickness (0.66 inches / 1.7 cm)

For P_{max} = 490 lbs or 2170 N which is a typical value for the rupture of a sandwich panel being used as aircraft floor, the maximum skin stress we can tolerate is σ_s= 6222 psi or 42.9 MPa. This is associated with a maximum stress of $Stress_{max1}$ = 6222 psi or 42.9 MPa.

E.2.0.1 Analysis of short beams shear failure

For such a beam, the typical failure mode is a shear failure in the core of the beam (not the skin). Provided that the failure occurs in the core, the core shear strength (average shear stress) can be calculated by the following equation: Shear stress:

$$\tau = \frac{P}{2.c.w}$$

P = total load applied on the surface of the beam (distributed or punctual)
c = core thickness (0.645 inches / 1.662 cm)
w = width of panel (30.48 inches / 12 cm)

For P_{max} = 710 lbs or 3150 N which is a typical value for the rupture of the core of a sandwich panel being used as aircraft floor, the maximum applied load we can tolerate is τ = 36.11 psi or 0.25MPa. This is associated with a maximum stress of $Stress_{max2}$ = 36.11 psi or 0.25 MPa on the beam. This value is quite low because these beams are designed to withstand mainly traction and compression forces. They are poor in shear resistance.

E.2.0.2 Analysis of floor panels flat wise tension/compression failure

We want to determine the core compressive limitation of the sandwich panel. Since we have a sandwich panel with thin face skin, the following equation can be used to determine the strength of the core:

$$\sigma = \frac{P}{s.w}$$

with s = 144 inches / 365.8 cm and w = 32.3 inches / 82 cm
$\sigma = 740$ psi or 5.1 MPa is a typical value for the rupture of a sandwich panel being used as aircraft floor. This is directly associated with a maximum stress of $Stress_{max3} = 740$ psi or 5.1 MPa on the floor.

In conclusion, the most sensitive parts of the cargo hold floor are the short beams: $Stress_{max2} < Stress_{max3} < Stress_{max1}$ This is because these beams are designed to reinforce the cargo hold structure when it is in tension due to pressurization. Since these beam are design to withstand tension loads if a very heavy element of the cargo hold applies a shear force on them they are quite sensitive to it and do not resist it very well contrary to the floor panels and long beams which are specifically designed for this. As a consequence, we need to design our wheelchair protection system such that the distributed load applied on the cargo hold floor does not exceed $Stress_{max2} = 36.11$ psi or 0.25 MPa. It means that for a wheelchair such as E.9 we need to distribute the load over a minimum contact area with the floor which is 8 $inches^2$ 51.61 cm^2. The floor of our protection system must exceed this surface.

F Appendix - Proposed App Interface

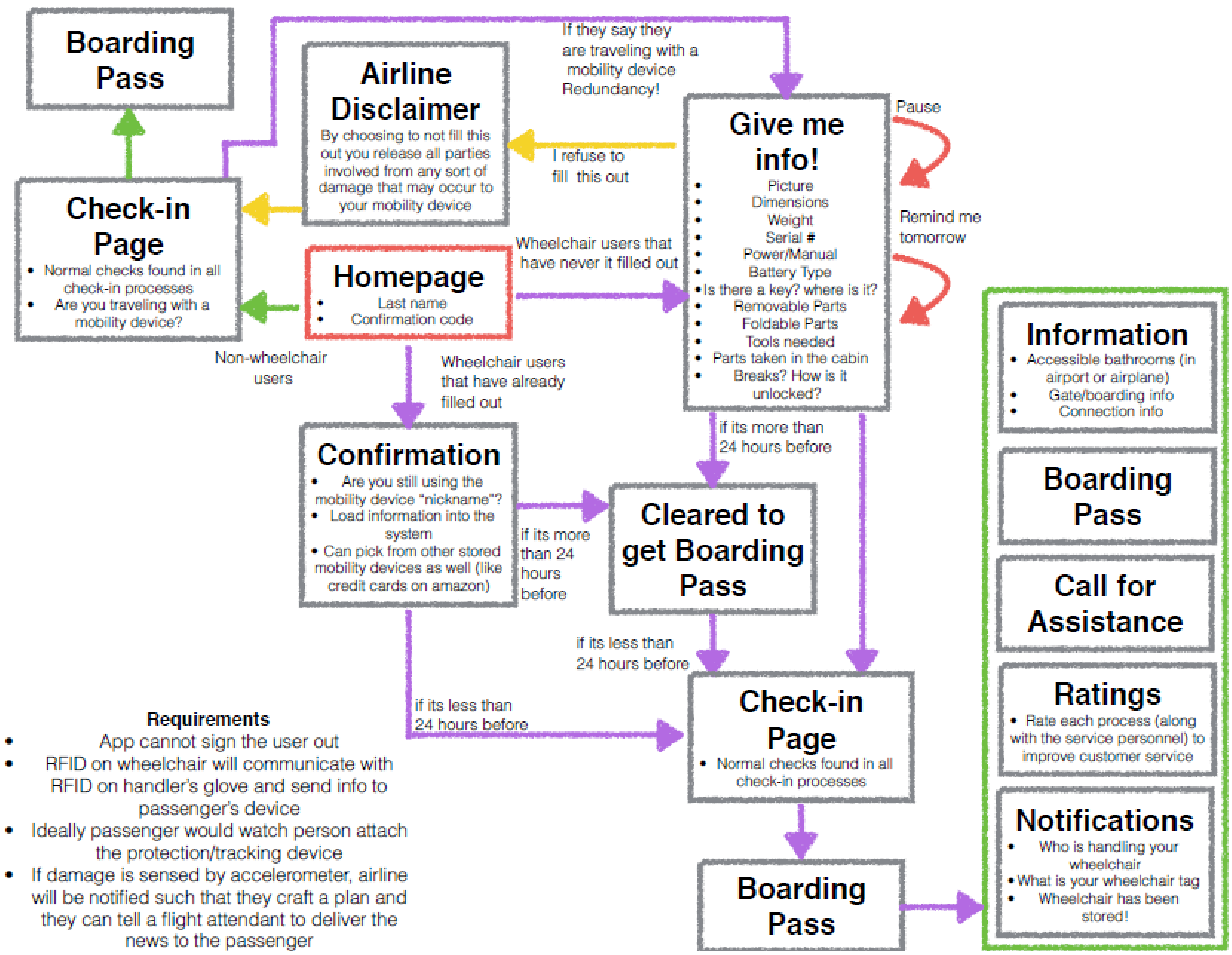


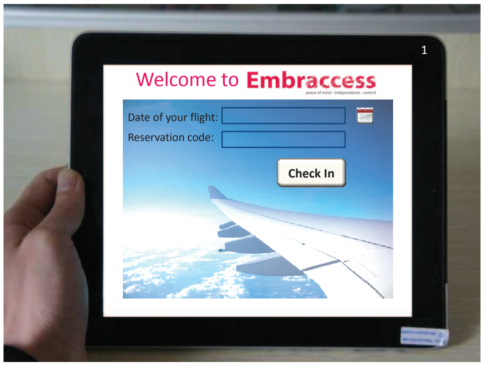
Figure F.1: *App flow we designed in order to implement the smartphone app*

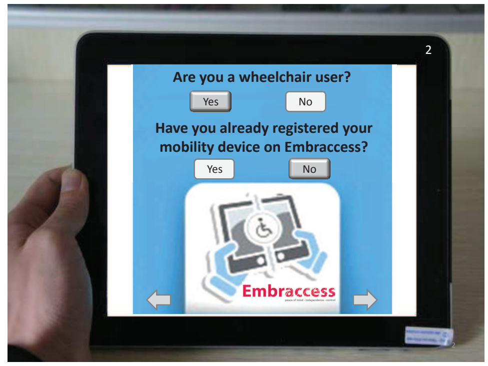
Our team thought it would be great if disabled passengers were able to give and receive important information via a smartphone app to make sure their flying experience would not turn out into a nightmare. As shown on the app flow and the user interface we imagined, this app could be integrated to the already existing airline app that enables every single passenger to get their boarding passes.

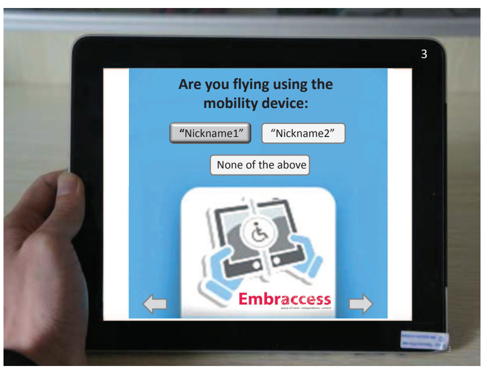
Since airlines do not always anticipate wheelchair users on their regular flight, we designed the app such that any wheelchair user would be strongly encouraged to give information about his situation and his mobility device before getting his boarding pass. This is a way to ensure that airlines are aware in advance of how many disabled passengers will be flying with them and what type of mobility device they will bring.

