COVR

Increasing Perceived Viral Safety in Air Travel

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Executive summary

The coronavirus, which emerged worldwide in 2020, has raised concerns about viral safety in air travel. Less passengers fly due to the imposed restrictions and the fear of catching the virus while traveling. These concerns might have a long-term impact on travel patterns, with nearly a third of travelers planning to fly less after the pandemic. The aviation industry, an important part of the global economy which provides 65.5 million jobs worldwide, has been hard hit since the virus outbreak. Experts agree that addressing new passenger concerns will be critical as their willingness to fly will drive the recovery.

Developed in collaboration with the aircraft manufacturer Embraer, this project explored ways to increase the perception of viral safety in current aircraft, and translated these findings into a product proposal, which provides a feeling of safety and privacy during a flight.

To understand the factors influencing the perception of viral safety, interviews were conducted with recent flyers and flight attendants. The collected data showed that contracting the virus is a big worry, especially while eating. Not only does it reduce the feeling of safety, it also exposes passengers to the risk of infection as a result of removing the masks.

In order to facilitate ideation, a brainstorming session with aviation experts was conducted. Prototypes were developed and tested with travelers using virtual reality technology to define solutions that evoke a sense of safety. The combination of insights allowed for the development of "COVR" – an aircraft interior element that separates passengers, providing a feeling of viral safety and, as a result, increasing the willingness to fly.

Reading guide

This reading guide describes the report layout and guides the reader towards the desired content.

The timeline on this page provides an overview of the chapters in this report and the actions taken.

Each chapter begins with a brief introduction. and ends with a summary in a form of the main takeaways.

- Key takeaways are formatted in this way.

Quotes are formatted in this way.

Main insights are highlighted in this way.

This dissertation is based on the Double Diamond method, which divides the project into four stages: Discover, Define, Develop and Deliver. To indicate each phase, chapters are marked with the corresponding symbol:

Discover **Define**

Develop **Deliver**

Research & methodology
Literature research
Trend Analysis
Assignment and approach

Chapter 1 Chapter 2

Problem Definition
Interview analysis
Problem Definition
Initial ideation

Chapter 5

Ideation & prototyping
Product feature matrix
Rapid prototyping
Harris Profile
Concept selection

Chapter 7

Final concept & Validation
Product embodiment
Feasibility
Sustainability assessment
Proof of concept

Chapter 9 Chapter 10

Users and Experts
Interviews
Expert Feedback session

Chapter 3 Chapter 4

Synthesis
Project considerations
Problem Definition
Existing concepts
Requirements and wishes

Chapter 6

Evaluation
User Testing
Expert Validation

Chapter 8 Chapter 11

Conclusion and discussion
Discussion
Requirements and wishes
Recommendations
Personal reflection

Chapter 12

Table of contents

Abbreviations

FA - Flight Attendant
GBP - Green Business Practices
GDP - Gross Domestic Product
HEPA - High Efficiency Particulate Air
HREC - Human Research Ethics Commitee
IATA - International Air Transport Association
ICAO - International Civil Aviation Organization
OEM - Original Equipment Manufacturer
PVS - Perceived Viral Safety
ROI - Return On Investment
TAT - Turnaround Time
UV-C - Ultraviolet Light
WHO - The World Health Organization
VR - Virtual Reality

Chapter 1

General introduction

This chapter presents an overview of the project context and its stakeholders. First, in order to allow understanding of the problem, it provides background information on the recent coronavirus pandemic, its impact on aviation, and the passengers' perception of safety. Finally, this chapter presents the assignment and approach that will be followed throughout the project.

1.1 General introduction

SARS-CoV-2, or coronavirus pandemic, which emerged in 2020, has had a profound impact on many aspects of human activity globally, including air travel. Mass means of transit, in which people travel in close proximity to each other, are a potential environment for virus transmission. Since the outbreak, travelling has been minimized to essential trips only, to prevent further contamination. In effect, international air travel, a key enabler of tourism, has decreased by two-thirds, or nearly 1,5 billion passengers (ICAO, 2020a), due to ubiquitous travel restrictions, quarantine obligations or low willingness to fly among passengers.

In order for passenger to travel they need to perceive it as being safe. As a result of pandemic, new viral safety concerns emerged, which will likely cause long-term changes in attitudes towards mass modes of transport. Addressing these concerns is identified by experts as vital for the recovery of aviation, which is a key industry in any economic restart post-pandemic (IATA, 2020a). Attention should be paid to both real safety and how passengers perceive it; although there is an unlikely chance of catching the virus on the plane, the paassengers' subjective judgment of safety may be different and lead to low willingness to fly (Molin et al., 2017; Mauro, 2019).

Recognising the significant investment involved and in order to remain future-proof, aviation companies will need to innovate for increased viral safety, and introduce measures that will ensure that travelers feel safe throughout the journey. Moreover, with the environmental challenges being an increasingly important part of the public debate, companies may have an opportunity to emerge amidst the pandemic as more sustainable and environmentally friendly.

Embraer is one of the four world's biggest commercial aircraft manufacturers. Airlines supplied with its aircrafts carried nearly 145 million passengers per year pre-pandemic (Embraer, 2020a). In order to contribute to the industry recovery, and explore the new futures for resilient and sustainable aviation after pandemic, Embraer decided to pursue a project aiming at understanding travelers' perceptions of viral safety to provide them with a safer and more reassuring experience.

This graduation assignment explores the phenomenon of perceived viral safety in the aircraft cabin among airline passengers travelling during coronavirus pandemic. By focusing on the psychological side of viral safety, it aims at defining the underlying concerns of passengers and tackling them to increase confidence in flying. The findings from this research will be used for developing a product proposal that is an element of an aircraft cabin.

In this chapter, an overview of the main findings from literature research is provided. To aid the research process, findings from the liteature were written down on color-coded cards and then grouped into main topics. For a preview of the process, see Appendix B.

"Successfully restarting air passenger travel while restoring confidence in the safety of air travel are vital pre-requisites to enabling the global economy to recover from COVID-19."

(IATA, 2020b)

1.2 COVID-19 pandemic

1.2.1 Coronavirus pandemic

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is a type of virus that can cause COVID-19 disease. It is spread by human-to-human transmission and is mainly associated with causing fever and severe respiratory problems (RIVM, 2020a), in some cases leading to death. A relatively low fatality rate is observed, however, the high transmissibility has caused difficulties in controlling the rapid spread (Khosravi, 2020). It can be transmitted through coughing and sneezing, but also through surface contact (RIVM, 2020b). Even with measures ensured, aerosols may travel more than 2 metres from the carrier and may accumulate in poorly ventilated indoor places (Prather et al., 2020). This increases the risk of infection in shared, enclosed spaces. Furthermore, new attitudes towards viral safety have emerged widely since the outbreak (Robson, 2020).

1.2.2 Common preventive measures

In order to tackle the spread of virus, general safety measures have been implemented in the countries affected. Due to the limited travel range of the droplets, social distancing is a common and effective way to reduce the risk of infection. Staying home, avoiding crowds, increased cleaning and wearing a face mask are widely recommended practice to reduce chances of contamination through contact. The protective value of commonly used cloth masks and single-use masks is not clear, however they have been identified as a beneficial layer of protection against spreading virus droplets (Devlin, 2020). The common measures are summed up in the Figure 1.1.

1.2.3 Medical developments

Several medical companies have developed COVID-19 vaccines such as Pfizer-BioNTech with over 90% efficacy (RIVM, 2021). In addition, since the outbreak, progress has been made in rapid testing to help detect genetic traces of SARS-COV 2 in the body.

Different solutions are emerging throughout the pandemic, such as immunity passports, also called “risk-free certificates”, which allow for tracking and sharing the immunity status. However, as of 2020, there is no evidence that individuals who have recovered from coronavirus disease are protected from a second infection, therefore tracking immunity is not recommended by WHO (WHO, 2020).

1.2.4 Implications for the research

At the time of writing, despite global efforts to curb the coronavirus, it has not been contained. New developments may render some of the information in this report obsolete. Furthermore, reliability may be affected due to the fact that little research is available on how a pandemic of this magnitude affects the long-term attitudes towards virus safety.

Figure 1.1: Common preventive measures to reduce the spread of Coronavirus.

1.3 Impact of COVID-19 on aviation

1.3.1 Introduction

Tourism and air travel play a significant role in global biotic exchange (Hall, 2019). Airplanes carry passengers across borders, therefore may enable a pathway for virus spread. To reduce risks, air travel has been restricted with quarantine and bans in many countries. Another factor driving the decline in air travel is concerns about the viral safety - about one in three passengers plans to travel by plane less frequently in the future as a result of COVID-19 (Inmarsat, 2020). Passengers are the main source of revenue for most airlines, and addressing their concerns will be a crucial part of the recovery of the aviation (Lamb et al., 2020), an industry positioned importantly in any economic restart post-COVID-19. (OECD, 2020)

1.3.2 Aviation industry

Prior to pandemic, aviation industry supported 65.6 million jobs worldwide and contributed $2.7 trillion per year in global economic activity (Amankwah-Amoah, 2020). In the recent decades it has been a key enabler of tourism and a carrier of 35% of world's trade in value (ATAG, 2020). Due to the coronavirus pandemic, it has been affected on an unprecedented scale. In 2020 only, total worldwide air travel has shrunk by over half, transporting nearly 2.9 billion passengers less than pre-pandemic, causing losses of 391 billion USD in revenue for the airlines (ICAO, 2021). This has many economic implications, such as widespread layoffs, lower businesses activity and seeking financial aid from the governments (The Economist, 2020). By the time of writing, IATA's prospect of a full recovery to pre-pandemic levels is dated to 2023, however many sources cite one or two years more (Subramanian, 2020).

1.3.3 Action of aviation industry

Recognizing the economical influence of aviation on many global industries, there is a demand for solutions that will drive the recovery. On April 2020, ICAO established Aviation Recovery Task Force (CART), with the aim "to identify and recommend strategic priorities and policies for States and industry operators" (ICAO, 2020b). Since its operation, it has provided a set of 11 guidelines for restarting aviation and a mitigating public health risks. "Strengthening public confidence" is one of the key aspects identified as drivers of recovery.

1.3.4 Post-pandemic opportunities

The pandemic has shifted the focus of airlines to saving jobs, capital and restarting operations. However, experts say that this time presents an opportunity for companies to emerge as more healthy and sustainable, with a stronger focus on decarbonization and implementation of Green Business Practices (GBP). This approach could enable aviation firms to develop deeper relationships with stakeholders and build a greener reputation, which is generally favorable among customers (Davis-Peccoud & van den Branden, 2020). Furthermore, decreasing waste and pollution facilitates the reduction of operating costs in the long run (Amankwah-Amoah, 2020), and adopting GBPs may help penetrate new markets and attract skilled workers (Agyabeng-Mensah et al., 2020).

1.3.5 Role of Embraer

Embraer is an aircraft manufacturer with around 18,000 employees worldwide prior to the pandemic. As an OEM that supplies aircraft to many airline carriers, it is in Embraer's best interest to take initiatives that will support the recovery. In addition, it demonstrates a commitment to decarbonising and reducing the environmental impact of aviation. This graduation project is one of the initiatives undertaken to improve the condition of passenger air travel, while respecting the company's green mobility goals.

Figure 1.2: Airplanes parked for the time of inactivity (CNBC, 2020).

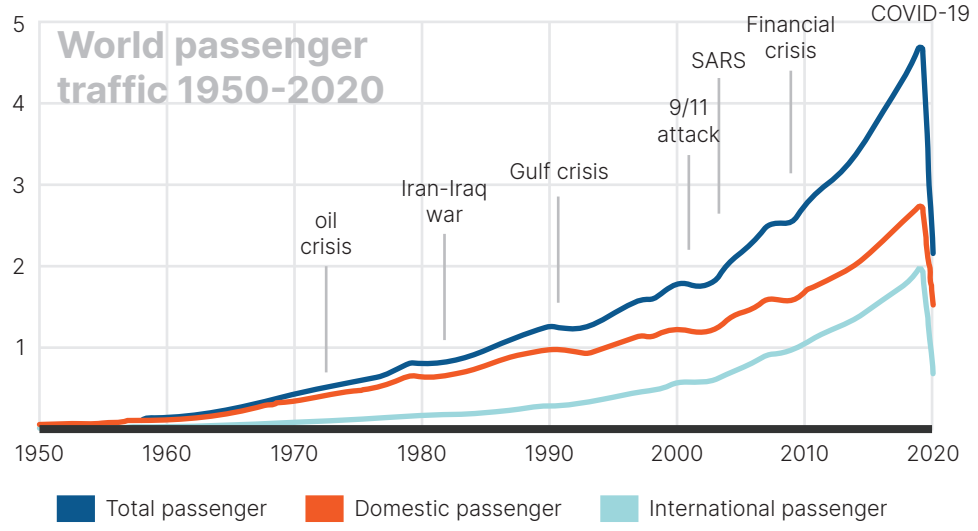


Figure 1.3: Impact of coronavirus on the passenger traffic (ICAO,2021).

