Redesigning the Flying Experience for Persons with Disabilities

Mechanical Engineering 310 Winter Quarter

Team Team: Embraer

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1 Front Matter

Embraer, the Brazilian airline manufacturer, decided to partner with Stanford University and the University of Sao Paulo to approach this 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 analogous situations, patents, regulations, and current concepts and solutions.

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 five themes we need to address with our solution. These themes are customer service, control, independence, seat preferences, and non-discriminatory. 1.1 shows the themes and how they each rely on the others to be successful. 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 the interaction 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 though 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 once arrived at their final destination they will be able to use their mobility device or not. Because of their situation, limited mobility passengers and passengers with disabilities have a condition that singles them out and makes their flying experience worse than normal to begin with so why should our design add insult to injury by singling them out more? We are focusing on a universal design that would aid and improve the experience for both the limited mobility passenger and the average passenger.

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 for a solution is a more dynamic cabin that allows the user to customize the space to his needs and allows for a more enjoyable and interactive experience. We want to change the way a passenger looks at the flying experience and how they feel before, during, and after the flight. The passengers should have more control over their seat and the way they access them. Giving passengers more independence and control while minimizing customer service interaction and discrimination is our motivation for a futuristic cabin. But beyond the idea of a futuristic cabin, airport logistics concerning wheelchair storage must also be improved. If once disabled passengers reach their final destination their wheelchair is broken then no matters how delightful their flight experience was, they will still have to face a very hard time trying to get their mobility device repaired.

In order to provide wheelchair users with an enjoyable flying experience from beginning

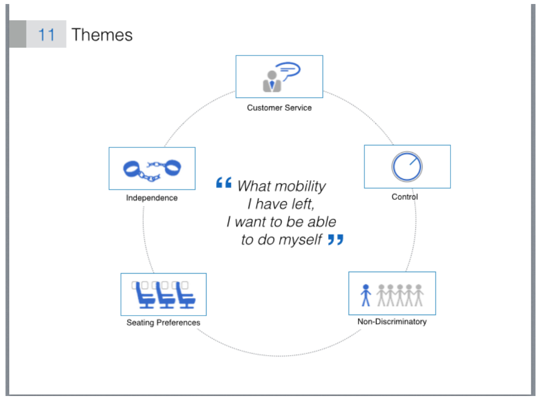

Figure 1.1: *Main themes driving our solution*

to end, our solution must provide them with first absolute piece of mind concerning what happens to their mobility device when it is taken away from them, and second a pleasant cabin experience that makes them feel independent, in control and not singled out. Both improvements are necessary to change wheelchair users' perception of flying to their final destination at any place in the world.

Glossary

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.

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

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.

CEP: Otherwise known as a Critical Experience Prototype, this is a physical prototype created to make an experience real enough to gather insights and understanding about the users experience.

CFP: Otherwise known as a Critical Function Prototype, this is a physical prototype built to test a concept that is critical to addressing the problem statement.

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.

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.

Herrmann Brain Dominance Instrument (HDBI): Illustrates and explains the way a person prefers to think, learn, communicate and make decisions. It identifies the preferred approach to emotional, analytical, structural, and strategic thinking.

Independence: Freedom from outside control or support.

Libras: Brazilian Sign Language

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 neuro-muscular 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

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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. [**?**]*

As global business continues to increase, people are constantly on the go and airports are becoming larger and larger, growing more busy each year. The distance from check-in to gate is increasing as more airlines expand routes and terminals. Therefore, it becomes a problem for passengers who have a hard time walking long distances or need assistance with bags or a wheelchair. More airport staff are needed to move the passengers with assistance needs, and often the staff are not trained in dealing 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 do not have the mobility or have some impairment that requires additional time. However, 58 million Americans live with a disability, including 5.5 million military veterans.

2.2 Problem Statement

The need of our users or the problems our users are facing can be broken down into two areas to be addressed:

- Mobility in the Cabin
- Storage and Security of Assistive Devices

The whole process (see Appendix Diagram A1) was analyzed, and the current systems that are in use today are based on what is required by the FAA and ADA regulations. However, these systems have gaps that need to fix in order to improve the user and passenger experience. Autumn quarter's user interviews showed the gaps and led to these two main pain points. These two pain points of mobility within the cabin and storage and security of assistive devices address our group of users who are passengers with limited mobility that use assistive devices. Our users want to be able to transfer from their wheelchair to the aisle chair independently and without the interference of others. 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 independence, and provides 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 increased time committment by making the solution inclusive into the flight crew's tasks.

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 all you can think about is what state your bag will be when you arrive 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 do not have your chair? 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 it was handled, to know it was safe, and to know where it is at all times and that it will be there 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 every 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, mobility in the cabin and storage and security of the wheelchair were the two places that 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 jet way in front of the user. The user will be able to supervise the entire process and will receive updates 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

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2.5 The Design Team

Team Embraer was assembled using the results of the Herrmann Brain Dominance Instrument (HBDI) to determine compatible thinking styles and personality traits. 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
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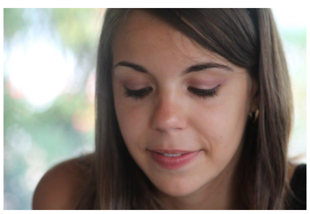
I was born in Colombia and moved to South Florida with my mom when I was 10. My dad and sister still live in Colombia so I tend to hop back and forth every chance I get. I did my undergraduate at Stanford also in Mechanical Engineering and have developed a deep interest for entrepreneurship during my 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
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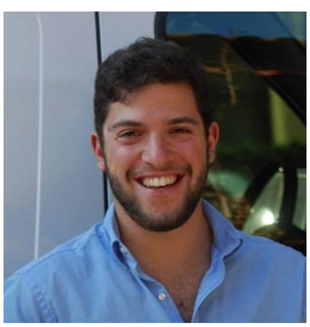
I come from Toulouse, France. I attended ISAE-Supaero (the French Graduate school of Aerospace Engineering) at Toulouse for my undergraduate degree in Aeronautics. I worked at Airbus head quarters in Blagnac, France as an intern last summer and want to make a career in the field of aircraft design. I'm also interested in dance (ballet, modern jazz, contemporary), gymnastics, scuba diving and reading.



Clifford Bargar
Status: Mechanical Engineering Graduate Student
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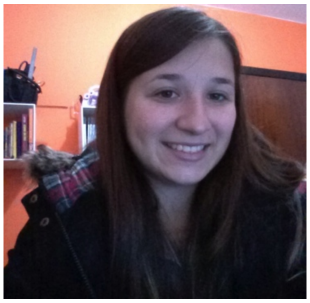
Website: http://cliffbargar.com

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. I've spent the last several summers as a student researcher at the Wyss Institute for Bioinspired Engineering at Harvard University, MIT Lincoln Laboratory, and the Tufts Center for Engineering Education and Outreach.

University of São Paulo



Amanda Mota Almeida
Status: Product Design Undergraduate Student
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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.