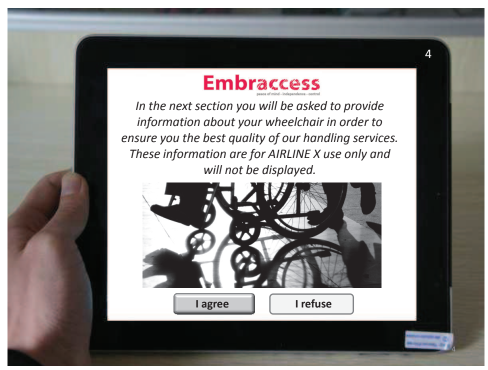
Indeed, we plan on using the smartphone camera to allow people to send pictures of their mobility device. This way, airlines know what to expect at the gate and can make special arrangement with the handlers if needed. Moreover, passengers have the opportunity to write down messages or important precisions on their pictures that will be carefully analyzed by baggage handlers.
Once all the information about the mobility device will be provided, users can access their boarding pass if available. After this, the app will offer an interface with four different categories available all along the flying experience:

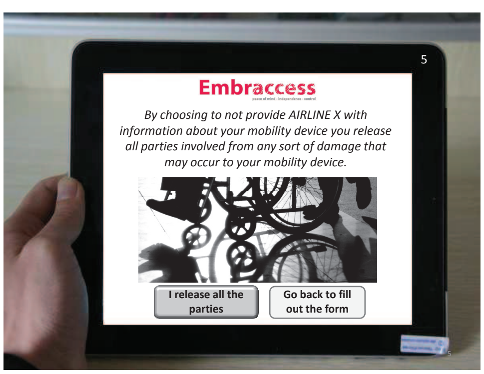
- textbfInfo about accessibility: this section will locate in which airport and terminal passengers are located and will provide them with information about accessible bathroom, elevator locations, etc.
- textbfAccess your boarding pass: if at any time passengers need to reopen their boarding pass our check information about their reservation, this section will allow them to do so.
- textbfCall for assistance: if at any time a disabled passenger needs assistance for carrying his luggage, get an airport wheelchair, go through security, etc., this section will enable him to call an airport employee that will come to help him.
- textbfRate quality f services: in order to make sure airline services meet disabled passengers expectations, the app will allow them to rate the quality of services (preboarding, wheelchair handling, transfer to the seat, assistance if using restroom during the flight, etc.)

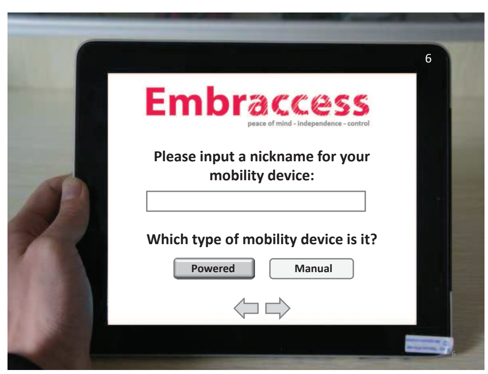

1
Welcome to Embraccess
Date of your flight:
Reservation code:
Check In

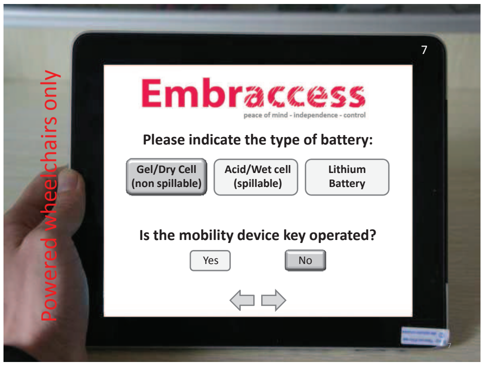

2
Are you a wheelchair user?
Yes
No
Have you already registered your mobility device on Embraccess?
Yes
No
Embraccess

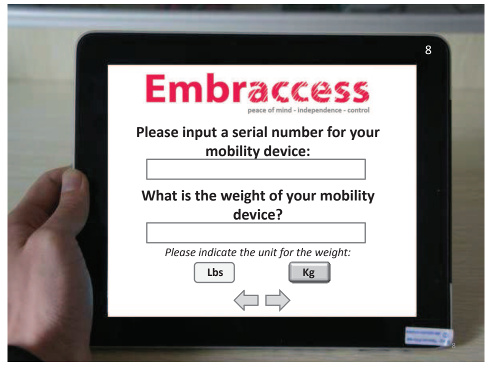

3
Are you flying using the mobility device:
"Nickname1"
"Nickname2"
None of the above
Embraccess

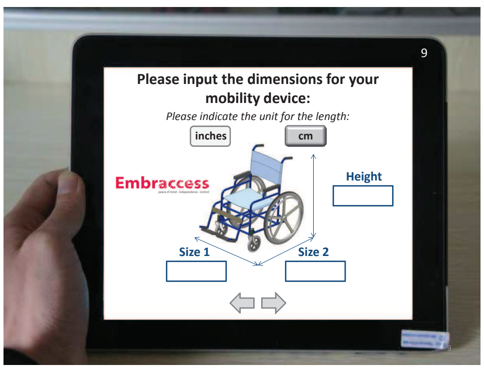

4
Embraccess
In the next section you will be asked to provide information about your wheelchair in order to ensure you the best quality of our handling services. These information are for AIRLINE X use only and will not be displayed.
I agree
I refuse

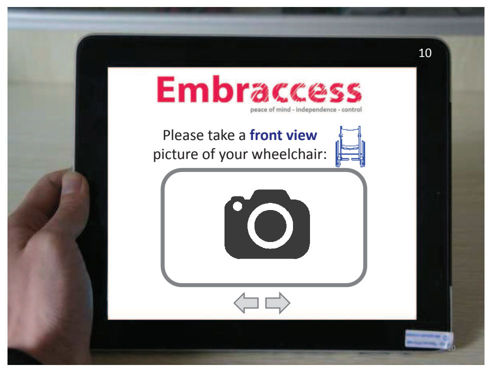

5
Embraccess
By choosing to not provide AIRLINE X with information about your mobility device you release all parties involved from any sort of damage that may occur to your mobility device.
I release all the parties
Go back to fill out the form

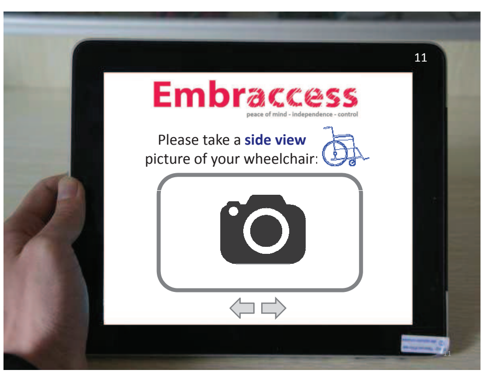

6
Embraccess
peace of mind - independence - control
Please input a nickname for your mobility device:
Which type of mobility device is it?
Powered
Manual

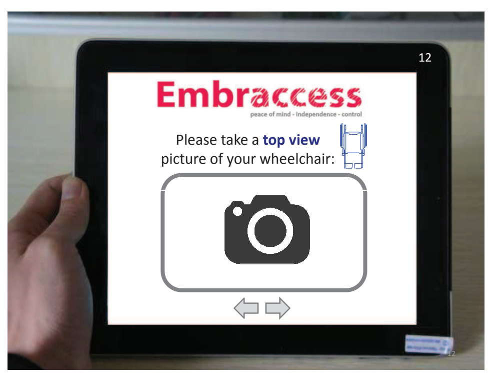

7
Powered wheelchairs only
Embraccess
Please indicate the type of battery:
Gel/Dry Cell (non spillable)
Acid/Wet cell (spillable)
Lithium Battery
Is the mobility device key operated?
Yes
No

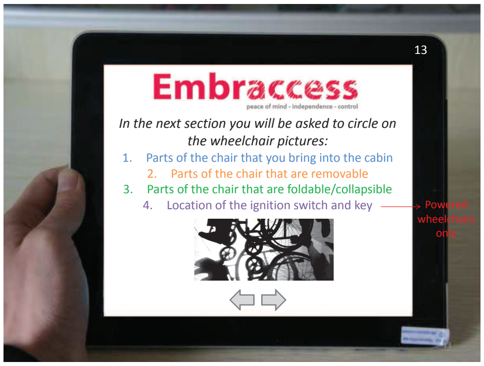

8
Embraccess
Please input a serial number for your mobility device:
What is the weight of your mobility device?
Please indicate the unit for the weight:
Lbs
Kg

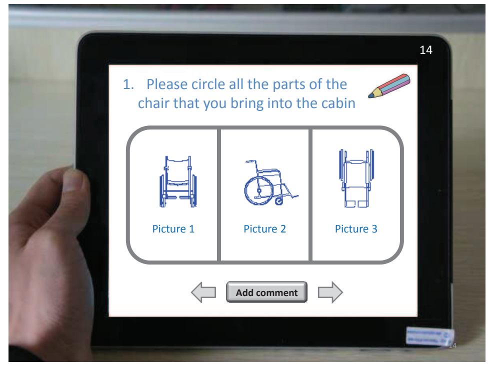

9
Please input the dimensions for your mobility device:
Please indicate the unit for the length:
inches
cm
Embraccess
Height
Size 1
Size 2