1.4 Emotions and the perception of fear

New travel concerns have arisen as a result of the COVID-19 pandemic. Passengers are afraid of catching the virus during the journey (IATA, 2020a), and the lack of knowledge about the virus may fuel anxieties. Perception of safety is one of the key factors influencing the decision to travel (Boksberger et al, 2007; Graham, 2020), and the low confidence arising amidst the pandemic is likely to have long-term impact on the travelling patterns in aviation. This chapter aims to gain a deeper understanding of how new virus safety concerns are emerging among passengers and how these concerns might affect the willingness to fly.

1.4.1 Perceived safety

Fear is a basic emotion, considered to be an integral part of human development, and plays an important role in decision making. The fear of catching a virus is the psychological response of our body to a threat that reduces our chances of survival (Robson, 2020), and avoiding shared means of transportation is one way to reduce risk. Human judgement of safety, however, is not always accurate. It has been widely acknowledged that passengers often make decisions based on perceived, non-materialized threats, rather than objective, measurable, "real" safety indicators (Molin et al., 2017; Tversky and Kahneman, 1979). The information about safety is usually scarce, and passengers have to make judgements using partially incomplete information (Fleischer et al., 2015). This can be seen in the studies by IATA - although experts agree that chances of virus transmission between passengers in the aircraft cabin are low, passengers determine sitting next to someone on a plane as the most concerning activity in air travel. Mauro describes that passengers build their perception of safety on a combination of facts and fears (Mauro, 2019), resulting in a distorted view of safety, and lower confidence in flying. These findings indicate that there is a gap between actual safety and how passengers perceive it, which is particularly important in the context of a pandemic, when a sense of security will influence the decision to fly and affect the travel experience more prominently. Therefore, the emphasis should be on addressing the psychological aspects of viral safety, alongside real safety measures, to ensure that passengers are not only safe, but also feel secure throughout the flight.

1.4.2 Willingness to fly

There has been already a high emotional load connected to flying (Mauro, 2019; Fleischer et al., 2015) and the pandemic is likely to amplify the concerns. Large studies conducted by IATA since outbreak reveal that more than one third of flyers claims to return to travelling no sooner than six months after the pandemic subsides, and 14% of them plan to wait more than a year (IATA,2020b). Another large study by Inmarsat provides an insight into the attitudes on the travel patterns - about a third of the respondents plan to travel less by air in general as a consequence of the pandemic (Inmarsat, 2020). For more study results, see Figure 1.5. This data shows that the new attitudes towards safety not only have a significant economical impact on the aviation industry during a pandemic, but also will likely continue to do so for years to come. As put by Lamb (Lamb et al., 2020):

"***Increasing passengers' confidence in their personal safety is a complex challenge that must be overcome before commercial aviation can move on to what will likely be a new era that is vastly different than what passengers have become accustomed to".***

The willingness to fly may be reduced among travelers due to the fact that memories of emotions can influence the perception of safety independently of facts long after the event has occurred (Mauro, 2019).

Furthermore, emotions are influenced by various physical, social and situational inputs (Ahmadpour, 2014), making them a highly individual and complex matter.

1.4.3 Opportunities for the research

Despite the importance of emotions in everyday life, there is a general scarcity of sound scientific methods to study emotional phenomena (Gu et al., 2019). Nevertheless, it may be assumed that humans can express their feeling of safety on a rating scale (Molin et al., 2017), which may provide valuable insights of the perceptions of safety for this graduation assignment. In addition, extensive research is available on the perceptions of safety on board pre-pandemic. However, there is a need to investigate how perceptions have been affected in the new context of COVID-19. Moreover, quantitative studies are available on concerns in flying during a pandemic, but there is still a lack of in-depth research into viral safety perceptions in the plane cabin.

In order to clarify the scope of this graduation project, a definition of perceived viral safety is established:

Perceived viral safety (PVS): One's emotional judgement of the chances of contracting a virus in a given circumstance.

Figure 1.4: A definition of Perceived viral safety developed for this graduation assignment.

Top concerns around contracting COVID-19:

(IATA, 2020b)

1. Sitting next to someone in the aircraft
2. Being in a crowded bus on the way to the aircraft
3. Using the lavatory/ Airport queues

Top measures that create a feeling of safety

1. Screening for COVID-19 upon departure
2. Mandatory wearing of masks in airports & planes
3. Social distancing on aircraft

Passenger travel habits

(Inmarsat, 2020)

2 in 5 Will travel less by any means

1 in 3 will travel less by air

Figure 1.5: Highlights from studies conducted by IATA and Inmarsat.

1.5 Aircraft cabin safety

1.5.1 Viral safety of the plane cabin

The airplane cabin is a highly controlled space and an unlikely environment for virus transmission. The design of the standard economy class cabin naturally reduces the spread of viruses, with vertical airflow from ceiling to floor, one-way seats, or backrests limiting the spread of droplets to successive rows (IATA, 2020b). In modern aircraft, cabin air changes every 2-3 minutes, about 20-30 times more often than in most office buildings, and High Efficiency Particulate Air filters (HEPA) capture 99.97% of viruses (Ziemelis, 2020) and are regularly replaced by the airlines. In addition, research by Harvard School of Public Health and US Transportation Command point to a low risk of transmission (Prezant, 2020; Silcott et al., 2020) as well as computational fluid dynamics (CFD) simulations by the leading aircraft manufacturers show a low risk of infection in the cabin. (Airbus, 2020; Boeing, 2020; Embraer, 2020b).

1.5.2 Additional safety measures

Furthermore, since the outbreak, aviation companies and organizations went far to addressing main concerns for sanitization and human interaction (Graham et al., 2020). Implementing measures such as airport screening, wearing masks and increased disinfection is a multi-layered approach to further reduce the risk of infection during air travel. Different precautions are described in detail below.

Social distancing on-board

The staggered boarding procedures adopted by some airlines ensure social distancing when boarding the plane. Some airlines practice leaving the middle seat empty to increase the distance between passengers. However, this solution is not recommended by many reputable aviation organizations (IATA, 2020a) as it has not proven to be effective or cost effective enough for the airlines; it lowers the maximum load factor to 62%, well below the industry breakeven average of 77% (IATA, 2020d), and would therefore require a fundamental shift in airline economics.

Masks

Masks have proven to be a beneficial protective layer on board. This measure has been shown to further reduce the already low risk, reducing the need for social distancing, a practice which would significantly increase ticket prices.

Sequential boarding

Boarding is an activity where physical contact can take place and therefore may facilitate contamination. Controlled boarding with increased social distancing, for example using Reverse Pyramid method, is one way to reduce the risk. (Milne et al., 2020)

Cleaning

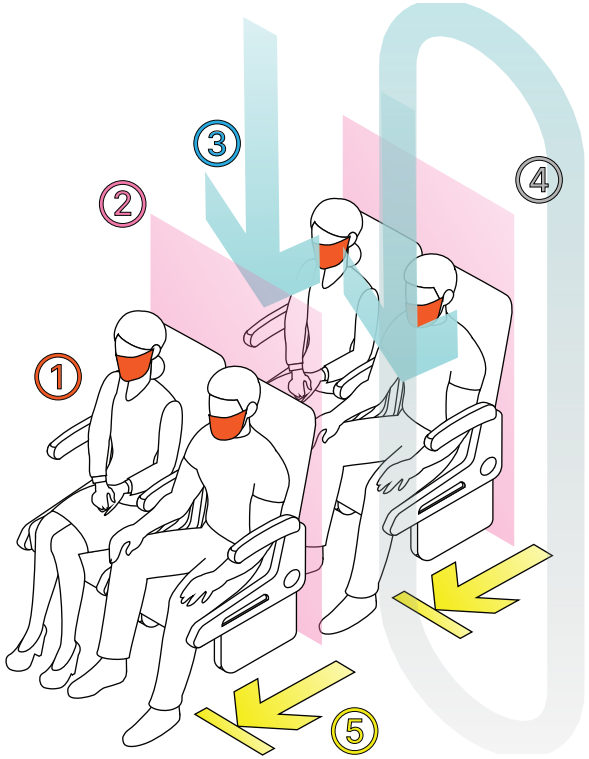
Intensified cleaning practices are implemented by airlines to ensure good hygiene and reduce the number of touchpoints where transmission may occur.

Other measures

Other measures described by IATA Medical Advisory Group (IATA, 2020c) include temperature checks, handing out cleaning wipes, or limiting carry-on luggage.

1.5.3 Discussion

The natural features of the cabin reducing the risk of infection, combined with the airline's efforts to increase hygiene, contribute to a relatively low risk of spreading the virus in the cabin. Therefore, passenger concerns identified by IATA study described in chapter 1.4 support the argument that more needs to be done to improve the way passengers perceive safety in air travel.



1. Masks and face protection
2. Seat backs preventing spread
3. Airflow from ceiling to floor
4. HEPA filters eliminating 99.993% viruses
5. Forward-facing direction

Figure 1.6: Viral safety properties in the plane cabin (IATA, 2020c)

1.6 Flying V aircraft concept

1.6.1 Introduction

Embraer develops short and long haul aircraft, but can learn from Flying V, a concept for an energy-efficient long haul aircraft, regarding pandemic solutions. It has been ideated by Justus Benad for Airbus, and further developed in a joint effort between the Delft University of Technology, KLM airline and a number of aviation companies. The design of this aircraft incorporates passenger cabin, cargo hold and fuel tanks in the wings, forming a shape of a letter V. With current propulsion system, it is set to use 19% less fuel than the Airbus A350, one of the most advanced long-distance airline aircrafts (TU Delft, 2020). Moreover, alternative carbon neutral propulsion systems are studied. By reducing fossil fuel consumption and emissions, this concept shows potential to reduce the negative impacts of air transport, which currently accounts for around 2% of CO2 generated by human activities. (ATAG, 2020). This concept is currently in development and will fly no sooner than by 2045 (Thomas, 2020).

1.6.2 Flying V interior

The unique aircraft shape, apart from the enhanced aerodynamics, provides new possibilities for the cabin arrangement. The interior is conceptualised around passengers' comfort and contains a range of innovative seating solutions, developed to provide a pleasant and user-centered experience for the travelers (Vink et al., 2020).

1.6.3 Staggered seat

Economy class seats in Flying V are a modified version of the Joy seat designed by a seat manufacturer Rebel Aero. They are aligned at 26 degrees angle respective to the oval tube of the wing. This seat arrangement provides an increased leg and shoulder space compared to current typical economy class seat layout. The seat pan is foldable, which allows for a more convenient ingress and regress and additionally allows for taking a more upright position in the seat. Furthermore, the armrests are positioned so as not to cause physical contact between passengers. Due to the limited physical contact between passengers, this seat concept has the potential to provide a higher level of viral safety compared to existing solutions.

Figure 1.7: The Flying V aircraft concept.

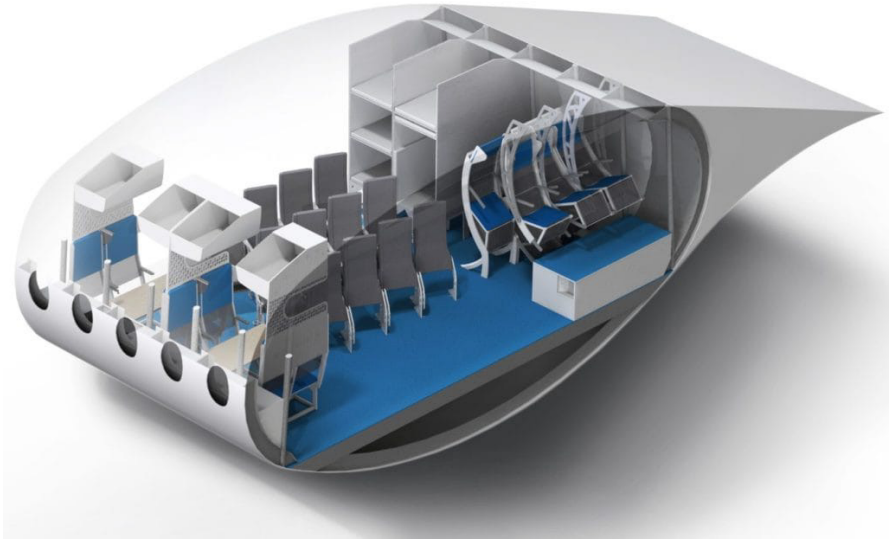


Figure 1.8: A section of the Flying V interior.

1.7 Future trends

1.7.1 Introduction

This chapter provides an overview of the trends that are likely to shape the future of commercial aviation. Emerging trends from websites, aviation magazines and reports were gathered and grouped into four key themes.

1.7.2 Personal

Airlines, striving to win customers and build loyalty, have been increasingly taking efforts to provide personalized services to their customers. (Future Travel Experience, 2019). The outlook for the future shows that the focus will be on improving the in-flight experience, going beyond the physical comfort to provide a more tailored service for each passenger. (Garcia, 2014) Passenger screens and personal devices will be used to deliver more personalized information and entertainment (Fast Future, 2020) Seamless connectivity and on-demand services such as video streaming or games will play an important role in this process. Dining experience will be improved with custom-picked meals served at the time of preference (Lam, 2020).

