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 or disabilities. The team from Stanford University is composed of two students and the university of Sao Paulo team is composed of 4 students, all with engineering degrees. 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 future solution. These themes are customer service, control, independence, seat preferences, and non-discriminatory. Figure 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 centers on automation and allowing the user to control their surroundings instead of the other way around. One major discovery we made concerned the seat that a person with limited mobility chose when boarding the flight. They chose to sit in the window seat instead of the easier-to-access aisle seat to accommodate other passengers, not themselves. This brought us to the idea of making every seat accessible for all passengers regardless of mobility status. The final theme motivating our solution is a non-discriminatory design. Limited mobility passengers and passengers with disabilities have a condition that singles them out to begin with so why should our design add insult to injury by singling them out more? Therefore, 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 cabin. The incremental fix was a swivel chair that would address the window versus aisle debate in the Embraer cabins with rows of 2 seats. But what if we wanted to apply our solution to larger cabins? We then looked at a more futuristic design, which came in the CFP of seats of rails. Figure 1 2 shows the concept of the seats on rails in a clay mock-up. Here, the rows will move forward and back to provide a certain row with extra room to allow a passenger to get in and out without disturbing the other passengers. This concept brought light to all the solutions that could be implemented and what we could make the design space to be.

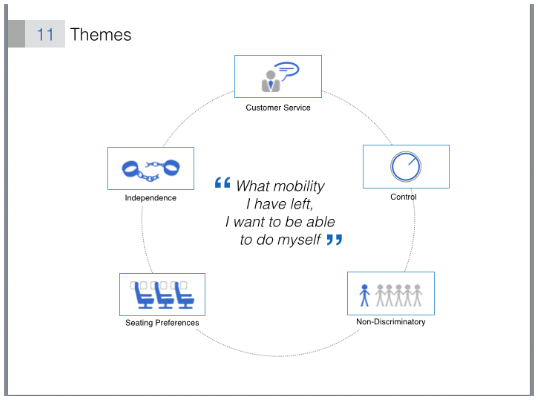

Figure 1.1: *Main themes driving our solution*

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. If the world we live in is dynamic, then why does the airplane cabin have to be static with the same seating arrangements in all planes? This is what we want to change. 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 the seat selection, the firmness/softness of their seat, the angle, and the orientation; this list is endless. Giving passengers more independence and control while minimizing customer service interaction and discrimination is our motivation for a futuristic cabin that will make the entire air travel experience from home to gate to destination out of this world.

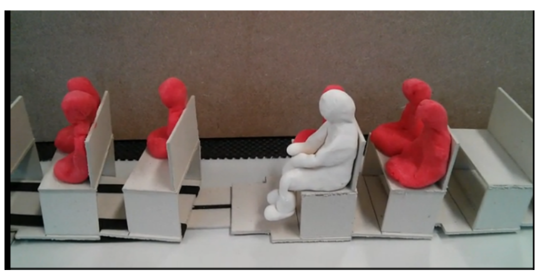

Figure 1.2: *Scaled mock-up of seats on rails prototype*

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 neuromuscular or orthopedic impairments. It may include conditions such as spinal cord injury, paralysis, muscular dystrophy and cerebral palsy. It may be combined with other problems as well (i.e. brain injury, learning disability, hearing or visual impairment).

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

Non-Discriminatory: Fairness in treating people without prejudice.

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

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

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

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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. Source: http://www.examiner.com/article/airlines-may-charge-fat-people-higher-fares*

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

To make this problem more tangible and approachable, we broke the project into different focus areas:

- Current systems in use in the airport and on the airplane

- User's Needs
- User's Complaints
- Identification of Critical Users

The whole process (see Appendix A Diagram A1) was analyzed and current systems that are in use based on FAA and ADA regulations were researched to determine the gaps in the system. The gaps helped identify possible user needs. In addition, user interviews were conducted to determine more needs and used to focus exact needs that we could address with our solution. The interviews enlightened us with complaints that the current users had and ideas on where possible innovation areas lay.