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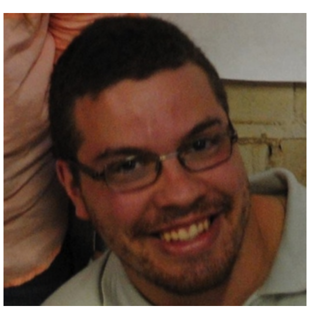
I have lived all my life in São Paulo. I am now graduating in Computer Engineering at USP and I also work in a technology development lab at the university. I have worked on several projects developing educational games and other educational interfaces that help children learn with technological devices.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



Luiz Durao
Status: Industrial Engineering Undergraduate Student
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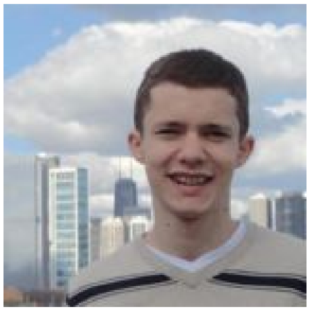
I was born and raised in São Paulo city. I attended Colgio Etapa for my High School and it was while participating in the Chemistry and Physics Olympiads that I discovered my taste for the sciences. I'm attending the University of São Paulo for my undergraduate studies in Industrial Engineering. I have 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
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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.

2.6 Coaches

Shelly Goldberg
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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
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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

3.1 Fall Quarter Review

Fall quarter was spent primarily focused on needfinding and benchmarking in order to get a firm grasp of the problem we were tasked with solving. Given that “redesigning the flying experience for people with reduced mobility” is a huge design space with a 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 storied 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 how 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 yet would significantly improve the experience for our target user.

3.2 Winter Quarter Introduction

When we started winter quarter we welcomed three new team members (Clifford Bargar, Robert Karol and Laura Hoinville). They brought a brand new look and prospectives on the project and in order to get the best 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 make the travel experience of the user we deicided to target after the end of fall quarter: a wheelchair user.

Through these brainstorming sessions we wanted to understand our design space and its limitations. It was also a way to try to learn how to work with one another and identify everyone’s skills to try to create a team dynamics. 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 is how we organized ourselves and tried to tackle the three steps of our design development: dark horse, funky funktional and functional prototypes.

3.3 Dark Horse Version 1

3.3.1 Introduction

Winter quarter began with the first of three prototyping missions, Dark Horse. Named for 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 plausible solutions. The learning that occurs from the mission is more important compared to the actual building process due to the intention to guide the team toward their final vision.

3.3.2 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 3.1, which would enable passengers to have a much more personalized and enjoyable experience.

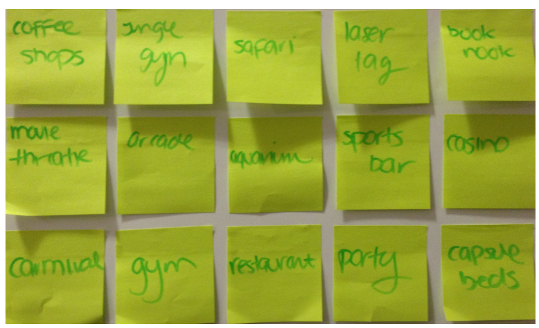


Figure 3.1: *Possible ideas for a new cabin configuration*

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 3.2, 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 3.2: *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 3.3 and 3.3.

Figure 3.3: *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 3.5. 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 3.4: *Example of cabin layout with built in beds. Source: http://www.aviationinsurors.com/chair.html*

Figure 3.5: *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.

3.3.3 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:

3.3.3.1 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 3.6: *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.

3.3.3.2 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.

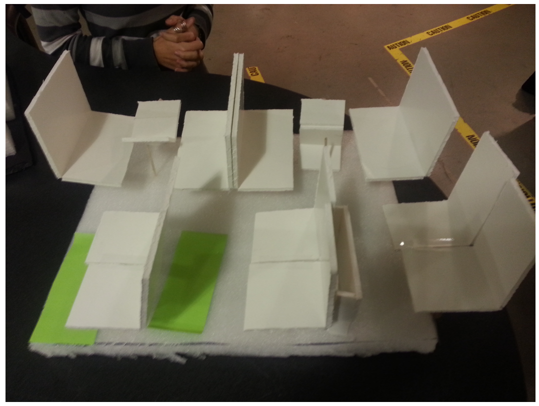


Figure 3.7: *Plane section dedicated to family with two configurations: take-off/landing (left) and cruise (right)*

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.

3.3.3.3 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.

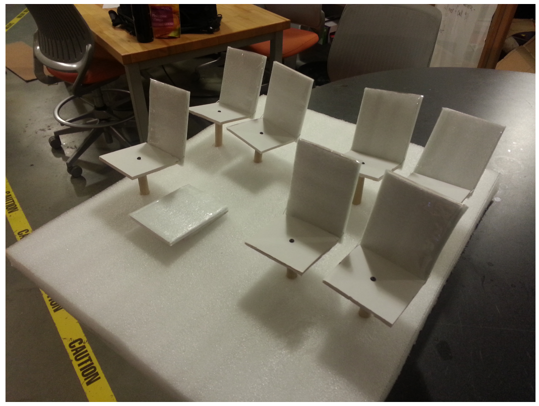


Figure 3.8: *Plane section dedicated to sports and physical training with two configurations: take-off/landing (left) and cruise (right)*

3.3.3.4 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 3.9: *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.

3.3.3.5 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.

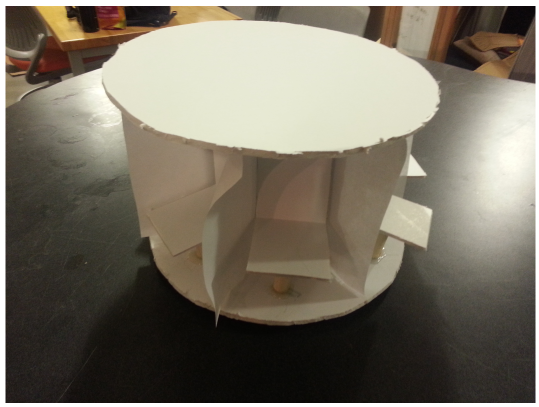


Figure 3.10: *Plane section dedicated to people who need easily accessible seats*

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.

3.3.4 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.

3.4 Dark Horse Version 2

3.4.1 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 3.11 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 3.11: *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 3.11, 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.

3.4.2 Description

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

Figure 3.12: *Hammock transfer to enable people to go from the airport chair to their seat*

- 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

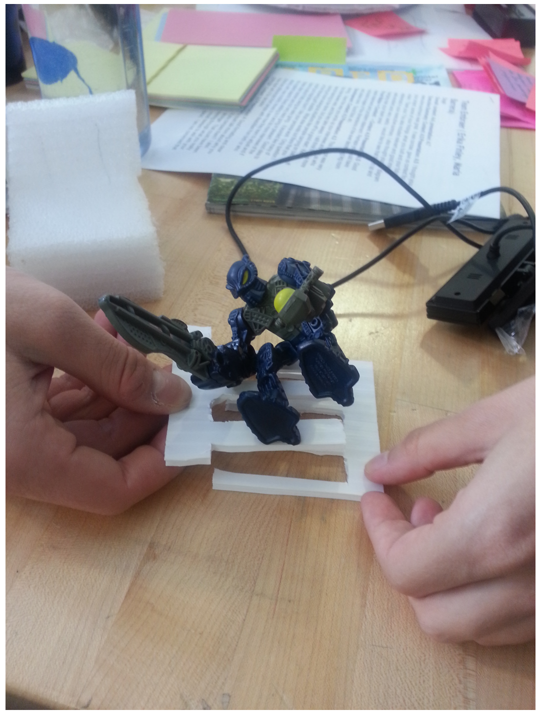


Figure 3.13: *Comb seats that would facilitate the transfer from the airport chair to the seat*

- 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.

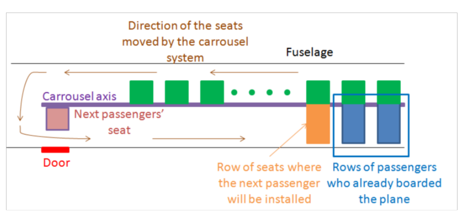


Figure 3.14: *Carousel system conveying the seats from the entrance of the plane to their appropriate location*

3.4.3 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.
- 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.