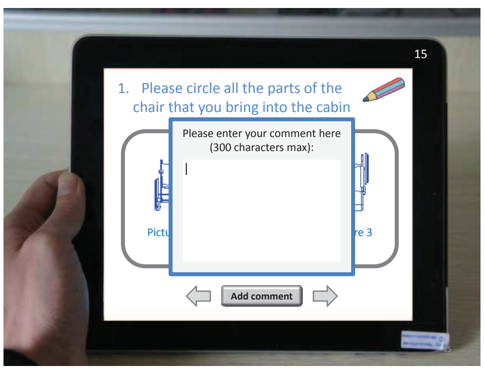

10
Embraccess
Please take a front view picture of your wheelchair:

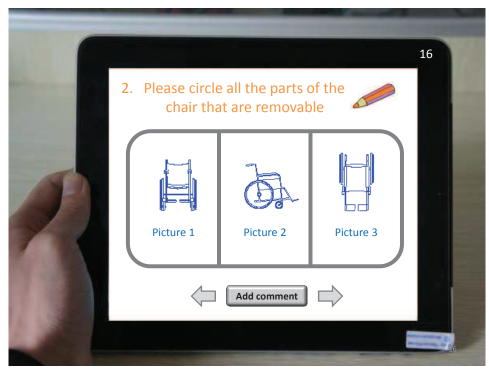

11
Embraccess
Please take a side view picture of your wheelchair:

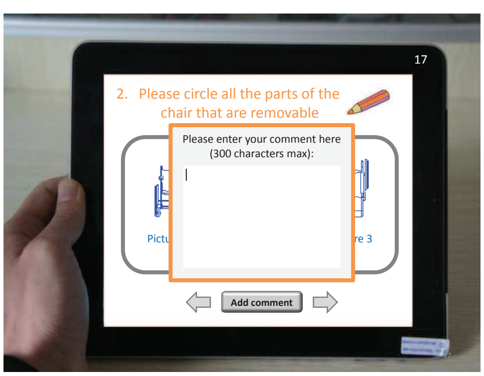

12
Embraccess
Please take a top view picture of your wheelchair:

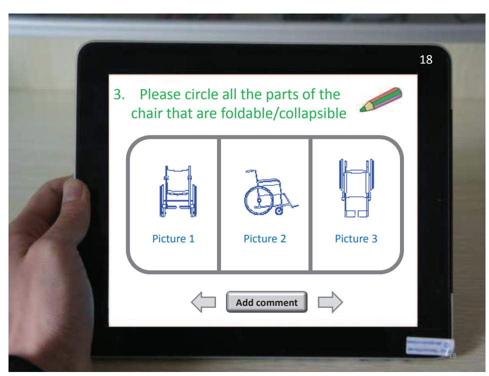

13
Embraccess
peace of mind - independence - control
In the next section you will be asked to circle on the wheelchair pictures:
1. Parts of the chair that you bring into the cabin
2. Parts of the chair that are removable
3. Parts of the chair that are foldable/collapsible
4. Location of the ignition switch and key
Powered wheelchairs only

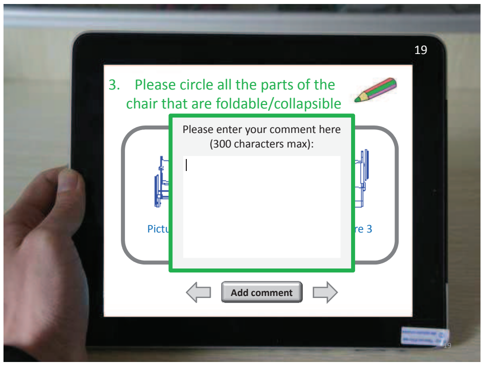

14
1. Please circle all the parts of the chair that you bring into the cabin
Picture 1
Picture 2
Picture 3
Add comment

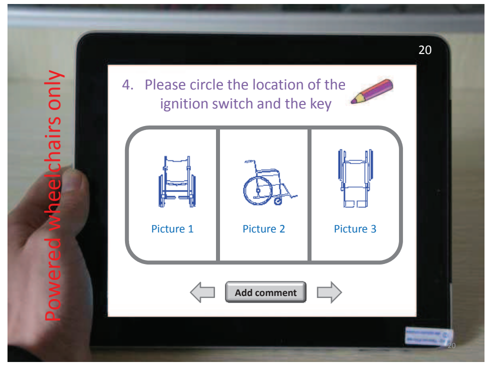

15
1. Please circle all the parts of the chair that you bring into the cabin
Please enter your comment here (300 characters max):
Add comment

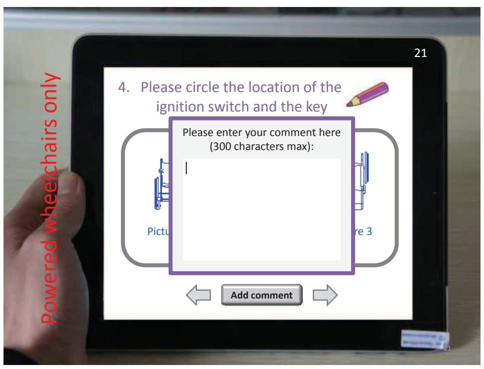

16
2. Please circle all the parts of the chair that are removable
Picture 1
Picture 2
Picture 3
Add comment

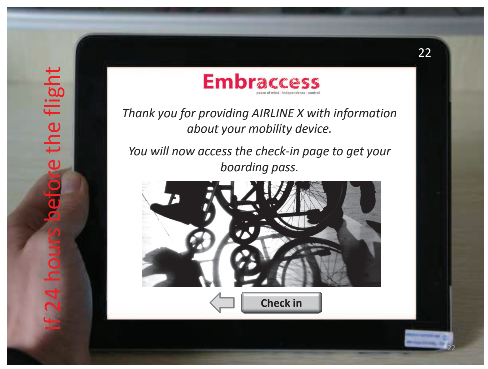

17
2. Please circle all the parts of the chair that are removable
Please enter your comment here (300 characters max):
Add comment

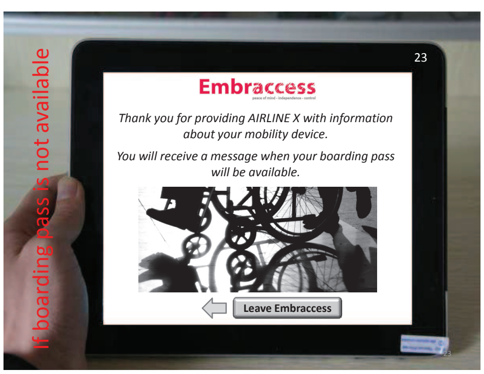

18
3. Please circle all the parts of the chair that are foldable/collapsible
Picture 1
Picture 2
Picture 3
Add comment

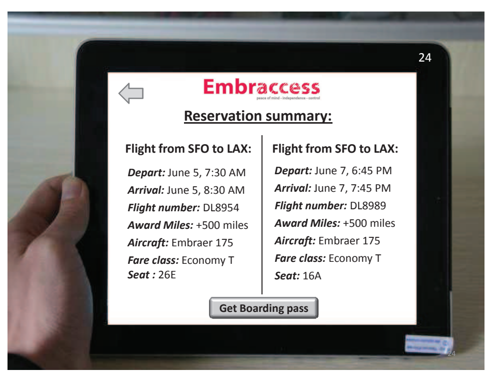

19
3. Please circle all the parts of the chair that are foldable/collapsible
Please enter your comment here (300 characters max):
Add comment


Powered wheelchairs only
20
4. Please circle the location of the ignition switch and the key
Picture 1
Picture 2
Picture 3
Add comment


Powered wheelchairs only
21
4. Please circle the location of the ignition switch and the key
Please enter your comment here (300 characters max):
Add comment


If 24 hours before the flight
22
Embraccess
Thank you for providing AIRLINE X with information about your mobility device.
You will now access the check-in page to get your boarding pass.
Check in


If boarding pass is not available
23
Embraccess
Thank you for providing AIRLINE X with information about your mobility device.
You will receive a message when your boarding pass will be available.
Leave Embraccess


24
Embraccess
Reservation summary:
Flight from SFO to LAX:
Depart: June 5, 7:30 AM
Arrival: June 5, 8:30 AM
Flight number: DL8954
Award Miles: +500 miles
Aircraft: Embraer 175
Fare class: Economy T
Seat : 26E
Flight from SFO to LAX:
Depart: June 7, 6:45 PM
Arrival: June 7, 7:45 PM
Flight number: DL8989
Award Miles: +500 miles
Aircraft: Embraer 175
Fare class: Economy T
Seat: 16A
Get Boarding pass

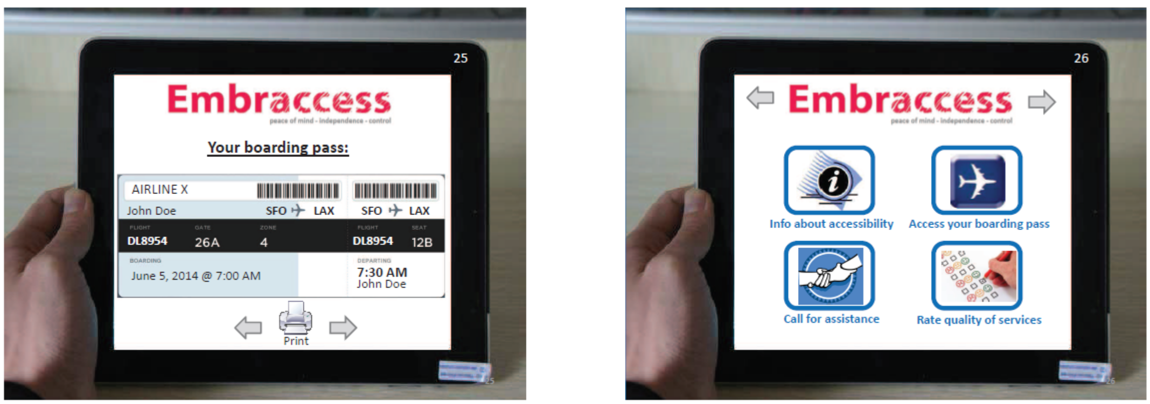


Figure F.2: *App user interface we imagined in order to implement the smart-phone app*