1.7.3 Clean

As concerns about hygiene in shared modes of transport increase, there will be a need to minimize the risk of infection throughout the journey. This can be done by improving communication regarding safety measures, increasing cabin sanitation, or by providing personal care products (Fast Future). Minimizing physical touchpoints while traveling will be an important step contributing to a more "contactless" and hygienic experience. Smart devices will likely in the future make it possible to increase cleaning efficiency at the airport and in the aircraft cabin, using heat, fogging or UV light for disinfection (PriestmanGoode, 2020). Surfaces will be made of antimicrobial materials, and the emphasis will be put on minimizing the "dirt traps" to prevent bacteria build-up. The development of clear and understandable communication channels for the measures taken will increase the safety of both passengers and cabin crew and increase confidence in flying (Lamb, 2020). As a result, some airlines will gain a competitive advantage if they provide healthy customer service (Amankwah-Amoah, 2020).

#sustainable

1.7.4 Sustainable

Accounting for about 2% of all man-made CO2 emissions globally, the aviation industry has a significant impact on the natural environment. In the wake of global social and political developments such as the Paris Agreement and the Sustainable Aviation Pact, green practices are likely to emerge as a key long-term aviation goal. The trend towards sustainable practices is growing across the industry (CAPA, 2020). Companies that follow these practices tend to be favorable among customers and attract new talent (Acquah et al., 2020). An additional benefit of reducing the amount of waste and pollution is the reduction of operating costs (Lamb et al.). Companies that will make efforts to support environmental practices in the aftermath of the pandemic are likely to recover from a better reputation and better relationships with key stakeholders (Amankwah-Amoah, 2020). Reducing fuel consumption, offsetting carbon emissions or using more environmentally friendly materials will increasingly be used to reduce the harmful impact of aviation on the environment.

1.7.5 Digital

The experiences of a pandemic will also likely propel the shift in personal infotainment. Passengers will demand more digitalization of in-flight services in order to create a more “contactless” experience with fewer touchpoints (Inmarsat, 2020). The rapid pace at which new technologies are developed may cause on-board multimedia systems become obsolete quickly. Therefore, there is likely to be an increase in the number of "bring your own" devices (PriestmanGoode), which brings benefits in terms of airline weight savings, reduced fuel consumption and maintenance, and potential cost savings for passengers. Digital technologies will empower users by allowing for a higher degree of entertainment and productivity during the flight. Airlines will increasingly introduce in-flight entertainment services that passengers can access through Wifi on personal smart devices. Furthermore, as Virtual Reality and Augmented Reality technologies become more efficient and affordable, they may prove desirable for the airlines that want to provide unique experiences for the passengers.

#digital

Takeaways from this chapter

- Restoring passengers' confidence in flying will be crucial to drive the recovery of the aviation industry.
- Passengers make decisions based on a mix of facts and fears, and their judgement of safety may be misleading.
- Concerns over viral safety will continue to be relevant after the pandemic subsides.
- The risk of infection on the plane is low, and airline companies have gone far to address on-board viral safety of passengers.
- Aviation of the future will likely be personal, clean, digital and sustainable.
- The Flying V concept has the potential to become a more sustainable and safer alternative to current aircraft.

Chapter 2

Assignment and approach

This chapter describes the general approach used to complete this thesis assignment. First, the results of literature research are translated into a problem statement and research questions. Next, an overview of stakeholders and the timeframe are discussed. This is followed by an explanation of the project's layout and the Double Diamond - a method used to achieve the completion of this graduation project.

2.1 Problem statement

1.4.1 Project scope

Findings from the previous chapter point out to a need of improving the perception of viral safety in air travel. The aircraft interior is a place where highest virus concerns are present. Therefore, the scope of this project is the passenger's perception of viral safety when travelling in the aircraft cabin. The first step towards improving perceived viral safety is to identify and reduce the aspects of the cabin experience that evoke strongest concerns. Furthermore, as fear can be evoked by social input, the passenger on-board behavior will be studied to identify the behaviors that may reduce the overall feeling of safety.

As passengers have different perceptions of safety than aviation professionals, exploring both points of view may help identify and reduce the gaps between the real and perceived safety. Therefore, both the passengers (general public) and flight attendants (aviation professionals) will be studied in this graduation assignment.

This project aims to advance the development of the Flying V, an aircraft that is expected to be operational no earlier than 2045. However, given the potential short-term benefits that this project may have for aviation, the feasibility of its implementation on current aircraft will be considered. The project will take into account the context of long haul flights, but due to data availability, the research will be conducted on European short haul and medium haul flights.

1.4.2 Solution space

The design solution envisaged as an element of the cabin interior will take into account the context of airline passengers during and after the pandemic. The proposed solution will aim to increase the perceived safety regarding airborne virus threats. Furthermore, as the product is intended to be part of a commercial aircraft, viability for the airline and producibility will be considered. In addition, the resulting design will be optimized to minimize the environmental impact.

Project timeframe

This project is being developed during an ongoing pandemic, which is also the context of the study. New developments may influence the perceived viral safety and therefore affect the reliability of the collected data. Overview of the important events throughout the project is presented in the figure 2.2.

1.4.3 Research questions

With the purpose of making the research process more specific and get a better understanding of the factors influencing passengers' perception of on-board viral safety, research questions and sub-questions are created in the Figure 2.1.

Research questions

1. What perceptions of viral safety are present in typical activities in the cabin during a pandemic?
1.1 During which activities the feeling of viral safety is the lowest?
1.1 Which activity is the most critical for passengers to tackle for increasing perceived viral safety?
2. What factors inside the cabin decrease passengers' perception of viral safety?
2.1 What undesired on-board behaviors occur among passengers when flying during a pandemic?
3. What are the features in the interior that increase the perceived safety among passengers?

Figure 2.1: Research questions and sub-questions for this thesis assignment.

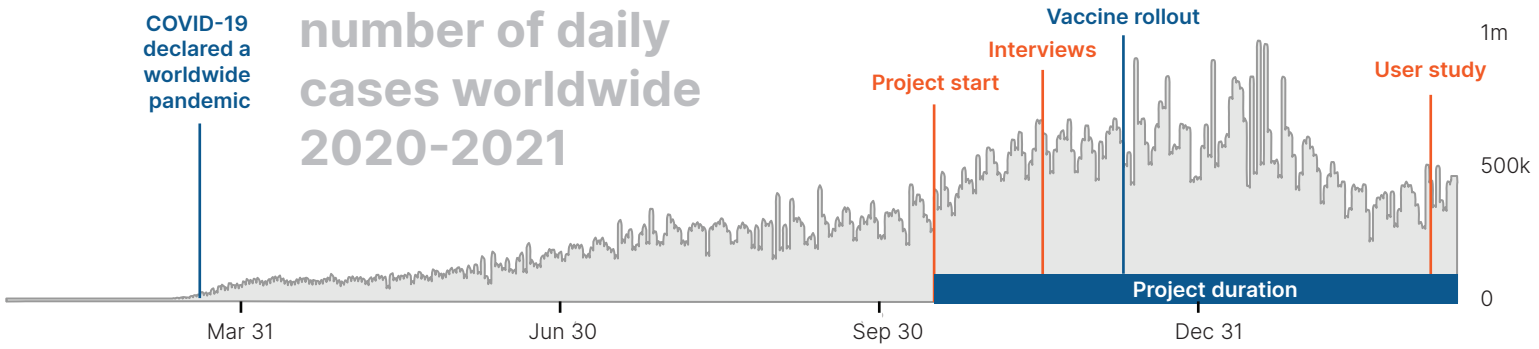


Figure 2.2: The timeframe of the project with respect to the SARS-CoV 2 pandemic developments (Statista, 2020).

2.2 Project layout

To answer the first two research questions, the first phase of the project will focus on creating an overview of viral safety perceptions among airline travelers during a pandemic. For this purpose, interviews with passengers and flight attendants as well as consultations with industry professionals will be conducted. The results obtained in this way, together with the findings from the literature, will provide an overview of problems related to the perception of viral safety. In the second phase, the results will be translated into a product concept embedded in the interior of the aircraft. An overview of different stages of the project is provided in Figure 2.3.

2.2.1 Assignment

To answer the research questions in the previous section, the following design task was created taking into account the solution space:

To develop a proof of concept for an aircraft interior element that tackles the most concerning moments in the aircraft cabin to increase passengers' perceived viral safety when travelling.

2.2.2 Embraer's wishes

During the meeting with Embraer, the key guidelines for the project were defined. It was decided that this project would be developed as part of the Future Journey Roadmap, a project initiated to address future perspectives of passenger air travel and to explore opportunities for Embraer to develop new mobility solutions. Therefore, this project will be developed within a scope that considers the entire journey from A to B, while focusing in particular on the passenger experience in the aircraft cabin.
Furthermore, it has been agreed that the product developed as part of this graduation assignment should be consistent with the environmental goals of Embraer, represented by the motto: "We build a sustainable future". (Embraer, 2020c). Therefore, an important goal of this project will be the low environmental impact of the solution. Some of the initial recommendations for a physical product include the low weight of the solution and the use of environmentally friendly materials.

In addition, Embraer wants to take an active position to accelerate aviation recovery from the negative effects of the coronavirus pandemic. Therefore, a recommendation in any product considerations is to address the current context of an ongoing pandemic, taking into account a low cost and implementability.

2.2.3 Project Scope

Figure 2.4 shows the scope of the project explaining Embraer's main current and future goals in the timeframe. In addition, it identifies the stakeholders involved - the airline as the main actor addressed in the current context and TU Delft, which is involved in the development of the Flying V project, as a potential beneficiary of the resulting product.

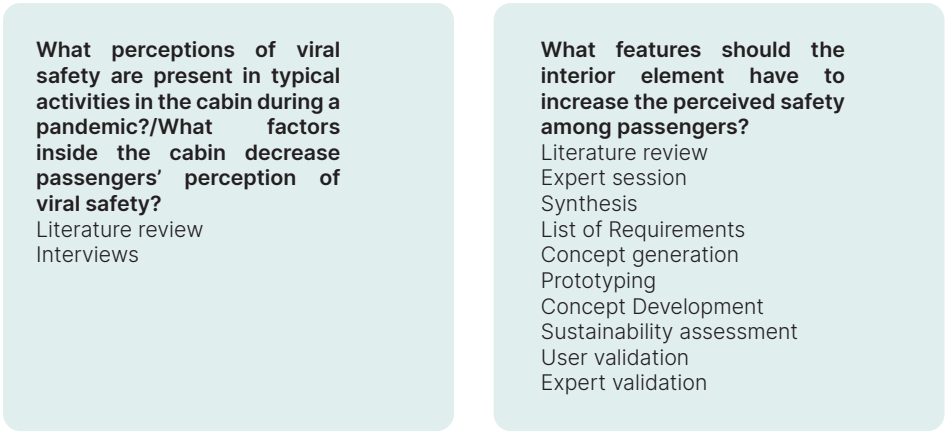


Figure 2.3: Approach used to answer research questions.

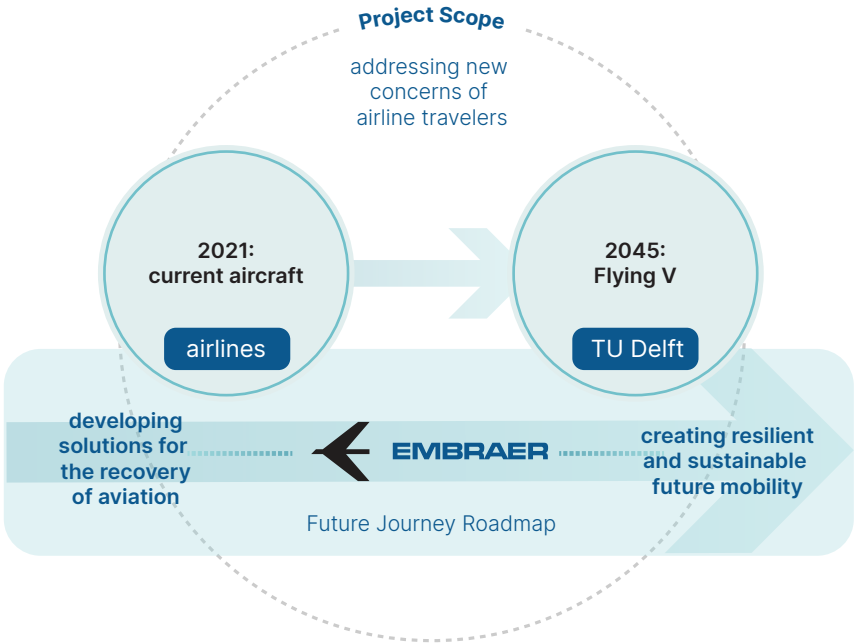


Figure 2.4: Overview of the project's scope and stakeholders.