3.5 Dark Horse Version 3

3.5.1 Benchmarking

During our user testing for our second version of the Dark Horse prototype, we realized carry-on luggage was a huge concern. Currently, luggage is stored in a very burdensome and unintuitive way and with version 3 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.

The design shown in Figure 3.15 displays a cabin layout where consecutive rows of seats are on different levels, allowing passengers to store their luggage behind their tray but under

Figure 3.15: *Design that allows for easier luggage storage for all passengers Source: http://www.gizmag.com/future-of-air-travel-comfortable-seating/17751/*

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 3.16, a standard design rule for access and mobility.

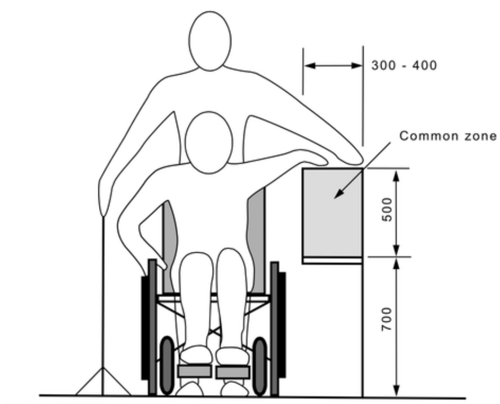


Figure 3.16: *Ideal height for reaching objects for both sitting and standing passengers. Source: https://law.resource.org/pub/nz/ibr/nzs.4121.2001.svg.html*

Another design solution we explored was actually having two seats on top of each other as shown in Figure 3.17. 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 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.

transfer

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,

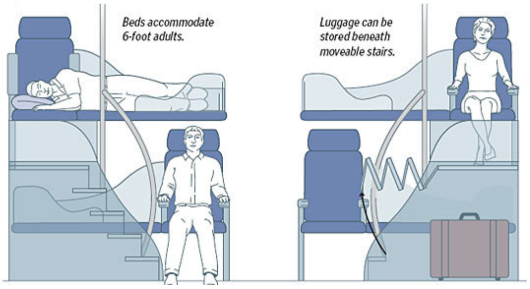


Figure 3.17: *Vertical cabin configuration with luggage storage*

they can be carried by someone else or, if they are strong enough, they can transfer themselves. We found that there are some products on the market that could make the transfer experience better, such as the harness shown in Figure 3.18 or the walker in Figure 3.19. 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. Eventually, we actually decided to widen the airplane aisle and get rid of the transfer all together.

Figure 3.18: *Harness used to get disabled out of the bath.*

transfer

Figure 3.19: *Walker that could be adapted to become a better aisle chair.*

transfer

3.5.2 Description

Currently, people with reduced mobility have to first transfer from their own wheelchair to the aisle wheelchair which is uncomfortable and narrow. 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. This process is long, it puts people with reduced mobility apart by making them different and it deprives them from their independence because the aisle wheelchair must be manoeuvered by a flight attendant. Therefore, since the boarding process is such a pain point for our users we decided to work on it to improve their experience and give them more independence.

During the boarding process the two steps that are critical for our users are :

- First, the access to their seats. 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.
- Second, the luggage storage. People with reduced mobility frequently cannot access the luggage compartment because it is too high, so our team thought that if we could imagine a system that makes the luggage compartment go up and down by just pressing a button it would also contribute to make the flight experience better for people with reduced mobility.

1. 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 3.20 .

Figure 3.20: *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 then be three times bigger than in flight, allowing people with reduced mobility to enter the aircraft with their own wheelchair which is on average 30 wide, as shown in Figure 3.21 .

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

Therefore, we thought of a second cabin layout for the boarding process which also makes the aisle wider but in a more reasonable way. We looked at the dimensions of a standard Embraer plane (Figure 3.22) and found out that if we were able to angle the rows by 46.2 (see Figure 3.23) 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 keeping the total number of seats the same.

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 to their plane seats. If they are strong enough they may be able to transfer themselves without requesting flight attendants assistance, but if they need help we imagined that they could use one of the transfer mechanisms mentioned in the benchmarking section.

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

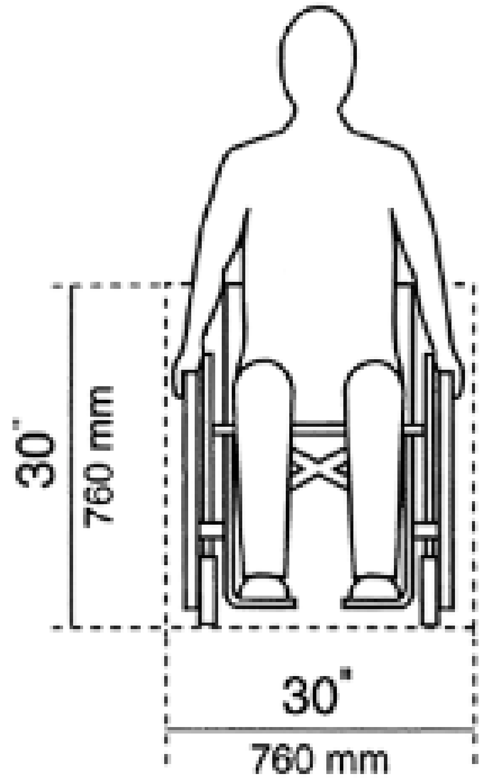


Figure 3.21: *Standard wheelchair dimensions*

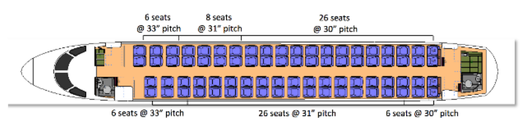


Figure 3.22: *Standard Embraer plane cabin layout*

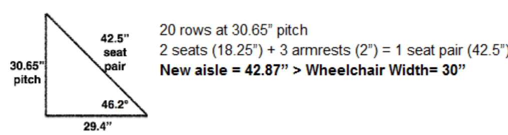


Figure 3.23: *New cabin layout with angled seats for boarding*

attendants would bring passengers with reduced mobility their own wheelchair so that they would be able to leave the plane on their own.

2. Helping our user accessing the luggage compartment :

We found out that accessing the seat is not the only problem disabled people are confronted with: they also have a big issue when they want to store their personal items in the luggage compartment. In order to fix this, our team designed a luggage compartment that can go up and down on demand, controlled by our user pressing a button (Figure 3.22).

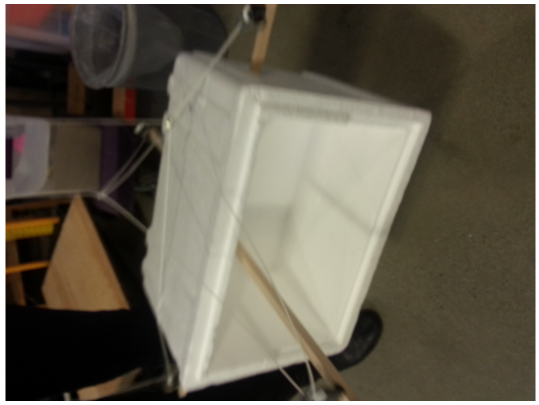


Figure 3.24: *Our luggage compartment which is accessible on demand by pressing a button*

In order to build this system we designed a mechanism made of rope and pulleys that is inspired from systems used to stabilize cameras that are mounted on drones and model aircraft. While piloting the system that causes the camera to move, the device has to remain stable. This mechanism avoids the creation of moments that could cause the ropes to tangle and knot. For our system we wanted to have a luggage compartment that does not experience torques and that can come up and down in the most smooth and stable way.