G Appendix - Wheelchair Protection Code

G.1 Wheelchair_Integrated.ino - Arduino

```
/**
*  ME 310 - Team Embraer '13-'14
*  Code for the Wheelchair-side system: integrated RFID and accelerometer
*  Accelerometer code adapted from https://www.sparkfun.com/tutorials/240
*  RFID code adapted from SparkFun code by Maria Barrera:
  RFID Eval 13.56MHz Shield example sketch v10

  Aaron Weiss, aaron at sparkfun dot com
  OSHW license: http://freedomdefined.org/OSHW

  works with 13.56MHz MiFare 1k tags
*  Cliff Bargar, 4/25/14
*/

//wiring
//Accelerometer http://www.inmotion.pt/documentation/others/images/
    adxl345_to_arduino_uno.png
//SDA pin -> A4 (Uno) (Pull-up resistor to 3.3V)
//SCL pin -> A5 (Uno) (Pull-up resistor to 3.3V)
//CS pin -> 3.3V
//VDD -> 3.3V
//GND -> GND
//RFID
// Based on hardware v13:
// D7 -> RFID RX
// D8 -> RFID TX
// D9 -> XBee TX
// D10 -> XBee RX


//********** includes **********
//Add the SPI library so we can communicate with the ADXL345 sensor
//#include <SPI.h>
#include <Wire.h>
#include "ADXL345.h"
#include <SoftwareSerial.h>


//********** defines **********
//***Accel***
//Free Fall threshold: 300m(g) to 600m(g) recommended
#define FALL_THRESH 0x09 //recommended value
      <-- needs to be adjusted
//Free Fall duration: minimum time for free fall, 100ms to 350ms recommended
```

```
#define FALL_DUR 0x14 //350ms     <-- needs to be adjusted
//Shock threshold: minimum acceleration value set in THRESH_TAP register, 62.5 m(g)/LSB
#define SHOCK_THRESH 0xE0 //arbitrary      <-- needs to be adjusted
//Shock duration: maximum time that an event exceeds SHOCK_THRESH to qualify as a tap
#define SHOCK_DUR 20 //12.5 ms      <-- needs to be adjusted

#define CS 10 //Assign the Chip Select signal to pin 10.

//interrupt pins on Uno:
#define SHOCK_PIN 2 //interrupt for shock on pin 2 (int.0) - INT2 on ADXL345
#define SHOCK_ISR 0
#define FF_PIN 3 //interrupt for free fall on pin 3 (int.1) - INT1 on ADXL345
#define FF_ISR 1

#define DEBUG 1
#define debugPrint if(DEBUG) Serial.println

//***RFID***
#define INDICATOR_PIN          13   //Pin for indicator LED
#define INDICATOR_DURATION     700  //duration of indicator

//last 2 digits of their serial number
#define ALBERT 0x9A
#define BOB 0xD0
#define CHARLES 0x5A
#define DIANA 0xC0
#define ELTON 0x00

#define RODRIGO 0x5A
#define LUIZ 0xD0

//********** module variables **********
//***Accel***
//This buffer will hold values read from the ADXL345 registers.
int values[3];
char output[20];

int loopCount = 0;
ADXL345 adxl; //variable adxl is an instance of the ADXL345 library

//These variables will be used to hold the x,y and z axis accelerometer values.
int x,y,z;
double xg, yg, zg;
char tapType=0;

boolean shockFlag = 0;
boolean fallFlag = 0;

//***RFID***
SoftwareSerial rfid(7, 8);
```

```
SoftwareSerial xbee(10, 9);
unsigned long indicator_time = -1;
int flag = 0;
int Str1[11];

//Prototypes
//***Accel***
void initAccel(void);
void tap(void);
void ff_int_response(void);
void shock_int_response(void);
//***RFID***
//void check_for_notag(void);
void halt(void);
void parse(void);
void print_serial(void);
void read_serial(void);
void seek(void);
void set_flag(void);

//********** functions **********
//Arduino setup()
void setup(){

  pinMode(13,OUTPUT);

  //Create a serial connection to display the data on the terminal.
  Serial.begin(9600);

  //RFID init
  xbee.begin(9600);
  rfid.begin(19200);
  while(!Serial){
    // set the data rate for the SoftwareSerial ports
    ;
  }
  pinMode(INDICATOR_PIN,OUTPUT);
  digitalWrite(INDICATOR_PIN,LOW);

  delay(10);
  //halt();

  debugPrint("ME 310 Stanford-Embraer Code Initialization Begun");

  //initialize accerelometer
  initAccel();

  //initialize XBee?
  xbee.println("initialized");

}

//Arduino main loop()
void loop(){

  //RFID
```

```
  read_serial();
  checkIndicator();


  //ACCEL

  //Reading data:
  //Reading 6 bytes of data starting at register DATAX0 will retrieve the x,y
    and z acceleration values from the ADXL345.
  //The results of the read operation will get stored to the values[] buffer.
  adxl.readAccel(&values[0], &values[1], &values[2]);
  //The ADXL345 gives 10-bit acceleration values, but they are stored as bytes
     (8-bits). To get the full value, two bytes must be combined for each axis
    .
  //The X value is stored in values[0] and values[1].
  x = values[0];
  //The Y value is stored in values[2] and values[3].
  y = values[1];
  //The Z value is stored in values[4] and values[5].
  z = values[2];

//   Serial.print(x, DEC);
//   Serial.print(',');
//   Serial.print(y, DEC);
//   Serial.print(',');
//   Serial.println(z, DEC);

  //Serial.println(sqrt(x*x + y*y + z*z));

  if(shockFlag == 1)
  {
    Serial.println("Shock experienced!");
    xbee.println("Shock");
    shockFlag = 0;
    adxl.getInterruptSource();
    //digitalWrite(13,LOW);
  }
  if(fallFlag == 1)
  {
    Serial.println("Fall experienced!");
    fallFlag = 0;
    adxl.getInterruptSource();
    //digitalWrite(13,LOW);
  }

  delay(100);
}

//Accel helper functions
void initAccel()
{
   //Set up the Chip Select pin to be an output from the Arduino.
  pinMode(CS, OUTPUT);
  //Before communication starts, the Chip Select pin needs to be set high.
  digitalWrite(CS, HIGH);

```

```
  adxl.powerOn();
  adxl.setRangeSetting(8); //16g range
  //set rate to 3200Hz
  adxl.setRate(1600); //sets rate bits of BW_RATE register to 0x0F

  //disable all interrupts
  adxl.writeTo(ADXL345_INT_ENABLE, 0x00);

  //setup free fall interrupt:
  //set ff threshold
  adxl.setFreeFallThreshold(FALL_THRESH);
  //set ff duration
  adxl.setFreeFallDuration(FALL_DUR);

  //setup single-tap (shock) interrupt:
  //set tap threshold
  adxl.setTapThreshold(SHOCK_THRESH);
  //set tap duration
  adxl.setTapDuration(SHOCK_DUR);
  //set X direction
  adxl.setTapDetectionOnX(HIGH);
  //set Y direction
  adxl.setTapDetectionOnY(HIGH);
  //set Z direction
  adxl.setTapDetectionOnZ(HIGH);

  //Map Free Fall to pin 1 (clear --> INT1)
  adxl.setInterruptMapping(ADXL345_INT_FREE_FALL_BIT, ADXL345_INT1_PIN);
  //Map Shock to pin 2 (set --> INT22)
  adxl.setInterruptMapping(ADXL345_INT_SINGLE_TAP_BIT, ADXL345_INT2_PIN);


  //set free-fall bit
  adxl.setRegisterBit(ADXL345_INT_ENABLE, ADXL345_INT_FREE_FALL_BIT, HIGH);
  //set single-tap bit (shock)
  adxl.setRegisterBit(ADXL345_INT_ENABLE, ADXL345_INT_SINGLE_TAP_BIT, HIGH);

  //attach interrupts on rising edges
  attachInterrupt(SHOCK_ISR,shock_int_response,RISING);
  attachInterrupt(FF_ISR,ff_int_response,RISING);

  debugPrint("Accelerometer Initialized");
}

void tap(void){
  //Clear the interrupts on the ADXL345
  //readRegister(INT_SOURCE, 1, values);
  if(values[0] & (1<<5))tapType=2;
  else tapType=1;;
}

//interrupt response for free fall
void ff_int_response()
{
    //flash LED
    //digitalWrite(13,HIGH);
```

```
    //code to read INT_SOURCE (?)
    fallFlag = 1;
    indicatorOn();
}

//interrupt response for shock
void shock_int_response()
{
    //flash LED
    //digitalWrite(13,HIGH);
    //code to read INT_SOURCE (?)
    shockFlag = 1;
    indicatorOn();
    indicator_time += INDICATOR_DURATION/2;
}

//RFID helper functions
void halt()
{
  //Halt tag
  rfid.write((uint8_t)255);
  rfid.write((uint8_t)0);
  rfid.write((uint8_t)1);
  rfid.write((uint8_t)147);
  rfid.write((uint8_t)148);
}

void parse()
{
  //Serial.println("parse");
  while(rfid.available()){
    //Serial.println("available");
    if(rfid.read() == 255){
      for(int i=1;i<11;i++){
        Str1[i]= rfid.read();
      }
    }
  }
}

void print_serial()
{
  if(flag == 1){
    indicatorOn();
    //print to serial port
//      Serial.print(Str1[8], HEX);
//      Serial.print(Str1[7], HEX);
//      Serial.print(Str1[6], HEX);
//      Serial.print(Str1[5], HEX);
//      Serial.println();
    //tagid=Str1[8]+Str1[7]+Str1[6]+Str1[5]
    print_handler();

    //print to XBee module
//     xbee.print(Str1[8], HEX);
//     xbee.print(Str1[7], HEX);
```

```
//     xbee.print(Str1[6], HEX);
//     xbee.print(Str1[5], HEX);
//     xbee.println();
    delay(100);
    //check_for_notag();
  }
}

void print_handler()
{
  if (Str1[5]==ALBERT)
  {
    Serial.println("Albert is now handling your wheelchair");
  }
//   else if (Str1[5]==BOB)
//   {
//     Serial.println("Bob is now handling your wheelchair");
//   }
//   else if (Str1[5]==CHARLES)
//   {
//     Serial.println("Charles is now handling your wheelchair");
//   }
  else if (Str1[5]==DIANA)
  {
    Serial.println("Diana is now handling your wheelchair");
  }
  else if (Str1[5]==ELTON)
  {
    Serial.println("Elton is now handling your wheelchair");
  }
  else if (Str1[5] == LUIZ)
  {
    Serial.println("Luiz");
    xbee.println("Luiz D.");
  }
  else if (Str1[5] == RODRIGO)
  {
    Serial.println("Rodrigo");
    xbee.println("Rodrigo M.");
  }
  else
  {
    //do nothing?
  }
  //delay(1000); //so there arent repeat alerts

//   switch (Str1[8], HEX) {
//   case ALBERT:
//     Serial.println("Albert is now handling your wheelchair");
//     break;
//   case BOB:
//     Serial.println("Bob is now handling your wheelchair");
//     break;
//   case CHARLES:
//     Serial.println("Charles is now handling your wheelchair");
//     break;
```

```
//   case DIANA:
//     Serial.println("Diana is now handling your wheelchair");
//     break;
//   case ELTON:
//     Serial.println("Elton is now handling your wheelchair");
////     break;

}



void read_serial()
{
  seek();
  delay(10);
  parse();
  set_flag();
  print_serial();
  delay(100);
}

void seek()
{
  //search for RFID tag

  //Serial.println("seeking");

  rfid.write((uint8_t)255);
  rfid.write((uint8_t)0);
  rfid.write((uint8_t)1);
  rfid.write((uint8_t)130);
  rfid.write((uint8_t)131);
  delay(10);
}

void set_flag()
{
  if(Str1[2] == 6){
    flag++;
  }
  if(Str1[2] == 2){
    flag = 0;
  }
}

void indicatorOn()
{
  indicator_time = millis();
  digitalWrite(INDICATOR_PIN,HIGH);
}

//determine if indicator light should be turned off
void checkIndicator()
{
  if((unsigned long)(millis() - indicator_time) > INDICATOR_DURATION &&
    indicator_time != -1)
```

```
    digitalWrite(INDICATOR_PIN,LOW);
}
```