2.3 Systems and stakeholders

Product design is interdisciplinary in nature. The holistic approach treats the product as part of a larger, interconnected system, which allows for a better understanding of the impact of this product on its environment and stakeholders. A process that involves a holistic approach often significantly improves the outcome (Ahmed, 2014). For this, an overview is created in the Figure 2.5, taking into account key systems and stakeholders and defining the relationships that the product has within them. This will allow a broader understanding of the context throughout the project and the formulation of comprehensive requirements for a more successful outcome.

User
Travelers will be the main users of the product, therefore their relationship to the product, especially perceived safety, travelling experience and viral safety will be the main scope of this graduation project.

Interior
The interior of the aircraft is a strictly controlled environment with a limited space, and each product implemented in it must meet various standards and regulations. In this project, cabin safety experts and product engineers will be consulted to ensure a feasible result.

Airlines
Airlines will be a key stakeholder responsible for buying and handling the product. Their interests, mainly regarding logistics, maintenance, reputation, as well as viability factors, such as return on investment, turnaround time, and fuel use will be addressed in this project.

Supply chain
Feasibility is an important aspect of a mass-produced product. To this end, the product will be designed taking into account mass production techniques and materials, and will be consulted with industry experts during the product development phase.

Natural environment
This project will consider the product's environmental impact. Efforts will be taken to optimize weight, material use, recyclability, end-of-life and CO2 footprint to ensure a controlled product life cycle and minimize its impact on the natural environment.

Parties involved
Figure 2.6 provides an overview of the main organizations, companies and experts involved or consulted within this project.

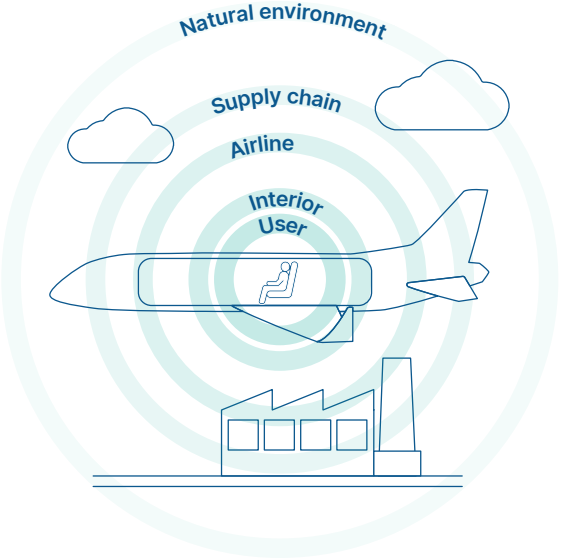


Figure 2.5: Overview of the systems addressed in this project.

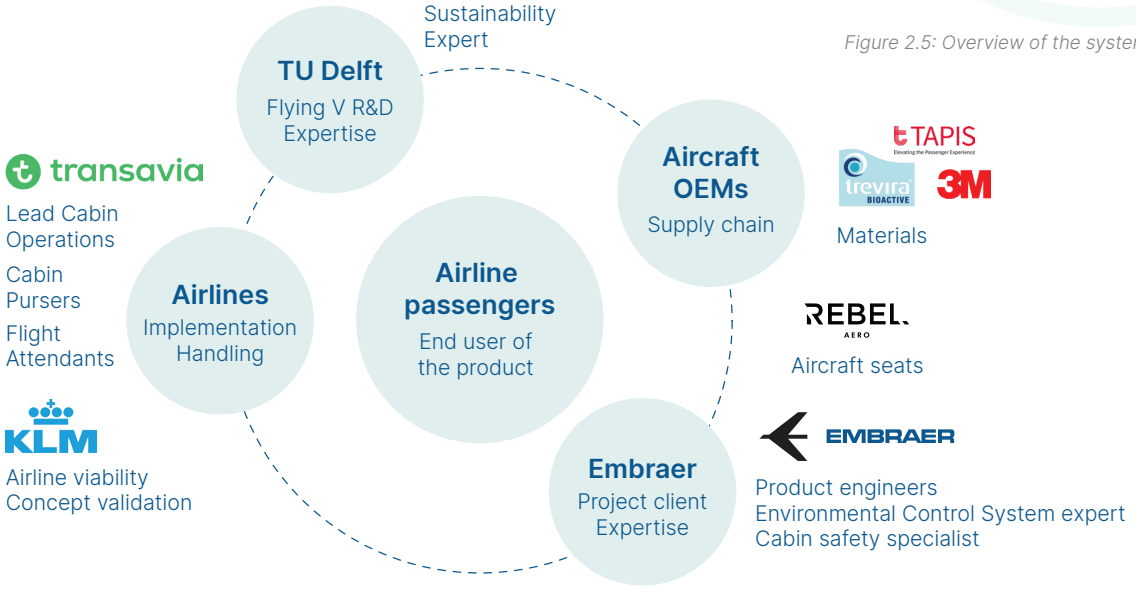


Figure 2.6: Overview of partners and advisers in this project.

2.4 Method

1.6.1 General approach
To accomplish the assignment within the given timeframe, this project follows the Double Diamond method (Design Council, 2019), which distinguishes the project into different phases of a divergent and convergent approach: Discover, Define, Develop and Deliver. Different steps of the project within this method are shown in Figure 2.7.

Phase I: Discover
The Discover phase will aim to understand the new developments in air travel that have arise as a result of the COVID-19 pandemic. To answer the first two research questions and sub-questions, this phase will focus on understanding what perceptions and behaviors passengers developed while traveling during the pandemic and how this influenced the overall perception of cabin safety. For this, interviews will be conducted and findings will be consulted with industry professionals to identify the opportunities for the project. Input from relevant stakeholders: passengers, flight attendants and experts will support the Problem Definition and guide the concept development in the Define phase. In addition, as new pandemic events may affect the project throughout its time frame, new findings from reputable sources will be followed, namely WHO, The Guardian and IATA websites, New York Times daily brief, Aircraft Interiors International magazine, and various scientific journals.

Phase II: Define
Next, in the Define phase, the collected data will be synthesized in order to narrow down the scope of the assignment and establish the requirements for developing the product. This phase will conclude with problem definition and the vision for the final product.

Phase III: Develop
During the development phase, directions for the final product will be explored. Concepts will be generated and prototypes will be tested with users to select the final product direction.

Phase IV: Deliver
In the final phase, Deliver, the selected solution will be further developed as a proof of concept and visualized as part of the aircraft interior. The final part of this phase will include a validation by experts and a reflection on the research questions, requirements and the design process.

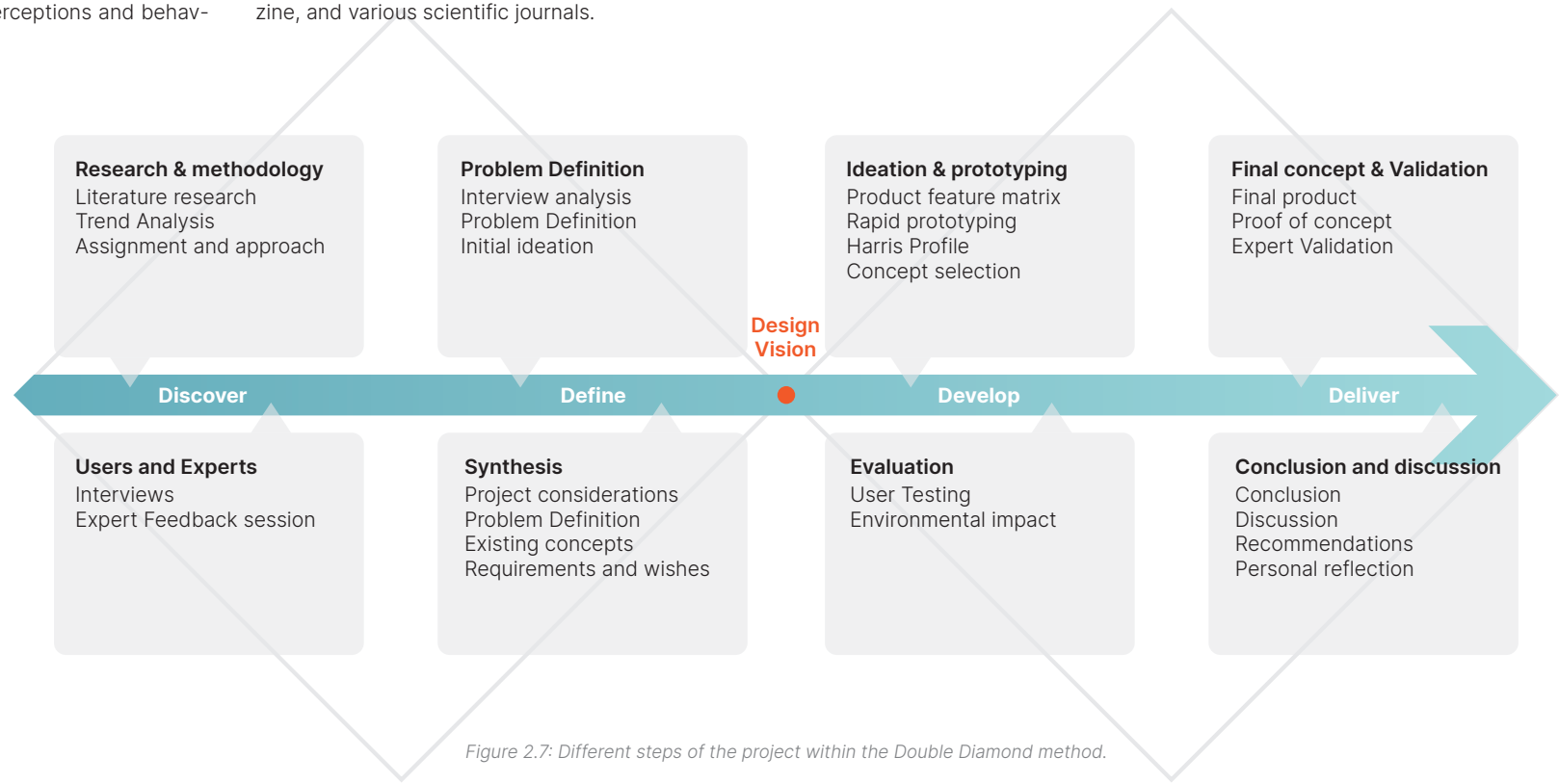


Figure 2.7: Different steps of the project within the Double Diamond method.

Takeaways from this chapter

- The scope of this project is the passenger's perception of viral safety when travelling in the aircraft cabin.
- Other aspects such as interior safety, producibility, airline viability, and sustainability of the final product will be considered.
- Experts from different organizations will be consulted to ensure a relevant result.
- This project follows the Double Diamond method.

Chapter 3

Interviews

In order to develop a product that tackles the main viral safety concerns among airline passengers, the need for a study of passenger safety perceptions has been identified. This is to understand the underlying concerns of passengers and the resulting low willingness to fly. This chapter describes ten interviews that were conducted with passengers and flight attendants who experienced flying during a pandemic.

3.1 Introduction

3.1.1 Method

Ten interviews with recent flyers were conducted to gain a better insight into the viral safety concerns and behavior on board. As passengers may have different judgements of safety than aviation professionals, both groups were interviewed to obtain richer insights. Semi-structured interviewing method was chosen for conducting the study, which allows for asking open-ended questions and gathering in-depth accounts of people's experiences (Adams, 2015). The research questions formulated for this study are provided in the Figure 3.1.

3.1.3 Participant selection

Recruitment took place via online channels, mainly e-mail communication and advertisements on Linkedin and on Facebook groups for stewards. A financial incentive of €10 was offered for taking part in the study. The participants were selected using Convenience Sampling (Miles, Huberman & Saldaña, 2014). The requirement for all participants was that they had flown both before and during the COVID-19 pandemic (before and after March 2020). Participants must have been 18 years or older, able to buy a ticket on their own (revenue passenger) or work for an airline (flight attendant). The full list of participants is provided in Table 1.

3.1.4 Research ethics

The study was approved by the TU Delft Human Research and Ethics Committee (HREC). Prior to the interview, each participant completed an online consent form via Google Forms (Google LLC).

3.1.2 Research questions

1. What perceptions of viral safety are present in typical in-flight activities during a pandemic?
2. Which activities are the most important to address for increasing the perceived viral safety?
3. What undesired on-board behaviors are present among passengers when flying during a pandemic?
4. What aspects of the journey inside the cabin decrease passengers' perceived viral safety?

Figure 3.1: Research questions addressed in the interviews.

Table 1: Details of the interviewed participants.

#	Type	Age range	Sex	Co-pass.?	Last flight	Flight date
1	Passenger	26-35	F	No	Netherlands-Turkey	Oct 2020
2	Passenger	26-35	F	No	Poland-Sweden	Sep 2020
3	Passenger	18-25	F	Yes	Netherlands-Portugal	Jun 2020
4	Passenger	26-35	M	No	Netherlands-Taiwan	Oct 2020
5	Passenger	26-35	M	Yes	Poland-Scotland	Aug 2020
6	Passenger	26-35	F	No	Netherlands-UK	Oct 2020
7	Purser	46-55	F	N/a	Netherlands-Morocco	Nov 2020
8	Purser, unit coach	36-45	M	N/a	Netherlands-Spain	Sep 2020
9	Purser	36-45	M	N/a	Netherlands-Portugal	Oct 2020
10	Purser	26-35	M	N/a	Netherlands-Spain	Nov 2020

3.2 Procedure

3.2.1 Collecting data

Interviews were conducted online using Google Hangouts (Google LLC). Audio was recorded via a smartphone using the Voice Memos software (Apple Inc.). For better clarity of the recording, an external Bose Revolve speaker was used. See Figure 3.2 for the interview setup. The collected recordings were transferred to a personal computer. Audio files were transcribed online using IBM Watson (IBM) automatic speech-to-text software, resulting in raw text, which was checked against audio recordings and manually edited to reduce transcription errors and improve clarity.