3.5.3 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. The learnings are divided into the reconfiguration and the luggage.

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 for all passengers. The users commented that the mechanism should be similar to the movement of a car seat because it is slow enough and does not cause a great amount of force and acceleration to be placed on the passenger. In addition, the window seat experienced less movement or felt like it experienced less movement than 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 tolerances 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 to access the window a handle may be needed.
- 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 aisles, allowing increased access to those seats specifically.

Luggage:

- The luggage bin needs to move with the seats into the angled configurations. With the bins situated parallel to the normal cabin configuration when the seats are angled, it is difficult to load the luggage into the bin without awkward movements.
- The luggage bin should be lowered to arm level instead of head or face level. Users felt claustrophobic when the bin was at head level due to the reduction in vision. The bin was in the line of sight which made it uncomfortable and a very closed-off space.
- The bin should have a door and have a slightly steeper angle or have a lip. Luggage moves during flight due to turbulence and shifting due flight. This would prevent luggage falling out on the passengers or items being broken.
- A more rigid lowering mechanism needs to be used instead of the string and rope mechanism that was used during prototyping. Users did not feel that the bin was stable and looked scared as it was lowered down. They feared the bin might move during lowering, raising, or turbulence causing it to hit them or bring their belongings.
- More research for optimal lowering position needs to be conducted. The position that we prototyped did not receive good feedback from the users. Therefore, several iterations need to be performed to see what would be best for our target users and other passengers
- Most of the users wanted to store luggage before they sat in their seat. The orientation of the bin and the height of the bin makes this a very awkward and uncomfortable task. When the users sat with their luggage, they felt that they were crowded and did not know what to do with the luggage until the bin was available. The mechanism to raise and lower the bin needs to be fast and stable to allow for ease of access to the seat and aisle depending on the activity.

3.6 Funky Prototype

3.6.1 Benchmarking

3.6.2 Description of the prototype

3.6.3 Learnings

3.7 Going Back to The Need

Following the wrap up of our funky prototype, the Stanford 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, 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 and that the team at USP should continue working on the transfer system. 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.

3.7.1 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 come back 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 comfirm 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 **??** 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 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 3.25.

Figure 3.25: *Tweet from Esther Appleyard-Fox explaining how she feels when she is transferred when she flies.*

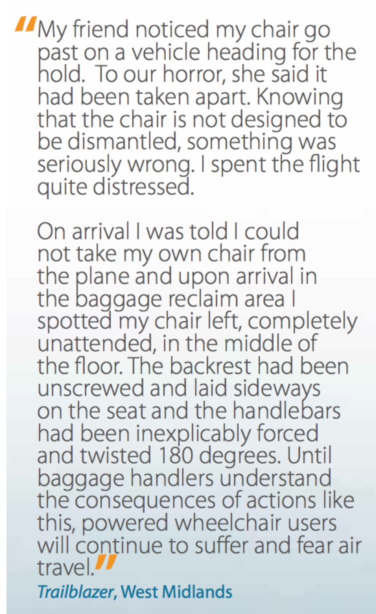
Wheelchair Storage

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 I am sure can be more comforting 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.

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 3.26 below, we must do better.

Figure 3.26: *Tweet from David Gillon on Trailblazers study that shows 60% of wheelchairs are broken in airline travel.*

Stories like the one shown in Figure 3.27 are not uncommon, with wheelchairs ending up like the one in Figure 3.28 due to airport personnel attempting to dismantle it or from the wheelchair moving around in the cargo hold.



"My friend noticed my chair go past on a vehicle heading for the hold. To our horror, she said it had been taken apart. Knowing that the chair is not designed to be dismantled, something was seriously wrong. I spent the flight quite distressed.

On arrival I was told I could not take my own chair from the plane and upon arrival in the baggage reclaim area I spotted my chair left, completely unattended, in the middle of the floor. The backrest had been unscrewed and laid sideways on the seat and the handlebars had been inexplicably forced and twisted 180 degrees. Until baggage handlers understand the consequences of actions like this, powered wheelchair users will continue to suffer and fear air travel."

Trailblazer, West Midlands

Figure 3.27: *Anecdote from a Trailblazer that had her wheelchair broken during flight.*

Figure 3.28: *Picture of a broken wheelchair after a flight.*

There are also instances of the wheelchair not even making it to the destination, just like what happened to Josie shown in Figure 3.29.

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 are you. As Aubrie stated "it 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 to focus on.

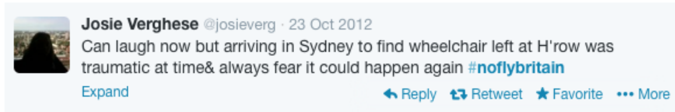


Figure 3.29: *Tweet from Josie Verguese about her experience when her wheelchair did not make it to her destination.*

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.

3.8 Functional Prototype

Winter quarter was brought to a finish with the third and final prototyping mission, Functional. Unlike Funk-tional, the functional mission desires the creation of a working prototype with system integrations using materials that could be possible in the final vision, which means no duct tape or foam core. The functional mission leads the team into the spring quarter by aiding in the finalization of the vision and creating 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. Functional mission serves as the stepping point from iterative prototyping missions to the iterative final product mission.

3.8.0.1 Benchmarking

Before prototyping our first wheelchair storage device we did 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.

****

3.8.1 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 3.30, focused on having a rigid floor to distribute wheelchair as well as a place to attach 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 of the person 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 an 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

Figure 3.30: *First prototype of wheelchair storage device.*

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

Part of having the wheelchair user present while their wheelchair is secured is also enabling an easy transfer from their personal wheelchair onto the aisle chair. As shown in the rendering Figure 3.31, right now this is accomplished by bringing the transferchair 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 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.

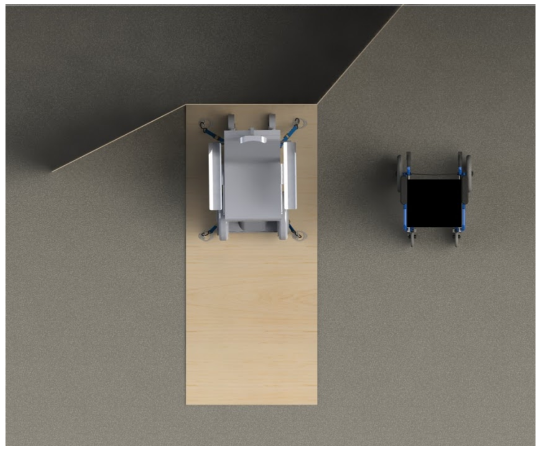


Figure 3.31: *Rendering of wheelchair and aisle chair side by side once wheelchair has been secured.*

3.8.2 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 correctly in between the hook protruding out of the base 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 expectedof 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 3.32 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.

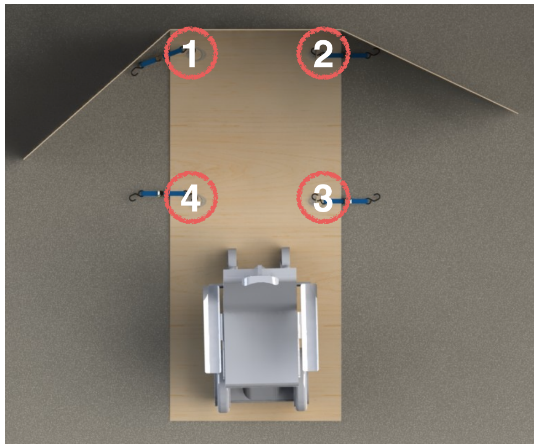


Figure 3.32: *Tweet from Josie Verguese about her experience when her wheelchair did not make it to her destination.*

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 3.33 With this in mind, we began a feasibility study to understand how possible the use of inflatables would be in the application.