G.2 Embraer_UI.pde - Processing

```

//ME 310 Embraer UI for wheelchair platform data

PFont f;
PImage logo;

String lastHandler = "Handler";
String lastTime = "Time";

boolean shockFlag = false;
int shockTime = 0;
int SHOCK_DURATION = 1000;

import processing.serial.*;

Serial myPort;        // The serial port

void setup() {
  size(1280, 720);

  logo = loadImage("logo.png");

  // Create the font
  //printArray(PFont.list());
  f = createFont("Myriad", 24);
  textFont(f);

   myPort = new Serial(this, Serial.list()[0], 9600);
   // don't generate a serialEvent() unless you get a newline character:
   //myPort.bufferUntil('\n');
   print("Initializing");
}

void draw() {
  background(255);
  image(logo,-15,-15,1181,236);
  textAlign(LEFT);
  fill(6,75,160);
  textFont(f,40);
  text("Platform",800,100);
  text("Status",800,150);

  //RFID notice
  textAlign(LEFT);
  fill(6,75,160);
  textFont(f,40);
  text("Wheelchair last handled by:",100,300);
```

```
  fill(255,0,0);
  textFont(f,44);
  text(lastHandler,100,360);
  fill(6,75,160);
  textFont(f,40);
  text(lastTime,100,420);

  //Accelerometer
  if(shockFlag)
  {
    textFont(f,55);
    fill(255,0,0);
    textAlign(CENTER);
    text("Wheelchair bumped!",900,400);
    if(millis() > shockTime + SHOCK_DURATION)
      shockFlag = false;
  }
}


void serialEvent (Serial myPort)
 {
   // get the ASCII string:
   String inString = myPort.readStringUntil('\n');

   if (inString != null)
   {
     print(inString);

     if(inString.indexOf("Luiz") != -1 || inString.indexOf("Rodrigo") != -1)
     {
       lastHandler = inString;
       lastTime = str(hour()) + ":" + str(minute()) + ":" + str(second());
       print("Update");
//         lastTime = concat(concat(str(minute()),":"));
     }

     else if(inString.indexOf("Shock") != -1)
     {
        shockFlag = true;
        shockTime = millis();
     }


   }
 }
```

H Appendix - Stanford Spring Expenses

ME310 Expenses Spreadsheet - Spring Quarter AY14

Team Name:	**Embraer**			**Budget Monitor:**	**Stephanie**		
Reference*	Purchaser	Date	Vendor Name	Description of Expense	Pre-tax Amount	Shipping & Handling (if any)	Amount Incl Sales Tax
Pcard	Cliff Bargar	4/4/2014	SparkFun Electronics	Various electronics/wireless components	$238.30	$22.20	$260.50
Pcard	Maria	4/7/2014	Full Source	Gloves for baggage handler EXPE	$10.00	$6.28	$16.28
Pcard	Maria	4/9/0214	SparkFun Electronics	Various electronics/wireless components	$45.22	$4.42	$53.60
Laura	Laura	4/14/2014	Amazon	Retractable wheels + jack	$79.97	$3.95	$85.67
Cliff	Cliff Bargar	4/17/2014	Room 36	LEDs, resistors, battery pack	$6.51	$0.00	$6.51
Pcard	Cliff Bargar	4/17/2014	SparkFun Electronics	Arduino, more XBee stuff, etc	$65.05	$11.39	$76.44
Pcard	Cliff Bargar	4/22/2014	Jameco Electronics	LEDs, Accelerometer	$39.70	$6.93	$49.61
Cliff	Cliff Bargar	4/23/2014	Alan Steel	Aluminum Sheet	$179.41	$0.00	$195.11
Pcard	Maria	4/24/2014	Bischoff's	Wheelchair	$870.00	$0.00	$870.00
Cliff	Cliff Bargar	4/27/2014	Home Depot	Hydraulic Jack	$49.94	$0.00	$54.43
Pcard	Cliff Bargar	4/29/2014	Amazon	80/20	$467.48	$54.13	$552.12
Cliff	Cliff Bargar	4/30/2014	Campus Bike Shop	Brake cable	$2.99	$0.00	$3.25
Pcard	Cliff Bargar	5/2/2014	Amazon	Electric jack + more 80/20 fasteners	$98.21	$49.25	$159.04
Pcard	Cliff Bargar	5/7/2014	Amazon	Charger	$35.64	$14.31	$54.32
Pcard	Cliff Bargar	5/7/2014	Jameco Electronics	Battery, etc	$47.77	$14.70	$62.70
Pcard	Cliff Bargar	5/9/2014	McMaster	Mounting stuff	$225.21	$24.05	$268.96
Pcard	Cliff Bargar	5/12/2014	McMaster	wire rope for mounting	$175.27	$7.93	$198.54
Cliff	Cliff Bargar	5/13/2014	Fry's	wire, battery box, etc	$52.35		$56.92
Cliff	Cliff Bargar	5/13/2014	Ace	fasteners	$30.90		$33.60
Cliff	Cliff Bargar	5/13/2014	Alan Steel	aluminum blocks	$52.00		$56.68
Cliff	Cliff Bargar	5/18/2014	Ace	fasteners, dremel bit	$34.85		$37.90
Cliff	Cliff Bargar	5/20/2014	Ace	fasteners	$6.40		$6.96
Pcard	Erika Finley	5/22/2014	Stanford Stationary	Business Cards	$38.75		$41.95
Pcard	Cliff Bargar	5/22/2014	Chipotle	SUDS	$403.00		$403.00
Cliff	Cliff Bargar	5/22/2014	Ace	Fasteners	$6.18		$6.72
Pcard	Cliff Bargar	5/23/2014	Amazon	jack	$61.39	$44.26	$114.89
Pcard	Cliff Bargar	5/23/2014	McMaster	mcmaster	$139.44	$7.13	$158.77
PCard	Cliff Bargar	5/27/2014	SparkFun Electronics	XBee	$71.80	$11.39	$83.15
PCard	Maria	5/27/2014	Moo.com	Business Cards			$184.62
?	?	5/29/2014	?	super suds			$77.94
PCard	Cliff Bargar	6/2/2014	TAP Plastics	Cabin for EXPE	$335.70		$365.07
PCard	Cliff Bargar	6/2/2014	CopyAmerica	Poster for EXPE	$168.00		$182.70
PCard	Cliff Bargar	6/2/2014	Home Depot	Fasteners for cabin	$28.76		$31.28
Pcard	Cliff Bargar	6/2/2014	Amazon	Ramp	$47.74	$24.96	$79.06
Pcard	Cliff Bargar	6/2/2014	Amazon	Vests	$31.65	$21.27	$57.54
Pcard	Cliff Bargar	6/2/2014	Jameco Electronics	Buttons	$11.80	$15.42	$28.10
Cliff	Cliff Bargar	6/4/2014	Macy's	ties, shirts			$197.74
Cliff	Cliff Bargar	6/4/2014	Macy's	scarves, shirts			$146.79
Cliff	Cliff Bargar	6/4/2014	CVS	EXPE supplies			$16.06
Pcard	Cliff Bargar	6/5/2014	FedEx/Kinko's	Handouts			$103.46
				Total	$2,851.92	$219.54	$5,437.98
				Rollover balance from Winter AY14	--------------------------		$2,454.69
				Spring Allocation	--------------------------		$4,000.00
				Available Balance	--------------------------		$1,016.71

I Appendix - Brochure from Winter Quarter

Embraccess

peace of mind - independence - control

Project Background

According to the World Health Organization, **1% of the world's population needs a wheelchair**, a number that is bound to increase with the global ageing phenomenon. Wheelchair users are able to enjoy every activity they want, yet due to the hostile airplane environment, they **struggle to find comfort and independence during the flight experience.** The challenge is how will Embraer be able to guarantee that people with disabilities get the same rights and are treated with the same dignity as all others.