For our problem, two distinct groups of users were identified: the flight crew and the passengers with limited mobility. While the passengers with limited mobility are identified in the problem statement, the flight crew are the users that will have to use the solution on an everyday. Therefore, the ease of use and the inclusion into the flight crew's tasks have to be considered in order to make the solution a success.

2.3 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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2.4 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. Additionally, Robert, Laura, and Cliff joined the team at the beginning of winter quarter. Our team has a diverse educational, cultural, and social background that encompasses many skill sets and multiple areas of study.

Stanford University

Marria 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.

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

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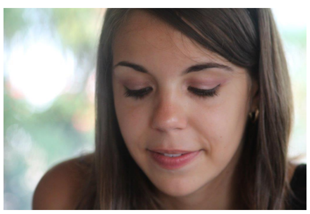
I grew up in New Jersey through high school. After that, I moved to southern california where I attended the California Institute of Technology majoring in Mechanical Engineering with minors in Aerospace Engineering and Control and Dynamical Systems. I have worked on robotics projects with NASA's Jet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



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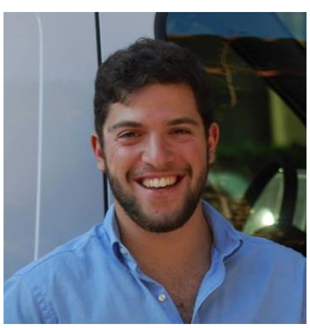
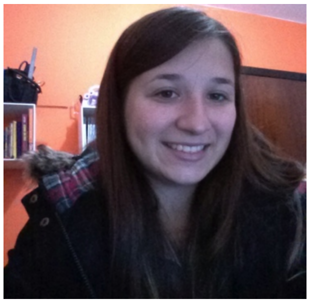
I come from Toulouse, France. I attended ISEA-Supaéro (the French Graduate school of Engineering) at Toulouse for my undergraduate degree in Aeronautics. I worked at Airbus head quarters in Blagnac, France as an intern last summer and want to make a career in the field of aircraft design. I'm interested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



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

Having spent the first 22 years of my life within a subway ride of Boston, Massachusetts, I decided to drive west and come to Stanford. I'm completing my MSME this spring, focusing on mechatronics, robotics, and controls. I graduated with a BSME from Tufts University, where I double majored in Mechanical Engineering and Mathematics, was an active member of Engineers Without Borders and the Tufts Robotics Club, and ran on the Tufts Cross Country and Track and Field teams. 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
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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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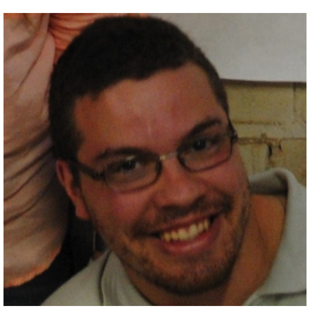
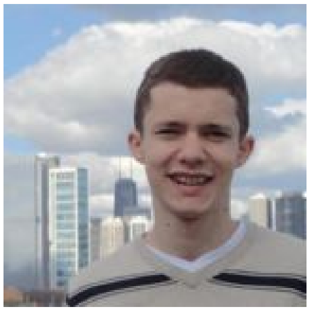
I have lived all my life in São Paulo. I am now graduating in Computer Engineering at USP and I also work in a technology development lab at the university. I have worked on several projects developing educational games and other educational interfaces that help children learn with technological devices. 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
Contact: luiz.durao@usp.br

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



Guilherme Kok
Status: Industrial Engineering Undergraduate Student
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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.

2.5 Coaches

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

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

3 Design Requirements

As we saw in the previous sections, our users need to be more independent and more in control when they transfer to the aisle wheelchair or to their seat and they give their own wheelchair to airline personel for cargo hold storage. In order to understand what our design space in the cabin and in the cargo hold is, we decided to carry out a detailed analysis of both layouts.

3.1 Functional Requirements

In this section we tried to explain and quantify what our design should do and must include to be integrated to the flight experience and considerably improve it for disabled passengers.