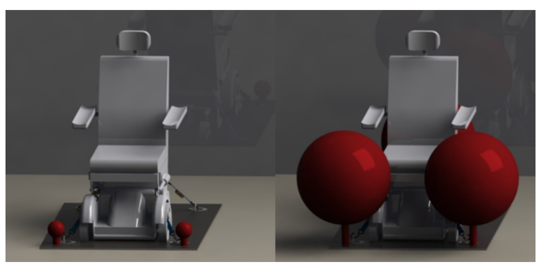


Figure 3.33: *Rendering of a preliminary idea of what an inflatable "wall" could be.*

3.8.2.1 Inflatable Materials

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.

3.8.3 Wheelchair Tracking

3.8.3.1 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 problems to arise in the cargo hold potentially making the situation worse.

3.8.3.2 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, as in the pressure situation the device must be designed reliably for an emergency.

3.8.3.3 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. However, 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 an arm flotation device fully filled 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.

3.8.3.4 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 groups prior experience with weather balloons a reasonably reliable estimate of 50,000 - 60,000 ft can be estimated for when the flotation device popped 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 altitude forming ice crystals.

3.8.4 Wheelchair Tracking Concept

4 Design Requirements

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

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 five 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
- A ramp that will enable the wheelchair to be driven on top of the pallet

The functional requirements for each of this part are in the tables from 4.1 to 4.5.

Requirement	**Metric**	**Rationale**
Support Load	Pallet must be able to support a minimum of 450 lb	Pallet must support the weight of the power wheelchair and the passenger
Light weight	Less than 60 lbs	Pallet must be made out of a lightweight material that will support the required load
Enable wheelchair to go on top of it	Platform height is less than 3"	The wheelchair cannot climb on top of the platform if it is too high
The pallet should not bend while wheelchair is loaded	Pallet will be reinforced so that the maximum deflection will be less than ½"	Pallet must be reinforced in places where it is likely to deform and bend
External wheels	Does not use wheelchair wheels and has other wheels	Handlers often break wheelchairs by trying to shift their gears
Transition from Movable to Stationary	Needs an actuator that activates the moving mechanism in less than 20s	Needs to be able to move at certain times and be stationary at certain times.
Time efficient	Putting the wheelchair on top of the platform, and securing it should take less than 5min	Baggage handlers are busy, they also have to deal with luggage and they need time
Wheelchair attachment to platform	Platform has straps for the wheelchair with placement conforming to 36 CFR 1192.23, D2	Wheelchair must be rigidly attached to platform to be secured
Fatigue	Platform must be able to withstand 5000 cycles	Platform should be replaced sparingly.

Figure 4.1: *Functional requirements for the pallet*

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

Figure 4.2: *Functional requirements for the moving mechanism*

Requirement	Metric	Rationale
Instantaneous feedback for check in	Feedback is received within 10 ms	Handler must immediately know when they have successfully checked in so they can continue doing their jobs
Visual feedback for check-in	Electronics includes 4 rows of 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.
Timely check-in	Check in process takes less than 1 second	For handlers, time is of the essence.
Detect free fall and mishandling	Electronics includes an accelerometer that is calibrated to detect any acceleration greater than 14 G's 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
Easily rechargeable	Battery should only need to be charged for 5-6 hours at a time	It should be able to get by only being charged during airport down-times (e.g. overnight)

Figure 4.3: *Functional requirements for the electronics*

Requirement	**Metric**	**Rationale**
Support Load	Handle must be able to move a load of at least 200 lbs without deflecting more than .1"	Handler needs to be assured that the handle can push the required load
House the RFID antenna	It should be more than 40" from the ground.	Handlers need an easy and quick access to the RFID antenna and they don't want to lean forward to check in or push the platform.

Figure 4.4: *Functional requirements for the handle*

Requirement	Metric	Rationale
Ramp Actuator	If ramp is attached, there is an actuator that the handler can use to raise and lower the ramp	Ramp should only be retracted when in use to reduce chance of wheelchair rolling away
Sustain weight	Ramp must withstand a minimum of 450 lbs without deflection of more than .1"	Ramp must withstand weight of passenger and power wheelchair
Multiple uses	Ramp must be able to withstand 5000 cycles	Ramp should not have to be replaced often

Figure 4.5: *Functional requirements for the ramp*

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 accomodate 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 4.6 to 4.12.

Requirement	**Metric**	**Rationale**
It shall be removable from the sliding base	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.
Its height shall be adjustable.	Minimum vertical variation of 13 cm	It has to be adjustable to people with different heights.
It shall provide support to the user.	At least one belt to hold the user.	The belts shall give safety and keep the user erect and locked to the structure.
It shall provide comfort to the user	The rest will be cushioned on the contact areas	To avoid bruises or sores on the user
It shall provide support to the body of the user.	Rigid structure should withstand a 150kg person leaning on it	It allows the user to feel secure while being transferred

Figure 4.6: *Functional requirements for the chest rest*

Requirement	**Metric**	**Rationale**
It shall allow the assistant to push/pull the wheelchair	Handles located 80cm above ground.	Allows assistant to push/pull the wheelchair
It shall allow the wheelchair to be steered inside the airplane.	Allows wheelchair to steer on a 40 cm radius.	To allow maneuvering inside the plane
It shall allow the wheelchair to be locked in a stationary position.	Locks on the wheels	To securely lock the wheelchair to avoid accidents.

Figure 4.7: *Functional requirements for the locomotion mechanism*

Requirements	**Metric**	**Rationale**
Shall be adjustable to different users	It should be at least 10 cm tall and the filling/stuffing should be adjustable (different pressure/padding)	Its common for wheelchair users to suffer injuries for staying long periods seated. Cushion must be adjustable to user to provide them with comfort.
Shall be removable from the sliding base	Use of detachable mechanism	To allow proper hygienization and maintenance.

Figure 4.8: *Functional requirements for the cushion*

Requirement	Metric	Rationale
Shall allow a lateral transfer between two seats that are not perfectly aligned	Allows a transfer with a gap of 5 cm and a 1 cm tolerance the seat's cushion base and the wheelchair's cushion base.	To make the lateral transfer easier and faster.
Shall allow a paraplegic user to transfer himself	A maximum 50N force will be required for the transfer	To allow independent transfers.
Shall be latchable to the seat and wheelchair	Existence of a latching device.	To avoid undesired lateral transfers and consequently accidents.

Figure 4.9: *Functional requirements for the sliding base*

Requirement	**Metric**	**Rationale**
Should withstand a person.	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	Casters with at least 12 cm	The chair must be able to easily move inside the aircraft.

Figure 4.10: *Functional requirements for the wheelchair structure*

Requirement	Metric	Rationale
Support feet	Feet support with 40x15cm - general dimensions	To prevent the feet from being dragged.
Fastening the feet	Foot does not slide (fall from the footrest) during use of wheelchair.	To keep the user's feet secure while moving the wheelchair.

Figure 4.11: *Functional requirements for the footrest*

Requirement	**Metric**	**Rationale**
Allow lateral transfer of the passenger	Straight and aligned base	Allow easiness on sliding of the spheres
Prevent the base sliding out of the seat	Lock mechanism on the transfer.	To give the passenger the safe feeling that the cushion will not slide at the wrong moment.