Need Statement

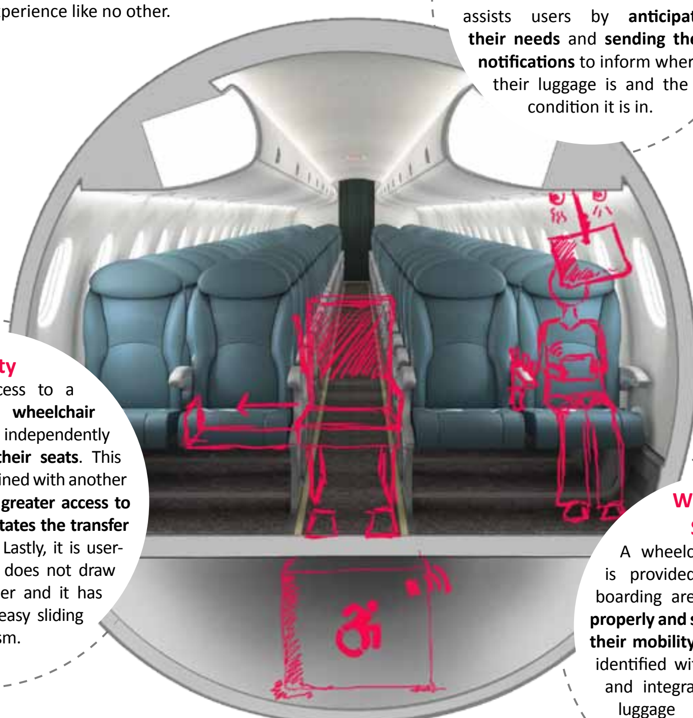
Imagine that you are required to gate check your bag which has something valuable or precious in it. You immediately **panic.** Now imagine if it was your wheelchair. **Your legs. Your independence.** What if you have no clue how you are going to move inside the cabin now that you don't have your chair? What if you can't be sure that you will be able to move after your flight, because your wheelchair may not make it safely to your destination? For our users, this is their **bitter reality.**

Our vision

We will create a more desirable and accessible experience by tackling the problems of mobility and comfort inside the cabin as well as the storage and security of the user's assistive device. With these two systems, we will be able to give our users the independence and control they desire, the peace of mind about their assistive devices they deserve, and an experience like no other.

Smart Cabin

By using an app, users are granted **control over their environment**, from turning on the light, to redirecting the fan. The smart cabin also assists users by **anticipating their needs** and **sending them notifications** to inform where their luggage is and the condition it is in.



Mobility

Users have access to a **redesigned aisle wheelchair** that allows them to independently **slide in and out of their seats**. This wheelchair, when combined with another sliding device, provides **greater access to onboard WCs and facilitates the transfer between wheelchairs.** Lastly, it is user-friendly because it is does not draw attention to the user and it has an intuitive and easy sliding mechanism.

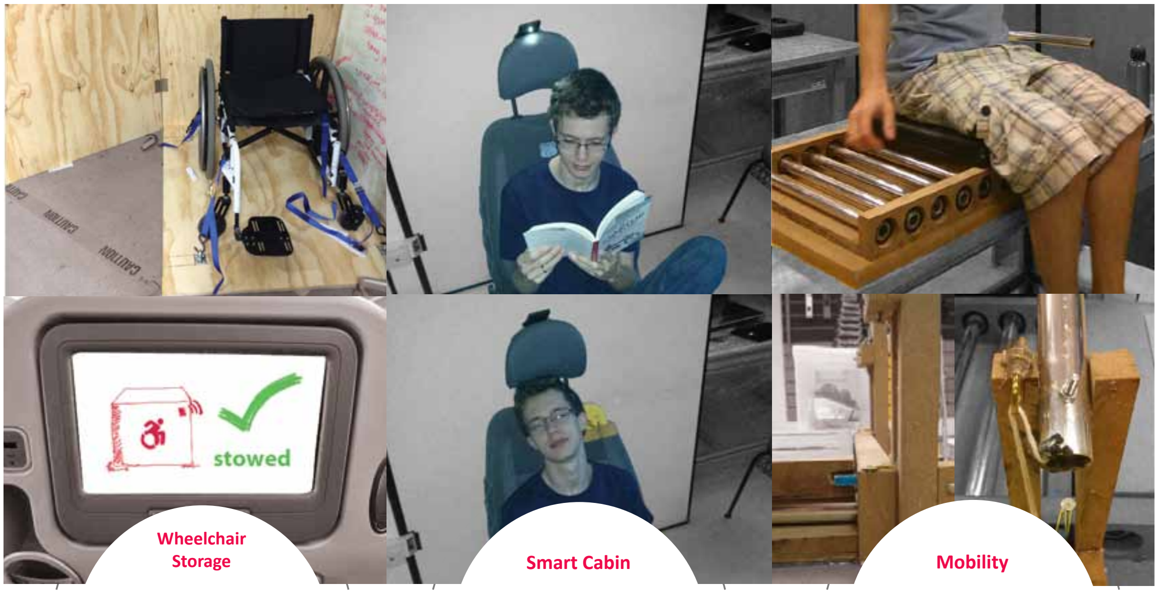
Wheelchair Storage

A wheelchair storage case is provided to users at the boarding area, allowing them to **properly and securely store and seal their mobility devices.** Each case is identified with a unique QR code and integrated to the airline's luggage tracking system, making these items **trackable**.

Design requirements light | safe | maintain passenger capacity

Figure I.1: *Winter Brochure*

Prototypes



Wheelchair Storage

A **special case** designed for storing a wheelchair with foldable walls and docking system. A **notification** of a user's **stowed wheelchair** represented on a display.

Smart Cabin

Simulating a system which **anticipates the users' needs** (e.g. reading a book) and **performs an action** (e.g turn on the lights).

Mobility

Simulation of the **lateral sliding and latching mechanism** based on the position of the armrest. Use of bearings, aluminum, and wood, among others.

Learnings

While we are designing for the wheelchair user's experience, our products must seamlessly integrate into or improve the current systems utilized by the cabin and airport crew.

The systems utilized by the airport personnel needs to have clear instructions and the process must take the least amount of time possible.

By simulating how the user would interact with the product, we were able to develop a more user-friendly latching mechanism. Armrest up, unlocked seat and vice-versa.

Next steps

We are looking into different types of telescoping designs as well as inflatables for the storage device's retractable light-weight walls that protect the wheelchair.

Our current tracking and control system utilizes MATLAB and we will be migrating that onto an iOS or Android platform.

Our focus will be directed to minimizing the need for adaptations on the plane as well as decreasing the weight of the aisle chair and transfer mechanism.

Maria Barrera - Laura Hoinville - Clifford Bargar
Erika Finley - Robert Karol

Guilherme Kok - Amanda Mota - Luiz Durão
Rodrigo Monteiro

EMBRAER

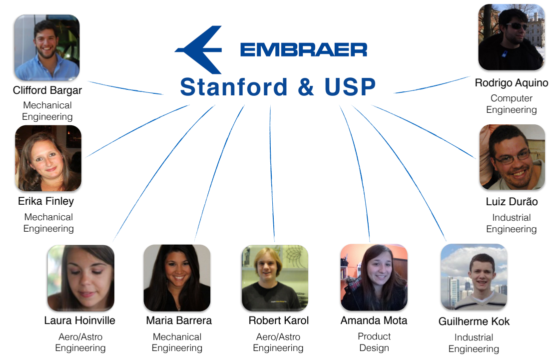
Brazilian aircraft manufacturer
world leader in regional jets

scan here to learn more

Figure I.2: *Winter Brochure*

J Appendix - Winter Presentation

01 Meet the Team



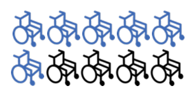
02 The Story

*"I'm not disabled **because** I use a mobility device, I'm disabled **when I don't** have my mobility device."*

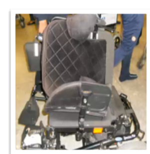
*"Passengers should be able to have the **same experience**, regardless of their **physical** or mental condition."*

03 The Problem: Wheelchair Storage

*"The most **emotional** part of my flight is when I have to **give up** my wheelchair"*



60% of wheelchairs suffer **damage** when flying



Josie Verghese @josieverg · 23 Oct 2012
Can laugh now but arriving in Sydney to find wheelchair left at H'row was traumatic at time& always fear it could happen again #noflybritain
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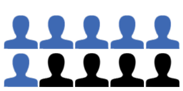
04 The Problem: Mobility Inside the Cabin



6 out of 10 passengers feel unsafe when **transferred** from wheelchair to airline seat

Esther Appleyard-Fox @AppleyardFox · 4 Sep 2012
@jonsnowC4 #noflybritain flying: one of the most undignified things:being manhandled over people's heads into a seat & proped up.
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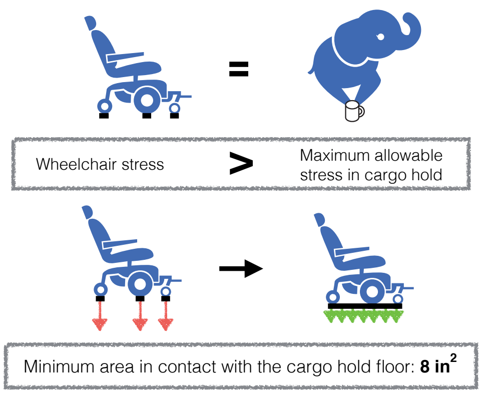
05 The Problem