3.2.2 Procedure

The interviews were guided by an interview guide with four general points of discussion (see Appendix C), described in the Figure 3.3. In the first part, introductory questions were asked, aming at collecting the demographic data and explore the motivations behind flying during the pandemic. In the second part, in order to answer the first research question, participants were asked to describe their experiences during nine typical activities in the cabin. To facilitate the analysis of qualitative data (see Appendix D), passengers were asked to use codes to describe their level of perceived safety, ranging from very unsafe to very safe. The third discussion starter prompted respondents to describe their experiences with other passengers in order to investigate what undesirable behavior on board affects perceived safety. The fourth point supported the discussion about the new attitudes towards flying during and after the pandemic, which may show how COVID-19 has affected future readiness to fly.

3.2.3 Data analysis

In order to answer research questions, transcripts were analyzed using Reflexive Thematic Analysis (Braun, V. & Clarke, V., 2006), which allows for identifying meaning patterns in qualitative data (The University of Auckland, n.d.). To facilitate the process, Quirkos software was used (Quirkos), which allows for coding and grouping interview transcripts into topics. The analysis was carried out in accordance with the steps of the Thematic Analysis method:

1. Familiarizing
The transcripts were examined by reading and comparing with audio recordings and interviewer's notes.

2. Coding
Text fragments identified as important for the research were selected and succinct labels (codes) were assigned, as shown in Figure 3.4. The process used an inductive approach where codes and topics are guided by the content of the data (The University of Auckland, n.d.).

3. Generating initial themes
The codes were examined for recurring patterns and themes, and combined into groups with similar meaning (eg, "General Anxiety"), as shown in the Figure 3.5 on the next page. The resulting themes were compared to the dataset for relevance and edited if necessary.

4. Defining and naming themes
Each topic was assigned an informative name according to the scope, as shown in Figure 3.5 on the next page.

5. Writing up
The analysis report was generated using Quirkos software (Appendix E). The results of the analysis were reviewed and compared with literature study from Chapter 1.

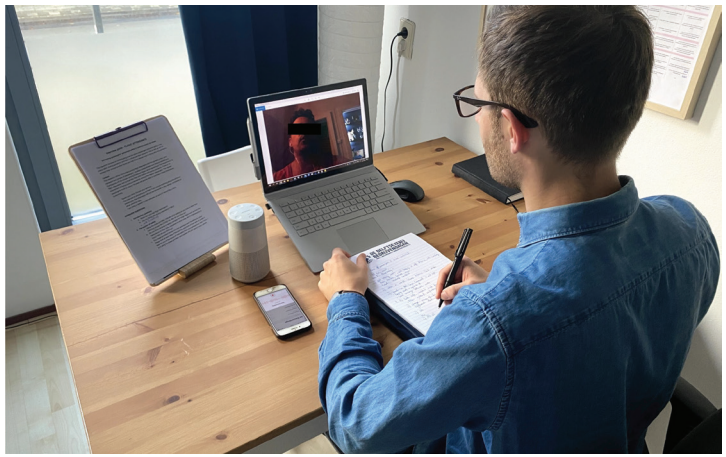


Figure 3.2: Interview setup.

Figure 3.3: Points of discussion used in the interviews.

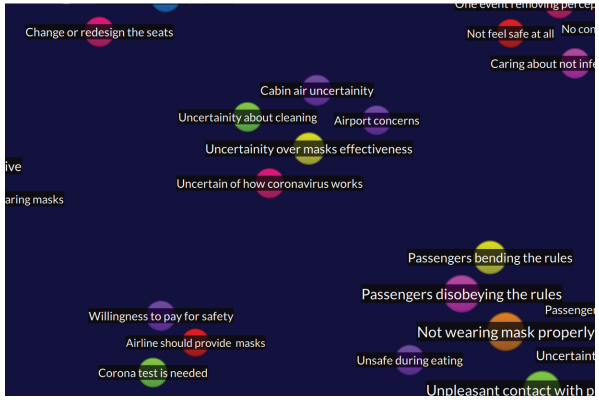


Figure 3.4: Clustering collected data in Quirkos software.

3.3 Data analysis

The graph on this page presents the steps taken to analyze the data, and provides an overview of the themes and clusters created.

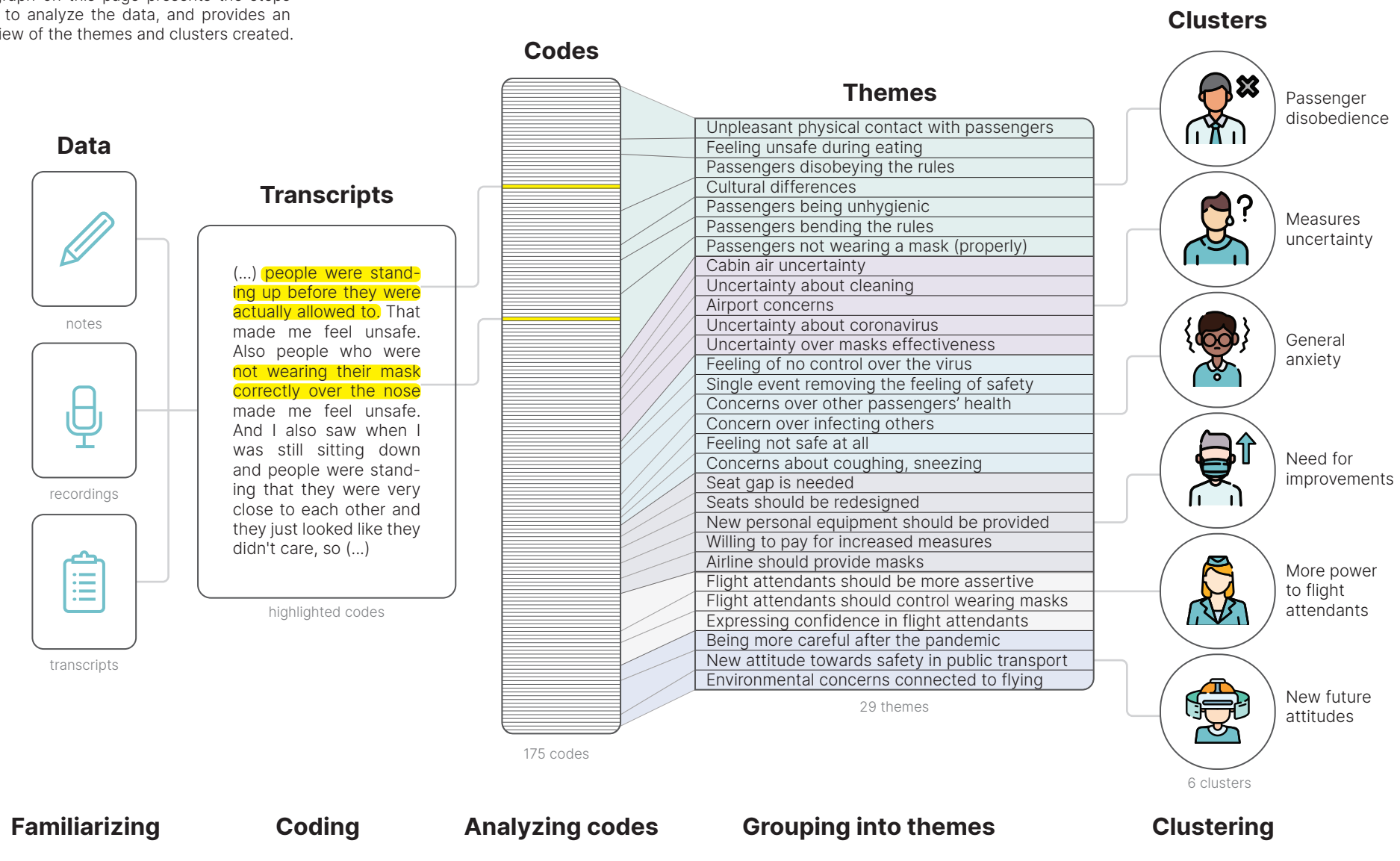


Figure 3.5: Processing collected data using Thematic Analysis.

3.4 Qualitative results

3.4.1 Introduction

To answer the third and fourth research questions, **"What factors inside the cabin reduce passengers' perception of viral safety?"** and **"What undesired on-board behaviors are present among passengers when flying during a pandemic?**, six themes were defined in the analysis, each one representing the most recurring problems in viral safety when travelling. This chapter describes the findings in detail.

3.4.2 Passenger behavior concerns

A prominent finding is that the perception of safety seems to be strongly influenced by the behavior of other passengers in the cabin. Many incidents were mentioned where other passengers disobeyed or did not fully comply with the rules, which was a cause for concerns. Among the most frequently cited problems were the misuse or lack of masks, both intentional and unintentional. Several events were described where participants experienced unpleasant interactions with other passengers, often involving physical contact. The disembarkation process has been cited as one such event that is particularly worrying. Strong anxiety was also associated with eating - this moment was described as particularly stressful, as it involves the necessity to remove the mask. For the passengers that sat alone in a row, concerns regarding eating were minimal. Other comments related to the unsanitary behavior of passengers and cultural differences, which were described as the cause of different behavioral tendencies among passengers.

3.4.3 Measures uncertainty

Passengers seem to be unsure about how some measures work. The main concerns relate to the effectiveness of the mouth masks, cabin air quality and the transmission behavior of the coronavirus. Insufficient knowledge or lack of confidence in these aspects caused some participants to develop their own view of how the measures work and to adopt overprotective attitudes during the flight. Some participants decided to undertake additional safety measures on their own, such as disinfecting the entire seat with the provided wet tissue.

3.4.4 General anxiety

General concerns are present that cause anxiety throughout the flight. Mentioned was uncertainty about the health of other passengers, concerns about coughing and sneezing, or fear of infecting others. Several passengers mentioned that a one-off incident, mainly involving physical contact with other passengers, had a strong impact on their overall sense of security.

3.4.5 A need for increased measures

There is a clear need for improving safety measures which have been cited as an important factor influencing the willingness to fly. Several solutions have been proposed to redesign the seats, provide personal protective equipment on board or to extend the scope of coronavirus testing. Several participants said they would accept a ticket price 10-30% higher if the airline tightened security measures for the most concerning parts of the trip.

3.4.6 More control by flight attendants

It was repeatedly mentioned that flight attendants have an influence on the feeling of security. Participants described several situations in which flight attendants were not sufficiently assertive in communicating with passengers, which resulted in disobedience. On the other hand, many participants expressed confidence and trust in the flight attendants - mentioning them as the persons with authority on the plane. While flight attendants appear to be generally respected, more effort should be made to control behavior on board. In reputable airlines, passengers described the measures taken by cabin crew as more than satisfactory.

3.4.7 New future attitudes

Most of the participants said the coronavirus pandemic will shape their attitude towards safety in the future. Responses were about being more cautious in public spaces such as public transport and requiring increased cleaning and social distancing after the pandemic has passed. In contrast, several participants stated that the pandemic does not significantly affect their willingness to fly and that their concerns will disappear as soon as the pandemic is over. Finally, several participants underlined the importance of caring for sustainability in their future flying decisions.

3.5 Levels of perceived safety

To answer the first research question, **"What perceptions of viral safety are present in typical activities in the plane cabin during a pandemic?",** passengers were asked to assess their perception of safety using codes ranging from "very unsafe" to "very safe". Responses of passengers are shown in Figure 3.6, and an experience line is drawn to indicate an average level of viral safety. Some activities were not rated by all respondents because they did not take part in them.

The second research question is "**Which activities are the most important to address for increasing the perceived viral safety?"** To define the most critical moments to be tackled, passengers were asked to select their top three most concerning moments in the cabin. The criticality level is based on the number of participants that included these activities in their top three most concerning moments. For comparison, see figure 3.6.