Figure 4.12: *Functional requirements for the airplane seat*

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 platfrom 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 nowadays.
- The new aisle wheelchair has to operate in the restrained space of the airplane aisle.
- In case of turbulences, the wheels of the new aisle wheelchair must be blocked.

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 in buses.
- The platform configuration changes (on the wheels to be moved or on the pallet to be stored) will be trigered by baggage handlers acting on an electric jack.
- Baggage handlers will be wearing their gloves with the RFID tag everytime that they handle a wheelchair and use our platform.

Wheelchair transfer mechanism

- All aisle seats 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 take-off and landing. This is what the FAA requires in order to make sure seats can withstand any type of accident happening during take-off or landing.

4.1.3 Functional Opportunities

Wheelchair storage device

- Our platform must be intuitive to use. A baggage handler should know how to attch a wheelchair to the platform after a 15 mn 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 on the device.

Wheelchair transfer mechanism

- Although we are desiging for a paraplegic user, it shall 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.
- The chest rest makes frontal transfer possible. Nowadays it cannot be done due to the current wheelchair dimensions.
- It reduces the risk associated to transfer because no one is carrying the disabled passenger. The chest rest is here to avoid human contacts that can be unpleasant and/or source of accidents.
- The chest rest allows paraplegic passengers to go to the restroom and use it.

4.2 Physical Requirements

Wheelchair storage device

Requirement	**Metric**	**Rationale**
Floor Safety Factor	Surface area in contact with the floor is greater than 24 in2	Reduces probability of failure
Light weight	Weighs less than 60lbs (find out what the current pallets they use weight and make it lighter)	Each extra lb costs money to the airline

Figure 4.13: *Physical requirements for the pallet*

Requirement	**Metric**	**Rationale**
Non-intrusive Tag	Tag is built in to their current equipment and it cannot be felt. We have selected the gloves	Tag should seamlessly integrate into their current equipment in order to reduce friction.
Intuitive Check-in	There is a mark in the appropriate finger that is to be used to check-in	Wheelchair handler needs to knows exactly what finger to use
Thin Electronics Enclosure	Thickness cannot be greater than 1/8"	RFID tag needs to be max .5" away to be recognize 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.
Easy to find	Electronics box is stands out because it is painted red (?) and is located on platform handle	Handler needs to be able to easily find the electronics box in order to check in.
Attachable	Enclosure has a grip (need a better word for this) that allows it to attach to the handle	Electronics must travel with the wheelchair platform at all times.
Plastic Enclosure	Enclosure is made out of plastic (need to define exactly what type)	Plastic is lightweight

Figure 4.14: *Physical requirements for the electronics*

Requirements	**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, 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.

Figure 4.15: *Physical requirements for the handle*

Requirement	**Metric**	**Rationale**
Ramp	There is a ramp present to allow user to drive power wheelchair on to the platform	Power wheelchair cannot climb over an instantaneous height difference of 1.5"
Solid Ramp	Ramp platform is composed of one solid material	User needs to feel safe as they are climbing ramp with their power wheelchair
Hinged Ramp	If ramp is attached to platform it is hinged such that it can rest completely on the platform when not in use	Minimize the surface area taken up by the platform in the cargo hold floor
Ramp wedges	There are 2" thick wedges under the ramp where the wheels will be in contact with the ramp	Provide support for the ramp platform in order to minimize ramp platform thickness
Ramp Indicator	There are stripes clearly indicating the path the wheelchair needs to take up the ramp	The wheelchair user needs to be cognizant of where he should drive his wheelchair
Plastic Ramp Wedges	The wedges are made of HDPE	HDPE is much lighter than metal and is high density enough to withstand the loads

Figure 4.16: *Physical requirements for the ramp*

Wheelchair transfer mechanism

Opportunity	Metric	Rationale
Be aesthetically pleasing and inclusive.	Clean design and smooth structures.	Inconspicuous design improves user experience.
Be ergonomic.	Adapted to average user size and body shapes.	Be comfortable and incite people to use it because it looks well designed.

Figure 4.17: *Physicall requirements for the chest rest*

Requirement	Metric	Rationale
Handles shall be retractable	Handles retract at least 15cm.	To allow the lateral movement of the system, avoiding handles getting stuck on the seat's backrest

Figure 4.18: *Physical requirements for the locomotion mechanism*

Requirement	Metric	Rationale
Shall provide enough comfort for the user during the transfer and during the flight	Be a special cushion for wheelchair users, inflatable system and to cover all the mechanism.	To avoid injuries in contact with rigid surfaces and mechanism.

Figure 4.19: *Physical requirements for the cushion*

Requirement	Metric	Rationale
Shall allow the “frontrest” to be attached onto it	Existence of a latching mechanism	Chestrest must be easily latched/removed

Figure 4.20: *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 in2 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 8 in2 figure are shown in appendix B).
- For th 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 .25".
- The box that encloses all the electronics must be very light weight (less than 3 oz).
- Power wheelchairs cannot climb an angle steeper than 6 degrees so the must inclination must be below this metric.

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

- The ramp has to be modular. It is an attachment, not the platform itself because wheelchairs shoud not be stored at a 6 degree angle during a long flight.
- The ramp 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.
- The ramp should be attached to the platform in order to reduce the number of parts the airport personnel needs to handle.
- Having a hinged ramp serves double purpose. It can be used as a ramp and also as a stopper in case the wheelchair unstraps. It is here to increase user's peace of mind.

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 piece 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 side.

5 Vision

Vision

Focusing on the needs of an underserved and suffering extreme user will enable us to design an all-inclusive universal solution. As those with disabilities require the most dramatic accommodation, a solution that would satiate their needs in a manner that normalizes their flying experience would also better the journey for all passengers. We thus aim to empower these extreme users by enabling greater autonomy while integrating them into a normative and shared flight experience, ultimately improving the comfort, convenience, and overall experience for all those sharing a flight.

The environment of both the airplane and airport will adapt to the needs of each individual. This futuristic system will be economically viable, as it will provide increased value to customers without a substantial weight increase or a loss of available seats. This additional value will foster a greater desire to travel by air and will consequently increase the quantity of prospective passengers.

In contrast to the sardine in a can-esque experience so prevalent today, the cabin in 30 years will be universally designed and provide a unique experience to each passenger. A more comfortable layout will liberate the passenger of unnecessary and harmful movements. Furthermore, the cabins design will diminish the requisite assistance sought today to help accomplish simple tasks (such as seating or going to the restroom).

5.1 Accommodation System:

The cabin will address several pain points with a system of accommodations. For example, the seats will have adjustable pitch. This will make it easier to get in and out of the seat. Furthermore, the seats would be adjustable for different body types, thus effectively improving comfort and satisfaction for the traveler.

5.2 Seat configuration:

The seat configuration will promote social interaction rather than personal entertainment. As a result, passengers could transplant their home experience into the plane; families can spend quality time together while friends can converse and play games. Business travellers will be able to work and participate in meetings as if they spent the flight within their offices. In other words, the cabin accommodates a variety of passengers by carrying their experience from home or work into the airplane.

5.3 Micro-airports:

Airports will shrink considerably, as there will be no more need to check-in physically, check luggage or arrive three hours in advance of flights. While airplanes will still transport a great amount of people, the boarding experience will be much like that of hailing a cab. The flight experience will be as simple as reserving a ticket, showing on time for departure, checking-in ones luggage when boarding and flying to ones destination.