06 The Challenge

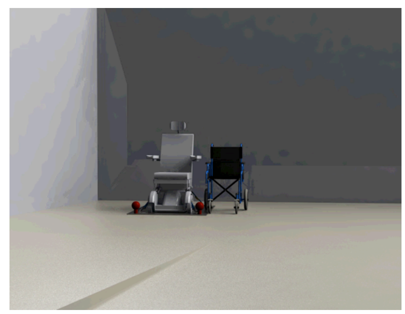
Independence

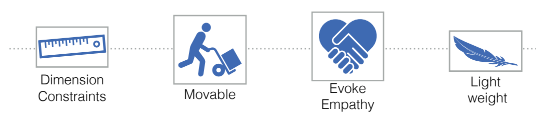
07 Wheelchair Storage

08 Structural Constraints: Cargo Hold

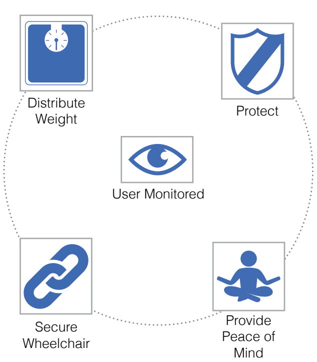


09 Wheelchair Storage: Vision

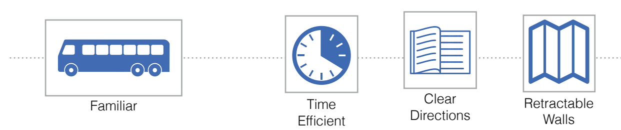


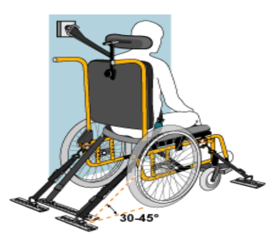


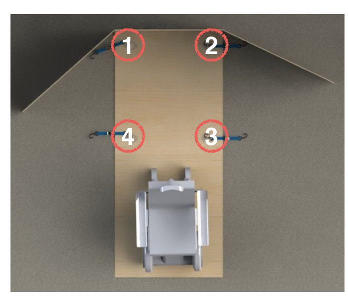
10 Wheelchair Storage: Prototype



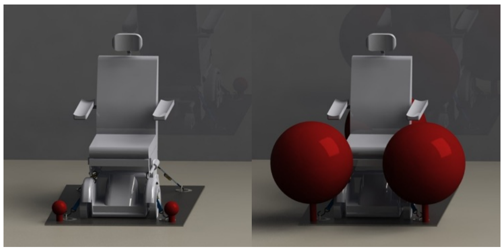
11 Wheelchair Storage: Learnings





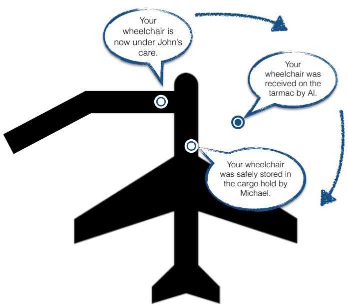


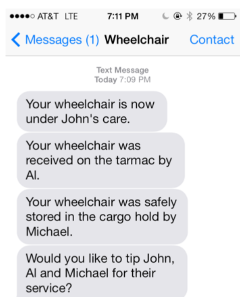
12 Wheelchair Storage Inflatable Walls



13 Inflatable Feasibility Test

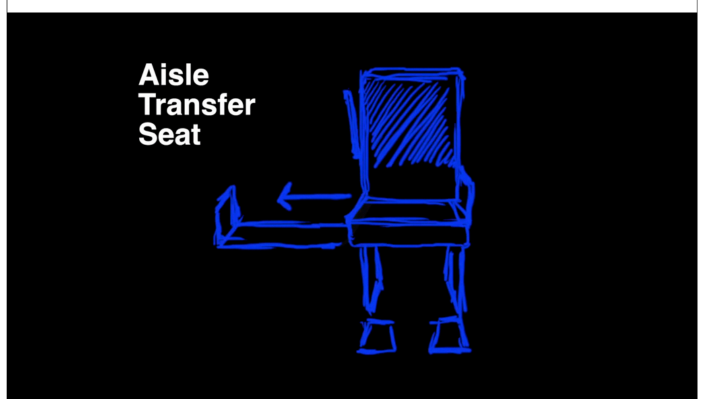
14 Wheelchair Tracking



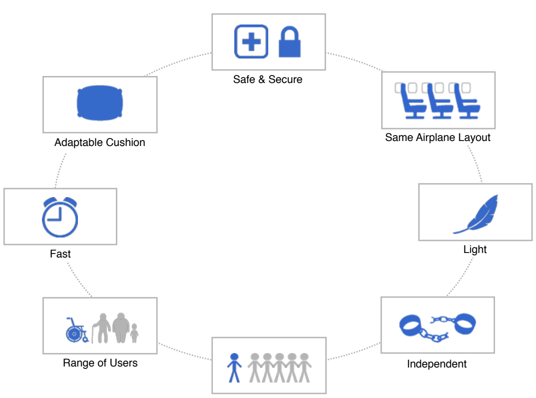


QR Code-enabled tracking

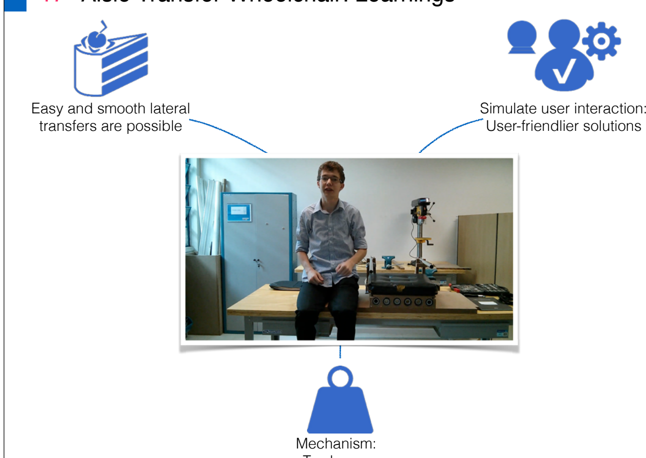
15 Aisle Transfer Wheelchair



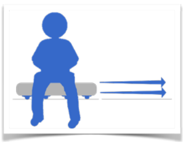
16 Aisle Transfer Wheelchair: Requirements



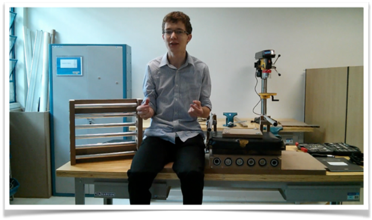
17 Aisle Transfer Wheelchair: Learnings



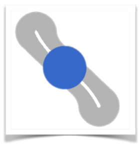
18 Aisle Transfer Wheelchair: Next Steps



Redesign Transfer Mechanism



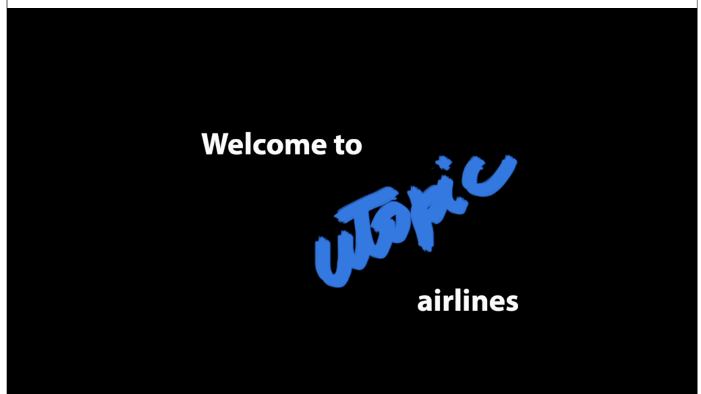
Build Aisle Chair



Test Transfer Boards

Test with Target Users

19 Our Vision



20 Conclusion

A great experience for

~~most~~

all

passengers

Travel to
Sao Paulo

Build!
Build!
Build!