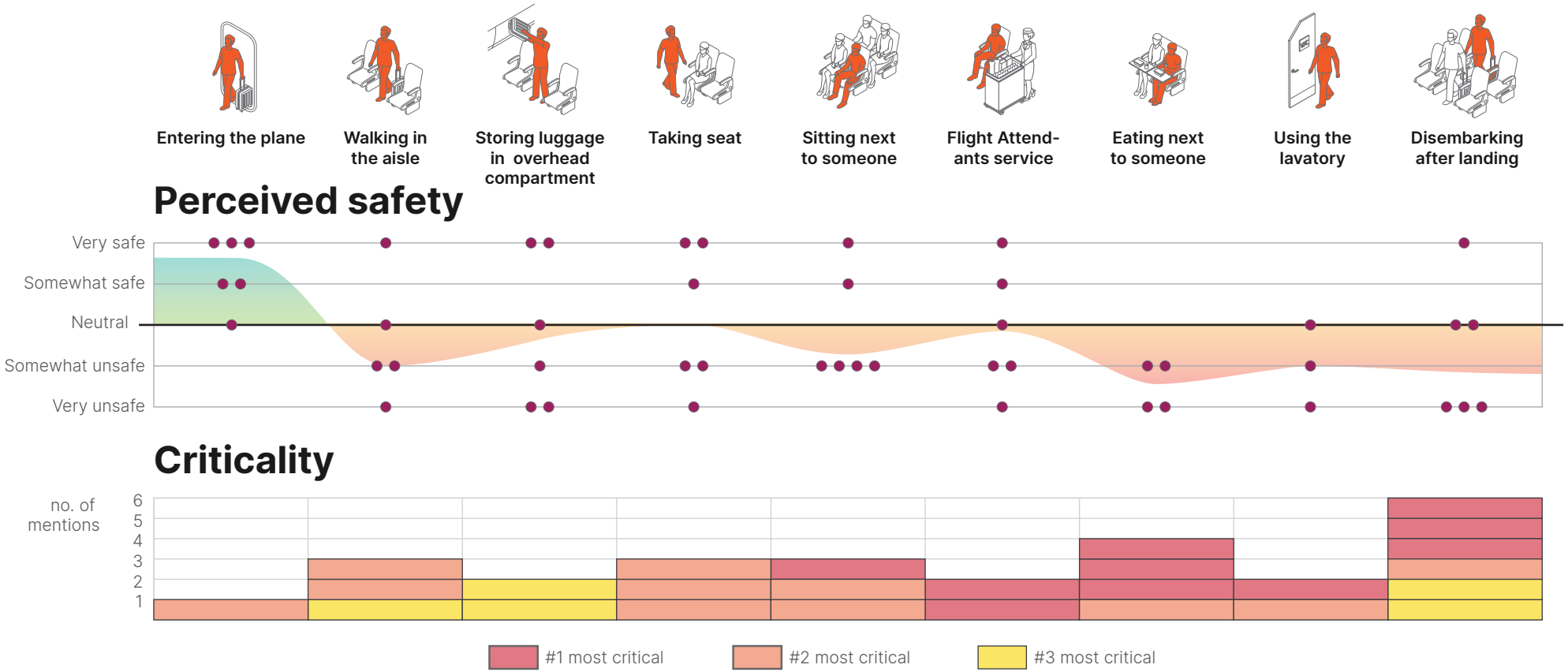


Figure 3.6: Processing collected data using Thematic Analysis.

3.6 Discussion

3.6.1 Discussion

This section discusses the conclusions of the interviews and compares them with the literature research from Chapter 1.

1. Disobedience

The most frequently cited reason for the low sense of security was the inappropriate behavior of passengers. This is in line with Robson's finding that people usually demand obedience in social situations during a pandemic (Robson, 2020). This is important for research as the behavior of other people on board appears to be a major concern for many passengers. Therefore, when increasing the perceived safety, it may be important to consider the behavior of other travelers.

2. Measures uncertainty

Interviews show that lack of awareness or uncertainty about safety measures causes overprotection and the development of subjective views on how measures work. This builds upon the finding that passengers often base their perceptions not only on facts but on a combination of facts and fears (Mauro, 2019). In addition, the data collected supports a study by IATA that revealed uncertainty about the cabin air as the second biggest problem in the aircraft cabin. The same study revealed that "seeing airplane sanitization" is one of the five most important measures to improve perceived safety while flying. Consequently, increasing passenger awareness regarding safety measures is likely to result in higher perceived safety.

3. Need for increased measures

Interviews show that there is a clear need for increased measures to alleviate the anxiety in the aircraft cabin. This is in line with IATA study, where participants selected different improvements of safety measures as two of the top three ways to increase the sense of viral safety.

4. General anxiety

The interviews revealed passengers' continued anxiety during the flight, even without recognizing any direct threats. These results build upon the findings of Robson, who describes that people can have anxiety without being directly exposed to the threat. This is important in research as viral safety concerns are likely to become a part of the travel experience even with no apparent threat, and thus affect passenger well-being even after the pandemic has resolved.

5. More power to flight attendants

The collected data provides new insight into the relationship between passengers and flight attendants during a pandemic. Although flight attendants seem to have authority among passengers, more control and assertiveness is expected from cabin crew in order to build a greater trust among passengers.

6. New future attitudes

Some participants expressed new attitudes towards safety and environmental impact of aviation after the pandemic. This is in line with the analysis on future trends in chapter 1.7 that describes sustainability and hygiene as increasingly important factors in future travel choices (Amankwah-Amoah; CAPA)

3.6.2 Levels of perceived viral safety

The collected data provides an overview of how levels of perceived safety vary in typical activities performed in an airplane cabin. The main observation is that some moments in the cabin are much more disturbing than others. This is important for research because prioritizing activities with lower perceived safety may yield more relevant results. Further assessment of the collected data may help define the most concerning moment in the plane cabin.

3.6.3 Criticality

The criticality measurement revealed that there are activities in the cabin that, while having a low perceived safety rating, are not necessarily critical to the majority. This is because some passengers were not involved in certain activities, such as eating or using the lavatory. The results obtained do not fit the theory that sitting next to an infected person is the highest concern when travelling (IATA, 2020a). In this study, greater concern was seen when disembarking and eating. This is important for research as solving the most critical problems is the scope of this thesis assignment.

3.6.4 Limitations and recommendations

The interviewing procedure was limited by the general coronavirus measures adopted by HREC. The interviews were conducted online, which limited the possibility of interactions between the interviewer and the participant. In addition, as concerns can be difficult to retrieve and formulate for the past events (Sanders & Stappers, 2008), the reliability of the data may have been compromised. In addition, respondents may not be able to remember some details of their experience. Although participants were asked to express their honest views, their responses may have been inaccurate due to the inability to comprehend what "perception" really is. Therefore, their responses may not fully reflect their observations. Testing with participants during the flight or shortly after it happened may provide more accurate results. No interviews were conducted with "early elderly" (65-74) or "elderly" (75+) age groups (Orimo et al., 2006), which are groups of an increased health risk in COVID-19. This has an impact on generalizability as these groups may have different perceptions of viral safety. Further research is recommended to investigate the relationship between age and perceived safety.

As the coronavirus pandemic continues, new developments could affect the reliability of the data. Additional post-pandemic studies can show whether attitudes have remained the same or have changed. A large survey may be beneficial for obtaining more quantitative results.

Takeaways from this chapter

- Increasing passenger awareness regarding safety measures is likely to result in higher perceived safety.
- There is a clear need for increased measures to alleviate the anxiety in the aircraft cabin.
- Viral safety concerns may affect passenger well-being even after the pandemic has resolved.
- More control and assertiveness is expected from the cabin crew.
- New attitudes towards the safety and environmental impact of aviation will likely influence the decision to fly in the future.
- Some moments in the cabin are much more disturbing than others.
- Eating and disembarking were the most concerning activities described in the interviews.

Chapter 4

Expert ideation session

In this chapter, the data collected in the interviews was discussed with industry experts. The purpose of the session with experts was twofold: first, to allow for an exploration of the possibilities for this graduation assignment, and secondly, to come up with feasible solutions for solving the current concerns regarding virus safety in the aircraft cabin.

4.1 Expert ideation session

4.1.1 Background

Interviews with recent flyers provided an understanding of the viral safety concerns in the cabin. Additionally, some respondents ideated solutions that, in their opinion, would increase the perception of safety. As the recommendation of Embraer is to consider the current aircraft safety in this project, a need was identified to collect the perspective of aviation experts. For this, Emraer's engineers, flight attendants and passengers were invited to an online session to ideate and evaluate different concepts for improving the perception of safety.

4.1.2 Method

The aim of this session was to gather different perspectives from aviation industry professionals to create short-term recommendations for airlines (current aircraft) and explore the possibilities for future aircraft (Flying V). The criteria for conceptualization and voting are shown in Figure 4.1. To conduct the session, Co-Creation method (Sanders & Stappers, 2008) was partially used, which allows participants to familiarize themselves with the collected data, generate ideas and collect feedback on concepts in a group discussion. For safety reasons, this method was adopted for helding online, which gave limited possibilities for interaction compared to a regular session as described in the method.

4.1.3 Participant selection

Participants were invited individually by email with the help of Embraer. A total of nine participants accepted the session invitation, however due to time constraints, only six experts participated in the online session throughout the entire duration. Participants who did not attend in the online session were asked to submit feedback via email.

4.1.4 Ethical considerations

Prior to the session, participants were asked to fill in a consent form. Moreover, the session procedure was consulted with the data administrator for compliance with the Human Research Ethics Committee.

4.1.5 Procedure

The session consisted of five parts, the first two of which were performed independently by the participants prior to the meeting and the remaining three were conducted online (see Figure 4.2). After completing the consent form, information guides were sent by e-mail to inform participants about the PVS Challenges (Appendix F). Next, the participants were asked to complete an online survey with ideas for tackling the above-mentioned challenges. The resulting proposals were combined with previously generated concepts and presented at an online meeting. For each concept, there was a voluntary discussion in which different points of view of experts were compared. At the end of each challenge, participants were asked to vote on pre-printed voting sheets (Appendix G) to define their preferences in an orderly manner. The voting criteria were 'feasibility' and 'best in category', as explained in figure 4.1. Voting sheets were collected from participants by e-mail and compared with the speaker recordings and notes.

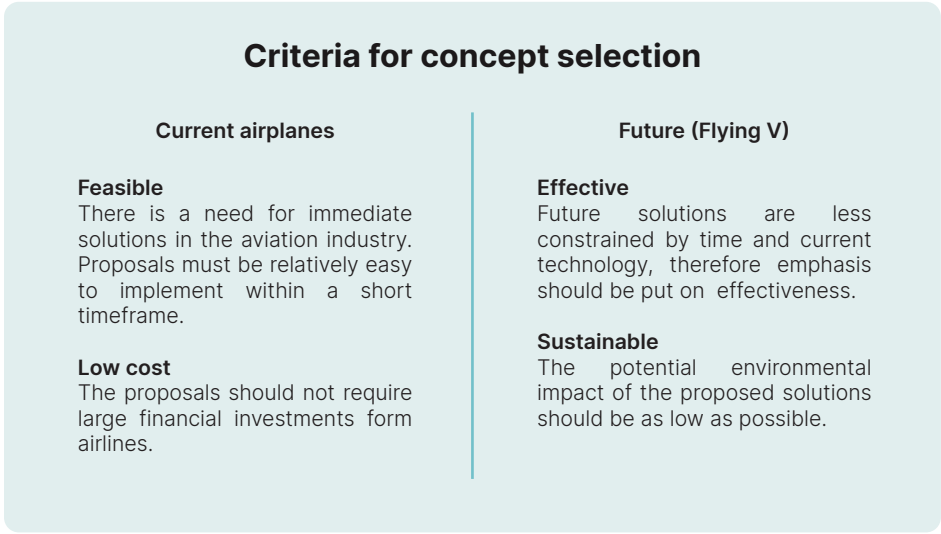


Figure 4.1: Criteria for voting on concepts during the expert feedback session.

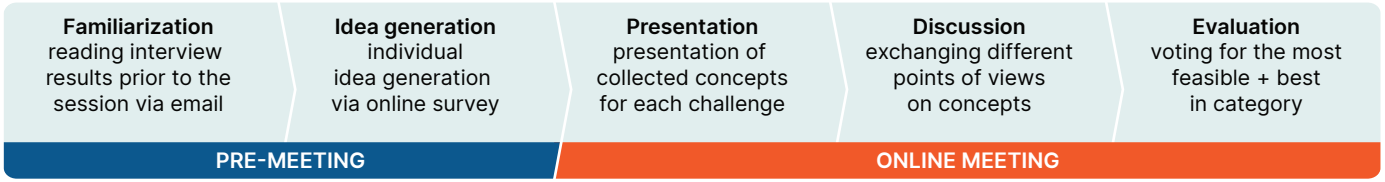


Figure 4.2: The procedure of the Expert meeting and actions taken in each section.

4.2 Results

This session resulted in a set of proposals for current airlines on how to increase the PVS, as well as an initial ideation on the opportunities for this graduation assignment. In the discussion, several new concepts emerged, which were added to the voting sheet. By combining findings from recordings, speaker's notes, and experts' votes, recommendations were selected on tackling the perception of safety in the short term. The ideas selected by experts' votes are presented in Figure 4.3.