5.4 The Personalized Information Era:

Information will be ubiquitous and fed in real time. Messages will be tailored to each individuals needs. The message will be transmitted with respect to the capacities of each passenger. Instead of being the era of information, it will be the era of personalized information, with accessibility and customization granted to all. This information can be brought into the cabin such that when you check in, the seat knows its you and automatically adjusts to your preferences.

5.5 The Experience

The solutions we developed are aligned with the group's vision because they seek to solve the individual problems of each user using global solutions. Thus, the flight condition is improved for all who use the software, processes and devices proposed, regardless of whether the passenger is disabled or not. When we developed a swivel seat, an application or an adjustable seat pitch, we considered that everyone can and should have access to a pleasant and comfortable experience. Each human being should have a special experience because a trip takes more than passengers; it carries dreams of a memorable tour or a successful business trip.

6 Project Management

6.1 Winter Quarter Review

Throughout the winter, we and our global team tried to explore our huge design space and identify which were the directions we should pursue and which we should eliminate. To do so we always tried to coordinate the work done at Stanford with the work done in Brazil.

At the beginning of the quarter we wanted their project to explore one aspect of the flight experience while we were exploring something else. The idea was then to see which approaches were feasible and which were not. For instance changing the changing the cabin layout turns out to be impossible under the constraint of keeping the number of passengers onboard the same. But at some point, USP and us needed to converge that is what we did after coming back to some of our users interviews and need findings.

We decided to create a new flight experience for disabled people that would start from the jet way where wheelchair passengers leave their wheelchair. At this point Stanford team decided to provide them with a protection system for their wheelchair as well as a wheelchair tracking device to reassure them and give them piece of mind.

From the jet way, once the disabled person is in the wheelchair then he needs to transfer to his seat and to do so without the help of any flight attendant USP decided to focus on the transfer mechanism that would give our passengers more independence.

Integrating both our prototype with USPs, we were able to build our vision for next quarter. When a wheelchair user is without his wheelchair he worries about two things: what happens to his wheelchair, his legs, and how he can actually move without it. By merging our ideas with our global partners we should be able next quarter to build a prototype that should this issue.

6.2 Deliverables

The official deliverables for the winter quarter focus on three main prototypes: dark horse, funky, and functional. In addition to these three prototypes, our team has set more deliverables within each one. Each prototype will have a dedicated brainstorming session after a project briefing, and two iterations of each prototype must be performed. The dark horse prototype is where we plan to address the futuristic cabin approach and bring that idea to life. We want to have the basis of our final solution started by the end of dark horse and continually increasing to the end of winter quarter. Our main personal deliverable will be to have a final solution design space and all the integral components decided before the end of winter so spring will be iteration after iteration until perfection.

6.3 Milestones

The milestones for the winter quarter are the darkhorse, funky, and functional prototypes. Each of these will represent a challenge to our design thinking and our solution space. In addition, we have the milestone of integrating two new team members into the ME310 experience and making a smooth transition. Another milestone will be the creation of our final design solution space. We will also be traveling to Brazil at the end of the winter quarter to do a prototype meeting.

6.4 Distributed team management

The entire team will be working on each of these projects and doing the documentation that accompanies each one. Each team segment will be responsible for the documentation concerning their prototypes and clearly articulating the lessons learned and the takeaways. We will also distribute the workload more thoroughly next quarter with the addition of two new team members. We plan to write the documentation in paragraph and bullet form from the beginning next quarter instead of bullets to make an easier transition. The bullet format will still be used to distribute ideas to our global team and the teaching team.

As for each team members role for the Stanford team, it has not been decided who will be the chief documentation and chief financial officers or if all the roles will be switched to accommodate the new team dynamic.

6.5 Project Budget

Below is the budget planning for the winter quarter prototypes. Iterations of designs are included in our budget to encourage testing and learning from failures. The budget is on the overzealous side and we hope to spend less than the allotted amount so that the majority of the money can be used during spring for the iterations and the final cabin experience.

6.5.1 Stanford Budget

6.5.2 USB Budget

6.6 Project Time Line

6.7 Reflection and Goals

6.7.1 Laura

As a new member of the team it was a little hard for me to jump right into dark horse as a first prototype to build, but once I understood what were the expectations both from the class and from our users I found at that this project is 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 you are 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 is allows to see aircraft design from the users point of view instead of the aircraft manufacturers point of view and for me this is extremely valuable.

Since I come from France it is actually the first time that I have the opportunity to work with both American and Brazilian people and this cultural diversity is also a great source of enrichment. Im looking forward to go to Brazil to meet our global partners in person.

But beyond this, this project now means a lot to me. I got the opportunity to talk to disabled people and understood how painful it is for them to travel. They care a lot about our project because they see it as way to improve their experience and I dont want to disappoint them. They deserve the right to enjoy their flights the way we do and for this reason Im very excited about Spring Quarter and I cant wait to build our final prototype and test it.

6.7.2 Rodrigo Monteiro

This quarter our prototypes required a lot of creativity and build knowledge, so we had to learn how to use the equipment and resources available to achieve our goals. Working with a tight time schedule was a challenge, but we managed to work with the available time. The dark horse was the major challenge, because we had to learn to work with wood and buy the right supply to build the prototype. On the funktional and functional prototypes we improved our ability to critically analyze our problems and see through them to refine our solution.

6.7.3 Luiz Duro

This quarter was a bit of a challenge to me both in the project way as in my personal life. The intensity of work, represented by weekly prototypes, aligned with the lack of experience in physical prototypes of the Brazilian made us learn how to work together to buy the right materials and to work on the workshop and to cover the other. This quarter we grow as a group. Another important thing I learned in the past 3 months is the importance of the critical thinking to the growth of the project. I used to believe that a critic is personal, but I learned that a health discuss can represent a huge earn to the final product.

6.7.4 Amanda Mota

Neste trimestre aprendi diferentes coisas com os trs temas de prottipos, desde a exigencia de abrir a mente a solucoes extremamente diferentes como o dark horse, como a exigencia que havia de fazerf prottipos em escala real, que trazem uma srie de dificuldades, at a execuo de solues que conseguissem se aliar as restries da aeronaveis e pudessem ser testadas. Um ganho muito grande foi o aprendizado de executar prottipos testveis com materiais fortes e reais. A minha capacidade de pensar em mecanismos e a pesquisa da parte mais tcnica de funcionamento com certeza foram melhorados.

This quarter I learned different things with the three themes of prototypes since the requirement to open the mind to very different solutions as the dark horse, like the requirement that was fazerf full-scale prototypes, they bring a lot of difficulties to execution solutions if they could combine the restrictions of aeronaveis and could be tested. A very large gain was learning to run testable prototypes with real materials and strong. My ability to think of mechanisms and research the most technical part of operation have certainly improved.