3.1.1 Functional Constraints

The ideal flight experience for disabled passengers should not require the intervention of flight attendants. Our user should be able to do everything on his own once inside the cabin. Any system that provides our user with more independence has to be safe and secure to use and should have be replaced at the same time as other items inside the cabin. This means that any new system that we could implement inside the cabin should be able to last at least five years which is the period of time associated with cabin replacement for most airlines. Our design has to be inconspicuous and should not make our user feel singled out. Disabled people are different, they know it but they do not need to be reminded it and they don't want to be separated from their travel comapnions.

3.1.2 Functional Assumptions

We assumed that the disabled passengers we are designing for have a minimum core strength that enables them to transfer from their own wheelchair to another aisle wheelchair or to their seat. They are able to use their arms for tranfering or clicking on buttons or using a smartphone.

We also assumed that disbled passengers have a smartphone from which they can download apps that would help them getting more independence during their flight experience.

We assumed that our user would be traveling with at least one travel companion from who he does not want to be separated from. He also travels with at least one carry-on that he needs to store in the luggage compartment in the cabin.

3.1.3 Functional Opportunities

These functional constraints and assumptions let us with a design space that gives us the opportunity to explore autonomous devices like a powered wheelchiar, or automated controls for tranfer, environemental control, wheelchair storage.

It also gives us the opportunity to explore different cabin layouts and new protection devices for wheelchair storage. Almost nothing has be done in terms of automation and accessibility inside the cabin so it gives us a lot of room for improvement.

3.2 Physical Requirements

The main physical requirement concern the cabin and cargo hold dimensions and the weight of any device we would like to add inside the aircraft. In order to understand are those limitations we conducted a very detailed analysis of both the cabin configuration and the cargo hold structure.

3.2.1 Physical Constraints

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 3.1: *Seats of a typical Embraer E175 in economy class*

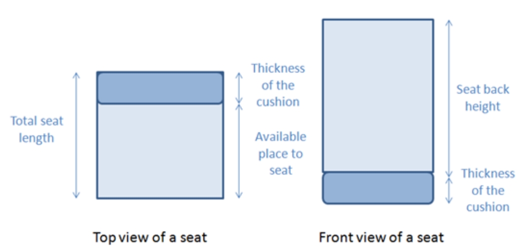

Figure 3.2: *Characteristics of the seat*

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 3.3: *Table presenting all the dimensions that define an airplane 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.

Figure 3.4: *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 3.5: *Table presenting all the 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 space dedicated to carry-on luggage. All the dimensions of the luggage compartment are represented on **??** and their values are presented in **??**.

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 3.6: *Table presenting all the dimensions of the fuselage of an Embraer jet E175*

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.

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 **??** 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.

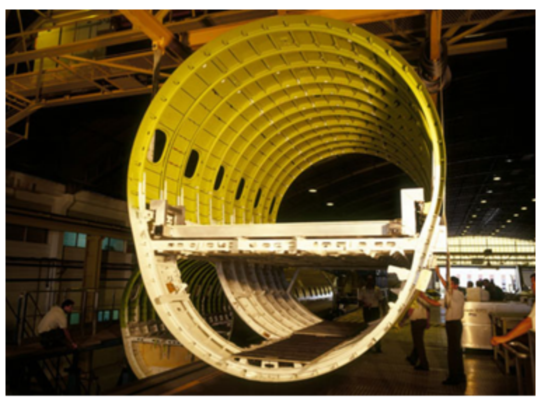

Figure 3.7: *Structure of an Embraer jet E170 - http://www.embraercommercialaviation.com/Pages/Ejets-170.aspx*

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:
1. The cargo hold characteristic dimensions that are shown on **??**

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 3.8: *Cargo hold characteristic dimensions*

2. The characteristic dimensions of one of the biggest powered wheelchair that is available on the market (**??**). Its dimensions are shown on **??**.

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 3.9: *Table presenting all the dimensions that define an airplane seat*

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.

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. In the annex section (**??**) there is 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 **??** we can see the three different types of beam that constitute the cargo hold structure:
3. The long beams that come across the entire fuselage. Because they are very long they are very sensitive to bending and flexural failure.
4. 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.
5. The floor panels that are sensitive to flatwise compression.