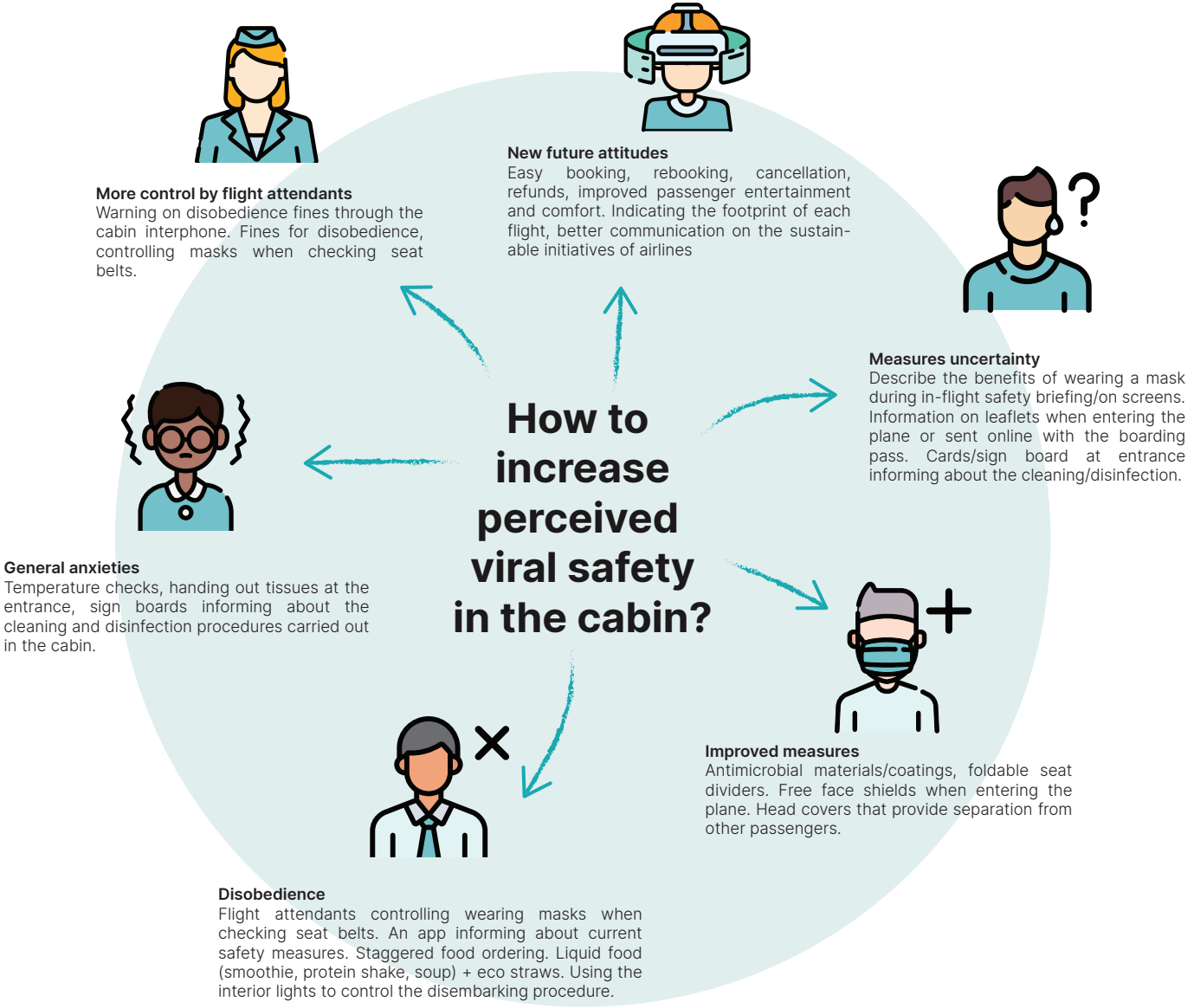


Figure 4.3: Selected ideas from the session voted on by the experts.

Takeaway from this chapter

- The Co-creation Session method was adapted to facilitate an ideation with experts for solving the current problems regarding viral safety in the aircraft cabin.

Chapter 5

Problem definition

This chapter presents a model for analyzing the results of interviews in order to identify the most significant problems in the aircraft cabin that should be addressed in this graduation assignment.

5.1 Procedure

5.1.1 Introduction

The goal of this chapter is to support the graduation assignment with a definition of the most concerning moments of the cabin experience. The data from interviews is analyzed to provide a structured selection of the design problem.

The data collected during the interviews provides the passengers' levels of perceived safety in different moments in the aircraft cabin and the priority with which these should be tackled. In order to define the solution space for the project, the scores are calculated to identify the most relevant issues to address in the next parts of the project. This chapter describes how the collected data is processed, and outlines the steps taken to redefine the Problem Definition.

5.1.2 Requirements and criteria

As no numerical requirements were provided by the client, the criteria proposal was developed and consulted with Embraer. It has been concluded that two passenger-defined factors, level of viral safety and criticality, will be the equally weighted variables for choosing the most relevant problems to tackle in this project. Levels of viral safety reflect the attitudes towards different activities in the plane cabin, and criticality assigns the priority with which these should be tackled.

5.1.3 Procedure

Perceived Safety Level (PSL) and Criticality Level (CL) will be the constituent parts of the Problem Relevance (PR) score. The resulting PR score will determine the cabin moment(s) to address in the final design. The overview of the approach taken to establish the problem definition is provided in Figure 5.1.

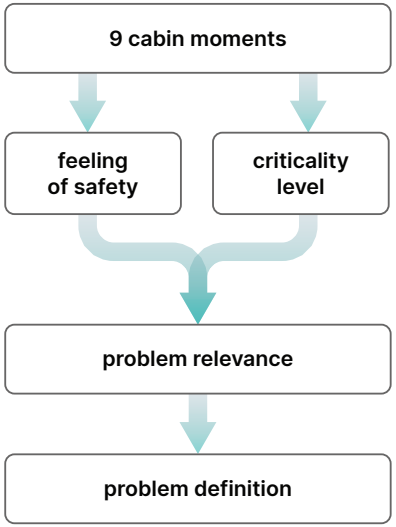


Figure 5.1: Approach to establishing the problem definition.

Perceived Safety Level (PSL)

During the interviews, participants expressed their views on viral safety in nine common in-flight activities using the five-point scale codes, ranging from "very unsafe" to "very safe". To compare results in a structured way, weights are assigned to each score to calculate the safety levels of each activity (Figure 5.2). The average of the scores is then calculated to provide the total level of perceived safety for each activity. The results are shown in Figure 5.5 on the next page.

Criticality Level (CL)

Some activities may be less crucial to tackle than others due to a low rate of passenger participation in this activity. Therefore, the second determinant is the priority at which passengers think that each activity should be dealt with. In the interviews, participants were asked to determine their top three most critical activities decreasing the perception of safety. In order to distinguish the activities with highest overall criticality, weights are assigned for each score, as provided in Figure 5.3. The results for each activity are then summed to reveal the total criticality level for each of the nine activities. The results are shown in Table 2 on the next page.

Problem Relevance (PR)

To provide a relative numerical comparison of relevance to the project, The Problem Relevance score is calculated using the perceived safety as a basis and criticality as a multiplier (Figure 5.4). The resulting PR score represents the total level of relevance, which will be used in selecting the project scope. For the results, see Figure 5.6 on the next page.

Perceived Safety Level

score	weight
Very safe	1
Somewhat safe	2
Neutral	3
Somewhat unsafe	4
Very unsafe	5

Figure 5.2: assigned weights for calculating PSL.

Criticality Level

score	weight
Top #1 critical	3
Top #2 critical	2
Top #3 critical	1
Not mentioned	0

Figure 5.3: assigned weights for calculating CL.

$$PR = PSL \times CL$$

Problem Relevance | Perceived Safety Level | Criticality Level

Figure 5.4: calculating the Problem Relevance score.

5.2 Discussion

5.2.1 Discussion

The methodology used allowed for a structured comparison of the nine moments in the cabin in terms of significance. The results indicate that eating meals is the most important issue that needs to be addressed in addressing the low perception of safety. Disembarking from the plane is another activity that is very similarly critical for passengers. Since scoring significantly higher, both eating and disembarking are identified as suitable spaces to increase perceived viral safety. Therefore, these two activities will be included in the initial idea generation process.

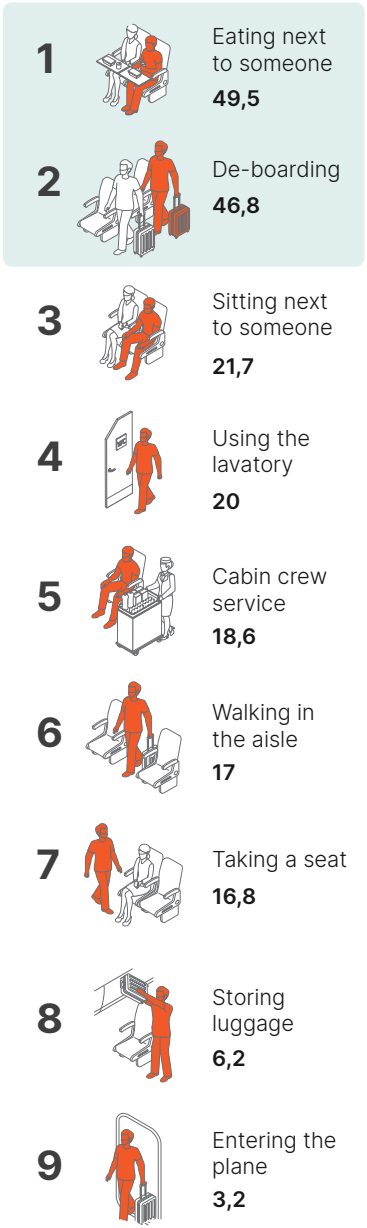


Figure 5.6: Problem Relevance scores, ranked.

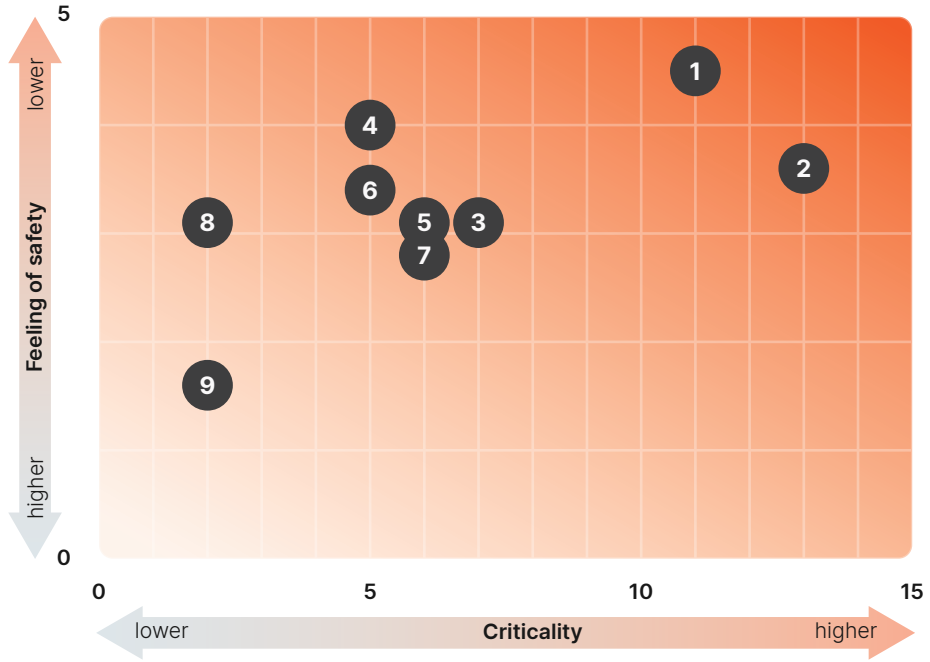


Figure 5.5: a graph showing the relations between criticality and the perceived safety.

Table 2: Total Problem Relevance scores for all nine activities in the cabin.

moment no.	1	2	3	4	5	6	7	8	9
feeling of safety	1,6	3,4	3,1	2,8	3,1	3,1	4,5	4	3,6
criticality	2	5	2	6	7	6	11	5	13
total	3,2	17	6,2	16,8	21,7	18,6	49,5	20	46,8

5.3 Initial ideation

Following the selection of the most relevant activities affecting the PVS, an initial ideation was made to provide a space for exploration.

The most relevant activities chosen in the previous chapter served as the scope for ideation. The data from interviews with passengers provided an overview of the problems in each activity:

Eating:
Too much physical contact
Unsafe eating without masks

Disembarking:
Too much physical contact
People rushing to the exit

To support ideation, the collected issues were translated into ideation challenges using "How Might We?" method (Design Kit, n.d.)

How Might We challenges:
1. How might we separate passengers from each other while eating?
2. How might we reduce the spread of droplets when eating without a mask?
3. How might we encourage passengers to stay seated after landing?

Takeaway from this chapter

- The analysis of the interviews shows that eating next to someone and disembarking are the areas that should be addressed in order to improve the perception of safety.