Shipping
Container

Iterate &
Iterate

K Appendix - Brochure from EXPE

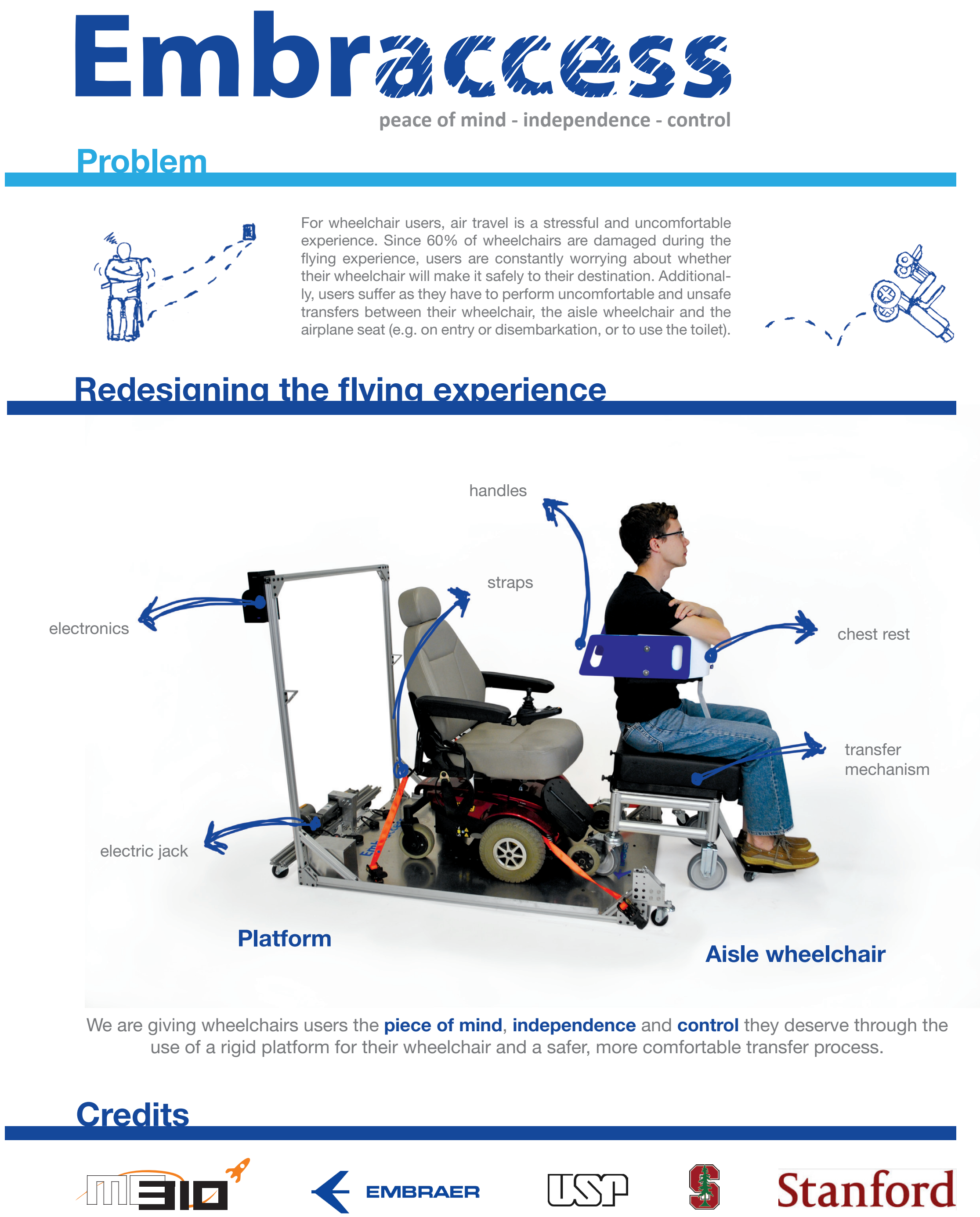


Figure K.1: *Brochure for EXPE*

Figure K.2: *Brochure for EXPE*

L Appendix - Poster from EXPE

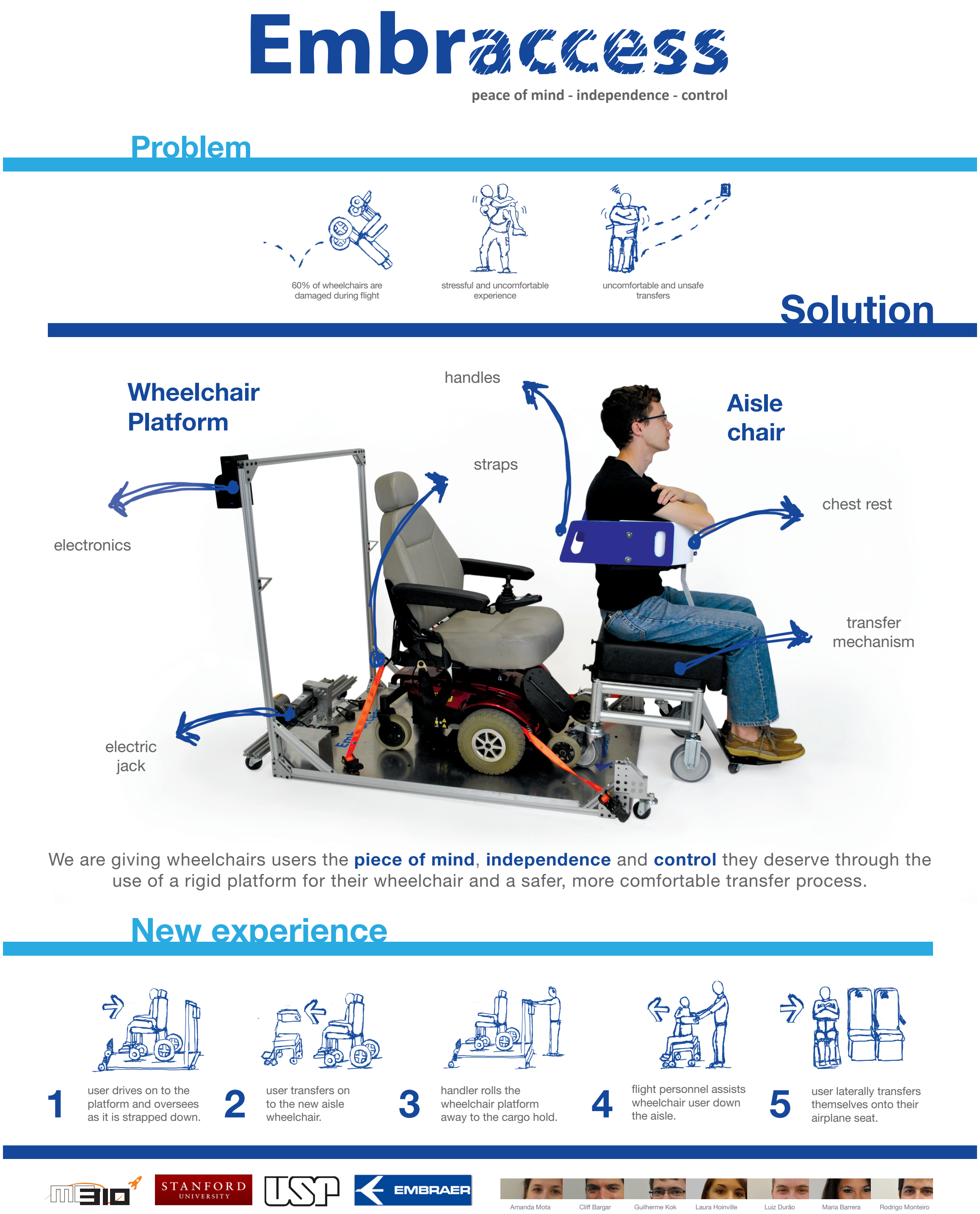


Figure L.1: *Poster for EXPE*

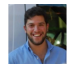
M Appendix - Final Presentation

Embraccess

Redesigning the flying experience for wheelchair users

ME310 design innovation . Stanford University . Embraer . Universidade de São Paulo . Inov@lab

The Team

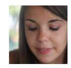


Clifford Bargar
Mechanical Engineering

EMBRAER

Stanford & USP

Rodrigo Aquino
Computer Engineering



Laura Hoinville
Aero/Astro Engineering

Maria Barrera
Mechanical Engineering

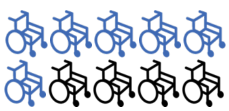
Guilherme Kok
Industrial Engineering

Amanda Mota
Product Design

Luiz Durão
Industrial Engineering

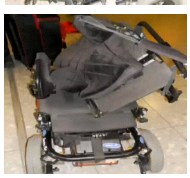
The Problem wheelchair storage

"The most **emotional** part of my flight is when I have to give up my wheelchair" Aubrie Lee

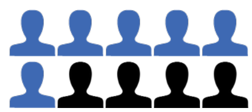


60% of wheelchair **suffer damage** when flying
(Trailblazers study by David Gillon)

Josie Verghese @josieverg · 23 Oct 2012
Can laugh now but arriving in Sydney to find wheelchair left at H'row was traumatic at time& always fear it could happen again #noflybritain
Expand Reply Retweet Favorite



The Problem mobility inside cabin



6 out 10 passengers feel **uncomfortable** & **unsafe** when being transferred from their wheelchair to the airplane seat.

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@jonsnowC4 #noflybritain flying: one of the most undignified things:being manhandled over people's heads into a seat & proped up.
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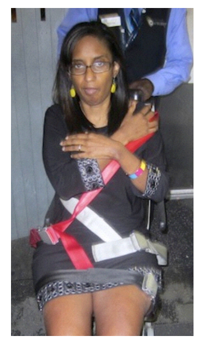


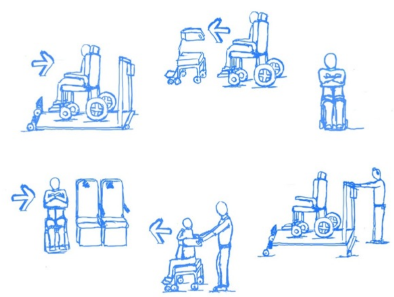
The Problem

The Challenge

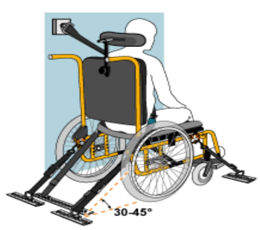
Independence

The Current Process

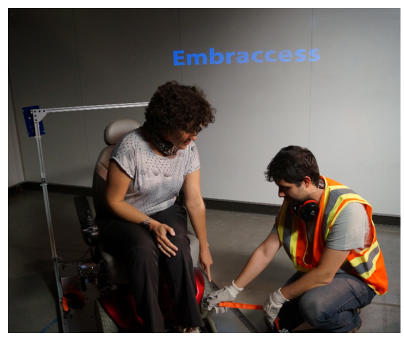
The New Process

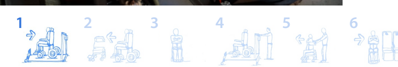


The Platform familiar experience

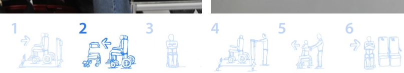


The Platform secure wheelchair





The Aisle Chair frontal transfer

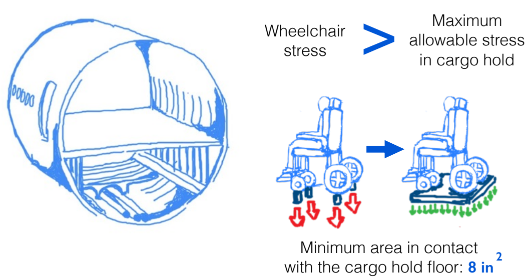


The Aisle Chair comfort

The Platform smart systems

The Platform movable

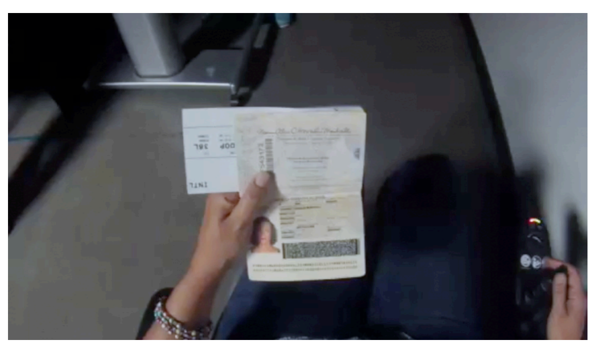
The Platform distribute weight



The Aisle Chair adjustable handles

The Aisle Chair lateral transfer

Redesigning The Flying Experience



Thank you