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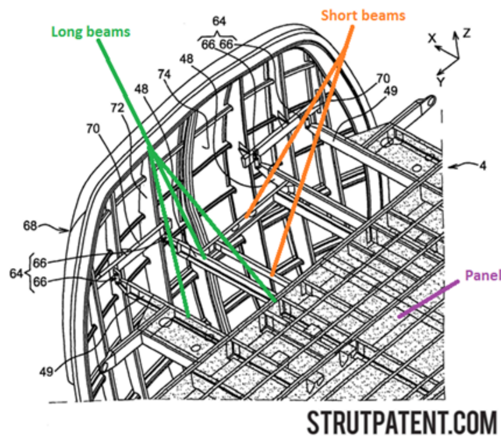

Figure 3.10: *Different types of elements that constitute the cargo hold structure from http://www.strutpatent.com/patent/07338013/floor-for-aircraft*

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

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

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

For

$$P_{max} = 490lbs2170N$$

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

$$\sigma_s = 6222psi42.9MPa$$

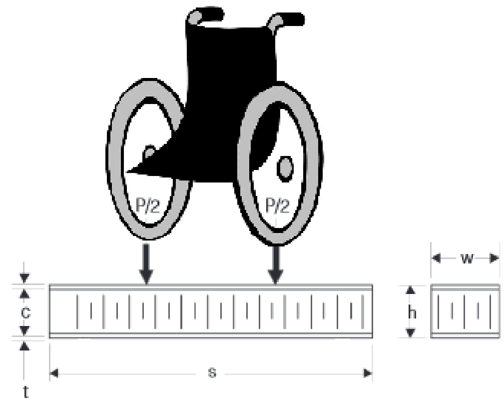

Figure 3.11: *Key parameters for the structural analysis of the cargo hold floor stress*

. This is associated with a maximum stress of

$$Stress_{max1} = 6222psi42.9MPa$$

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3.2.1.1 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:

$$\tau = fracP2.c.w$$

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

For P_{max} = 710 lbs 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 $\tau = 36.11psi0.25MPa$. This is associated with a maximum stress of $Stress_{max2} = 36.11psi0.25MPa$ 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.

3.2.1.2 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:

$$\sigma = fracPs.w$$

with s = 144 / 365.8 cm and w = 32.3 / 82 cm

$$\sigma = 740psi5.1MPa$$

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

$$Stress_{max3} = 740psi5.1MPa$$

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

$$Stress_{max2} = 36.11psi0.25MPa$$

. It means that for a wheelchair such as **??** 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.

3.2.2 Physical Assumptions

We assumed that the airline personel would be trained to assist or use any device that would make disabled people's flight experience better. We also assumed that anything we would design and implement in the cabin or in the cargo hold would be easy and quick to use and would not cause any delay in the boarding process, especially for every device that would concern wheelchair protection for storage in the cargo hold.

Indeed, airlines have a lot of constraints to take into account when it comes to storing items in the cargo hold and since wheelchairs can be big and heavy we wanted to know more about how they currently handle them from the jetway to the cargo hold. Our goal is to protect the wheelchair of disabled passengers from all the aggression it could experience from the moment when the user left it at the jet way to the moment when the user get it back. 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.

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:

6. 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.
7. 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 (see**??**) 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.

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

Figure 3.12: *Contact area between the wheelchair and the cargo hold floor: its causes an important stress on the aircraft structure*

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.

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.

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.

Based on this interview, we assumed that our disabled passenger would not require in advance any specific help or information for wheelchair storage inside the cargo hold. Our user would tell the airline just before boarding that he needs to store his wheelchair and our device would have to accomodate it quickly and safely.

3.2.3 Physical Opportunities

With all these assumptions and constraints in mind we were left with yet a huge design space to explore and that is what we did this quarter and what is decribed in the following section entitled design development. First, with dark horse and funky we, with our USP counterparts tried to change the cabin layout to improve the boarding process before exploring the issue of wheelchair storage during functional prototype.