A Appendices - Flying experience from A to Z

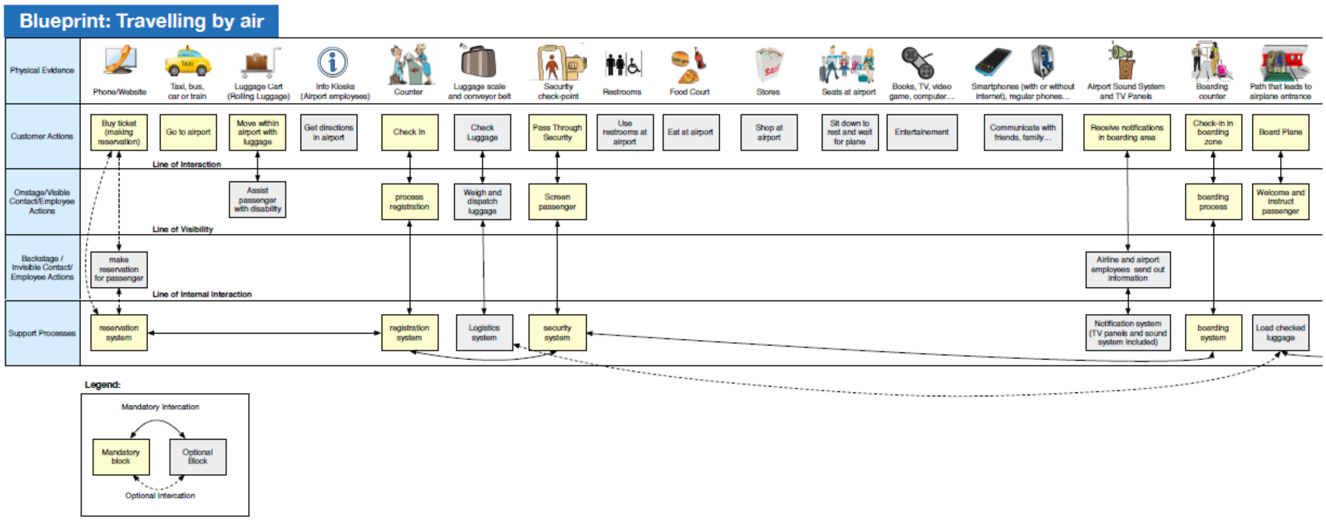


Figure A.1: *Blue Print - Flying experience from A to Z (part 1 of 2)*

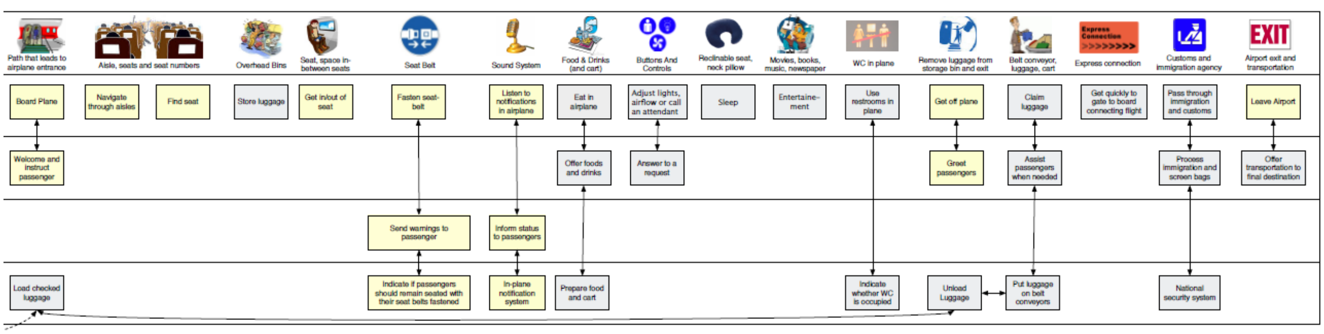


Figure A.2: *Blue Print - Flying experience from A to Z (part 2 of 2)*

B Appendices - Characteristics of Embraer jet E175

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

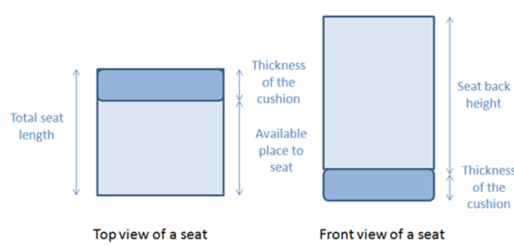


Figure B.2: *Characteristics of the seat*

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

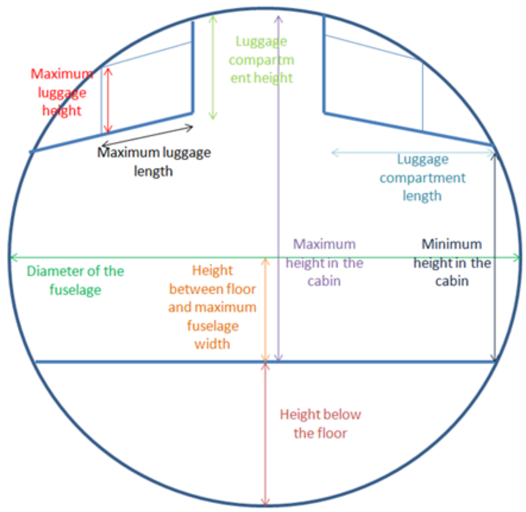


Figure B.4: *Characteristic dimensions of the fuselage of an Embraer jet E175*

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 B.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 B.5 and their values are presented in B.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 B.6: *Table presenting all the dimensions of the fuselage of an Embraer jet E175*

B.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 B.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.

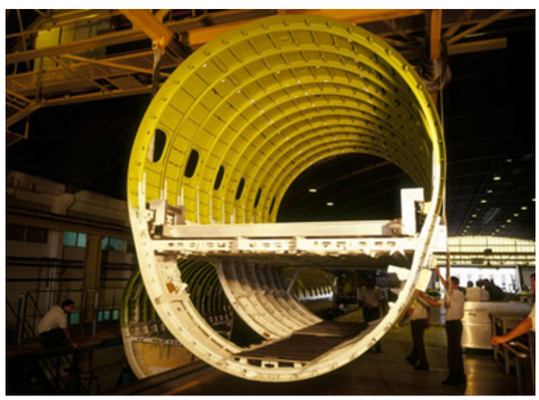


Figure B.7: *Structure of an Embraer jet E170 [**?**]*

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 B.8
- The characteristic dimensions of one of the biggest powered wheelchair that is available on the market (B.9). Its dimensions are shown on B.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 B.8: *Cargo hold characteristic dimensions*

Figure B.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 inch² / 51.61 cm²
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 B.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 B.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

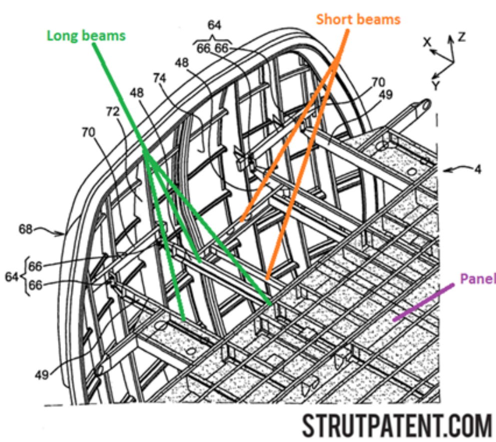


Figure B.11: *Different types of elements that constitute the cargo hold structure from http://www.strutpatent.com/patent/07338013/floor-for-aircraft*

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

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

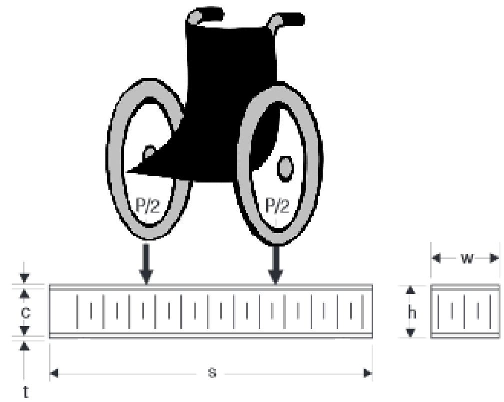


Figure B.12: *Key parameters for the structural analysis of the cargo hold floor stress*

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.

B.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.

B.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 B.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.

C Appendices - Interview of an Air France employee in charge of baggage handling

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

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

C.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.

C.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.

C.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.