4 Design Development

4.1 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. // Throughtout 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 ”experinence” 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 the wanted since the row would shift when someone else needed to get out as well, 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.

4.2 Winter Quarter Introduction

4.3 Dark Horse

4.3.1 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.

4.3.2 Benchmarking

4.3.3 Description of the prototype

4.3.4 Learnings

4.4 Funky Prototype

4.4.1 Benchmarking

4.4.2 Descrption of the prototype

4.4.3 Learnings

4.5 Need finding through user interviews

4.6 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.

4.6.1 Wheelchair Storage

4.6.2 Inflatable Materials

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.

Bibliography

[1] B. Beedu, Ganguli A., and R. Steffens. Toyota driver condition detection system. Me310 spring design document, Stanford University Dept. of Mechanical Engineering, Stanford, CA, June 2001. http://wikibox.stanford.edu:8310/06-07/Public/ResourceFiles/.

[2] E. Cooper, G. Lee, J. Walker, D. Zhai, C. Elverum, J.M.G. Farstad, S. Hussain, S. Ulonska, M.L. Hegdal, R.E. Somby, and K. Stalsett. Electric mobility norway. Me310 spring design document, Stanford University Dept. of Mechanical Engineering, Stanford, CA, June 2012. http://wikibox.stanford.edu:8310/FileShare0910/TC2/2011-2012/.

[3] A. Delepelaire, W. Dong, C. Fiszer, T. Liu, T. Makabe, E-S Ng, S. Samuel, and D. Volkov. A building energy relationship. Me310 spring design document, Stanford University Dept. of Mechanical Engineering, Stanford, CA, June 2012. http://wikibox.stanford.edu:8310/FileShare0910/TC2/2011-2012/.

[4] T. Eloranta, K. Frankovich, F. Hollsten, K. Kauppinen, C. Pell, A. Rudolph, M. Syrjala, and Y-S Woo. Audi: Interaction. Me310 fall design document, Stanford University Dept. of Mechanical Engineering, Stanford, CA, December 2008. http://wikibox.stanford.edu:8310/08-09.

[5] X. Ge, J. Ji, T. Bow, I. Castaneda, R. Mayani, and C. Hansberg. Lockheed martin configure to order spacecraft design. Me310 spring design document, Stanford University Dept. of Mechanical Engineering, Stanford, CA, June 2011. http://wikibox.stanford.edu:8310/FileShare0910/TC2/2010-2011/.

[6] L. Heine, M. Situ, A. Wong, P. Garcia, D. Muriel, and J.L. Torres. Autodesk: Multi-user design collaboration. Me310 fall design document, Stanford University Dept. of Mechanical Engineering, Stanford, CA, December 2007. http://wikibox.stanford.edu:8310/07-08/Course.

[7] Andrew Joseph Milne. An information theoretic approach to the study of ubiquitous computing workspacessupporting geographically distributed engineering design teams as group-users. In *Thesis*, 2005.

[8] A. Osterwalder and Y. Pigneur. *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*. Wiley Desktop Editions. Wiley, 2010. http://books.google.com/books?id=fklTInjiPQAC.

[9] K. Otto. Robust systems and strategy. Corporate website, August 2007. http://www.robuststrategy.com/.

[10] Kevin N. Otto and Kristin L. Wood. *Product design : techniques in reverse engineering and new product development*. Prentice Hall, Upper Saddle River, NJ, 2001.

[11] Karl T. Ulrich and Steven D. Eppinger. *Product design and development*. McGraw-Hill, New York, 1995.

[12] D.J. Wilde. Using student preferences to guide design team composition. In *Proceedings, ASME Design Engineering Technical Conferences*, DETC97/DTM-3890. ASME, September 1997.

[13] D.J. Wilde. Teamology: The construction and organization of teamology: The construction and organization of effective teams. Monograph, Stanford University Dept. of Mechanical Engineering, Stanford, CA, July 2007. http://wikibox.stanford.edu:8310/06-07/Public/.