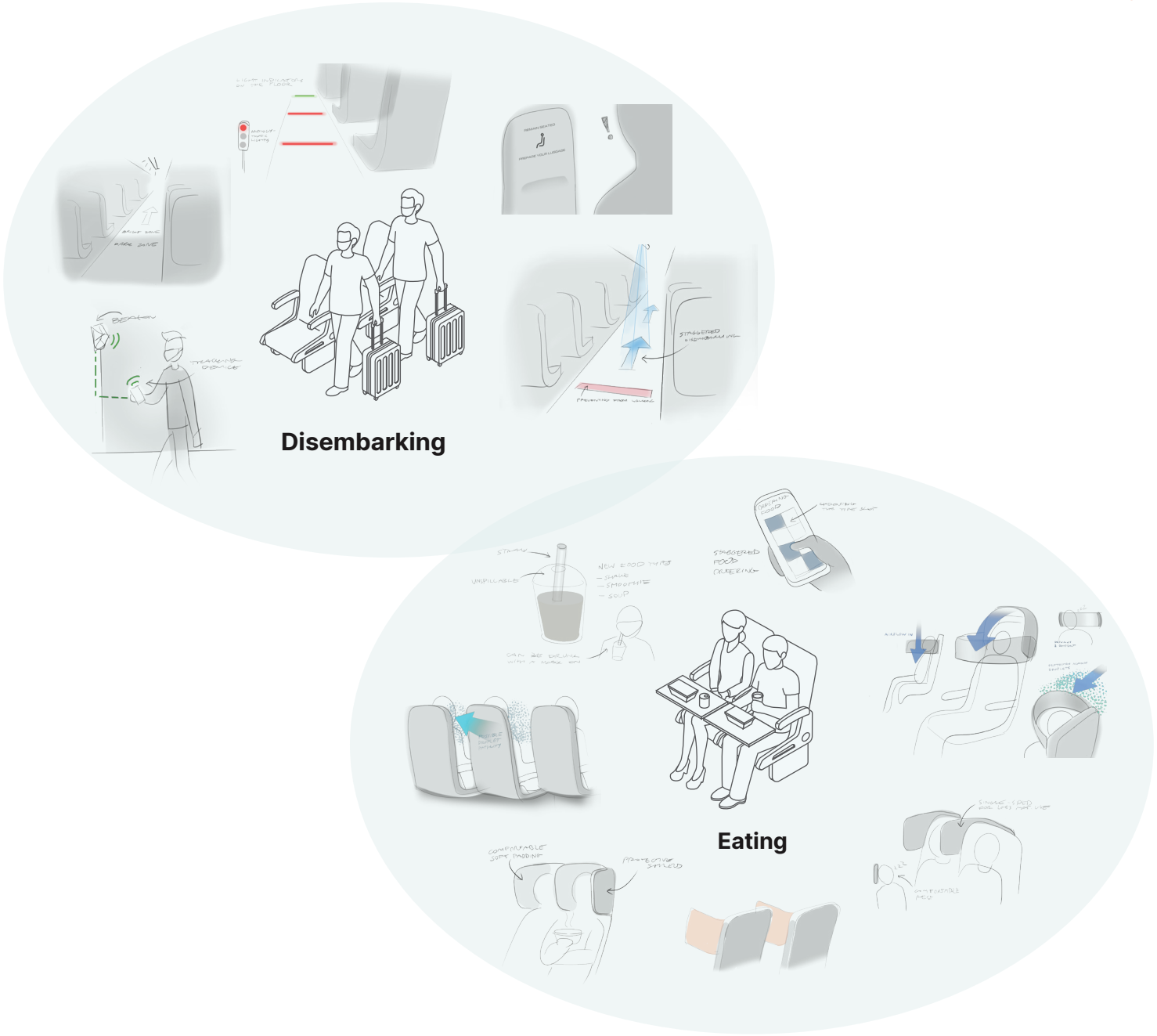


Figure 5.6: Initial sketch ideation based on the results of the interview analysis.

Chapter 6

Synthesis

In this chapter, the two previously selected issues are discussed in detail to explore the possibilities for this project and redefine the problem. This allows for generating a vision for the project and a set of requirements and wishes that will guide the development of the final product.

6.1 Approach

6.1.1 Introduction
In the previous chapter, two activities were distinguished that require special attention in order to increase the feeling of viral safety. However, the need for a more extensive comparison was identified, taking into account the state of research and the current methods of solving selected issues. This chapter outlines the steps to define the scope of this thesis assignment, create a design vision, and establish requirements and wishes for measuring the successful outcome of the project. Figure 6.1 illustrates the steps taken to achieve this.

6.1.2 Design considerations
with a purpose of creating a more in-depth understanding of the selected issues in the plane cabin, the activity of eating and disembarking are compared agianst the previously collected data, as well as additional desktop research. The aspects taken into consideration:

- Qualitative input from the interviews
- Existing ways of tackling the issues
- Real virus safety
- Relevance to the project assignment

The resulting discussion will lead to a selection the final scope for this graduation project.

6.1.3 Problem Definition
In order to structurize the design assignement, design problem. For this, Problem Definition method is used. To support it, different product proposals by interview participants are reviewed to serve as an inspiration for the product direction.

6.1.4 Design vision
The most important conclusions from the previous chapters are summarized in chapter 6.4. This leads to the definition of a design vision that will guide the ideation phase and thus inspire the final product.

6.1.5 Requirements
In the last step, the requirements are set to define specific goals that the project must meet in order to be considered successful. They will also support decision making at the conceptual stage and during product development. Chapter 6.5 provides the requirements and wishes developed in cooperation with the client.

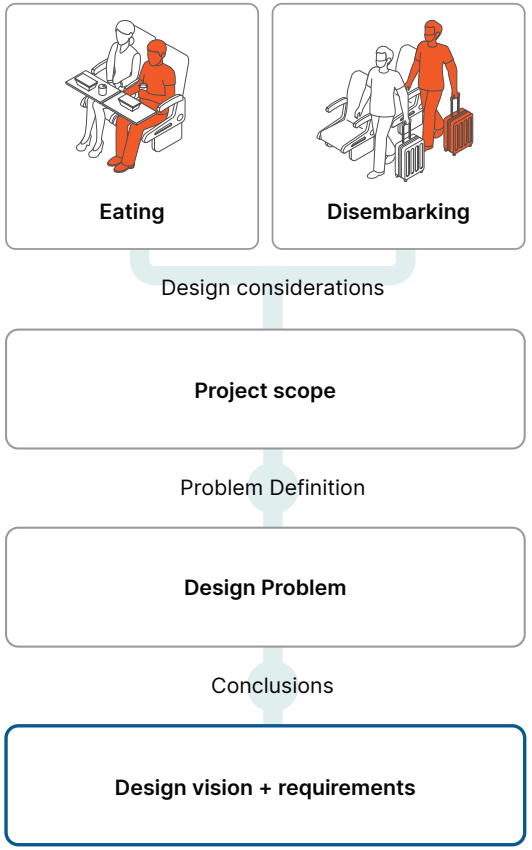


Figure 6.1: Approach to define a design vision and requirements.

6.2 Project scope discussion

6.2.1 Introduction

The previous chapter identified two relevant activities that affect the perceived viral safety: eating and disembarking. In this paragraph, these two areas are discussed in detail with the aim of selecting one activity that will serve as a solution space for this graduation assignment.

6.2.2 Interviews

Eating

The analysis of audio recordings and interviewer's notes revealed that experiences from eating were often described with a strong emotional load. Quotes from the participants:

"I felt really uncomfortable, especially during eating process, because he was definitely careless, he was talking a lot, and while eating he was talking too"

"Everyone took off their masks and I was just in shock. I was keeping my mask. I didn't take it off for a minute but I was feeling extremely unsafe. And I was really regretting being on this plane and taking this flight."

Interestingly, as taking masks off seems to be generally concerning, the issue was relevant even for the passengers that did not consume any meals on the flight. In cases where social distancing was maintained by leaving the middle seat empty, participants stated a relatively high perception of safety. Several participants had no opinion, as no meals were offered on their flight. This issue however may be more relevant when considering long-haul flights.

Disembarking

In the interviews, disembarking was cited as an important issue affecting perceived viral safety, but also as annoying:

"They tried to give you the right information and they try to guide you, but in the end no one listened, so that was just very annoying and it felt unsafe because I was waiting in my chair but everyone was standing, already and grabbing their things."

"I think a lot of people, at least on my flight, are really rushing to go out of the plane and maybe are less cautious on distancing and safety. So I think it creates more chaos."

The analysis of recordings revealed a high emotional load when describing the eating experience. This is important for the scope, because research shows that memories of emotions can play a role in the decision to fly in the future.

6.2.3 Current solutions

At the time of writing, the airlines are implementing several solutions to address eating and disembarking issues:

Eating

Especially on short-haul flights, airlines adapt to the coronavirus pandemic by restricting food and drink offerings (Ankel, 2020). On long-haul flights, a common way to reduce the risk is to maintain social distancing. This is now done, for example, by leaving the middle seat empty, which ensures less contact between passengers. However, as social distancing is not a legal requirement for airlines, a number of low-cost carriers do not provide social distancing on board, leaving the issue untackled. Social distancing reduces the maximum load factor far below the industry's average of 77%, which is not viable for airlines in the long run.

Disembarking

Interviews have shown that disobedience during disembarking is usually more firmly tackled in reputable airlines, where flight attendants are more assertive in executing the disembarking procedure. Interviewees who flew with such airlines claimed that higher safety standards resulted in a higher obedience among passengers. This shows that the concerns may be alleviated by ensuring adequate staff training and reconfiguration of the disembarking procedure, and is achievable today.

Unlike disembarking, there are currently no viable solutions for providing a safe environment when eating. Separating passengers without reducing the load factor could provide safety without generating losses and therefore may be desirable for airlines.

6.2.4 Real safety considerations

Eating

Eating involves removing the mask, which is a layer of personal protection that has been shown to be effective in preventing or at least significantly reducing the spread of the COVID-19 virus (Leung et al., 2020; Chu et al., 2020). Previous airflow tests by major aircraft manufacturers show the importance of a mask in reducing droplet dispersion. Despite that, many airlines still have not provided an effective solution to address this issue.

Therefore, it may be concluded that if no social distancing is maintained, dining is an activity with the highest risk of droplet transmission on board. The seriousness of the risk was emphasized by Sanjiv Kapoor, former chief operating officer of SpiceJet:

"It's a glaring loophole and nullifies all of the other safety measures such as touch-less travel, masks, and shields," (Thomas, 2021).

Disembarking

When performed without distancing, exiting the airplane poses an increased risk of transmission by contact. However, current sequential disembarkation solutions are proving effective in reducing risk (Milne, 2020) because they eliminate physical contact and rely on wearing masks.

6.1.4 Project relevance

Dining is especially important on long-haul flights, where meals are usually offered to most travelers. This is important for the project as the Flying V is primarily intended for long-haul flights. Furthermore, as the exact physical interior space of Flying V has not yet been defined, the disembarkation procedure has not yet been fully established on this airplane.

6.1.5 Project scope

Eating on the aircraft is a scope selected for this thesis assignment. An important argument supporting this is the increased risk of droplets spreading between passengers after removing the masks. It is also an activity that has not been tackled by many airlines, unlike disembarking which can be generally safely handled with staggered boarding. In addition, a strong emotional response was observed in the interviews, which indicates that these unpleasant experiences may reduce the propensity to fly in the future. Finally, a solution that provides separation of passengers may be desirable for airlines for increased safety without reducing the number of passenger seats.

6.3 Problem Definition

After defining the most relevant problem to focus on in this graduation assignment, a Problem Definition is developed (Boeijen, 2014), which allows for creating a structured description of the design problem.

Procedure
The relevant data to define the problem is given in Figure 6.2.

What is the problem?
The process of food consumption decreases the perception of viral safety in planes

Who has the problem?
Airline passengers, primarily long-haul flights

Context factors
New epidemic-related concerns, context of an active or subsiding epidemic

Goals
Addressing the viral safety concerns of the passengers during a flight; increasing the perceived safety, doing so in a sustainable manner

Side effects to be avoided
Providing a false sense of safety; decreasing cautiousness during a pandemic; decreasing viral and emergency safety of the interior

Admissible actions
Reducing the sources of concerns, preventing virus spread, separating passengers, ensuring privacy, giving passengers control, raising awareness about the nature of viruses.

Figure 6.2: Problem Definition.

Interviews - ideation
Interviews have shown that eating seems to be an activity people use as an excuse to take off the masks. In the interviews, participants were asked to come up with improvements that would make them feel more at ease in most disturbing moments. Most of the respondents mentioned social distance or physical separation as a means of successfully solving this problem. Below are selected quotes describing various concepts for increasing virus safety:

"(...) a huge helmet which is around your head, your own bubble. I think that would be the safest way for me, because if I will have the filter and make sure that I breathe the air that is somewhat clean, and virus free that would be the safest."

"One seat gap. Then they can put something like a screen. "

"I really think that if we can stay in our bubbles that would be the best option. But the thing is you would have to have clean air"

"And if there's no gap then maybe a screen in between, that would also help for the feeling"

"They could give the food for the first one and the third one, and the middle one has to keep his mask on. Then they have a second round, and then just the middle one can eat the food, and the rest puts the masks on."

Expert ideation
Several concepts for solving eating problems emerged during the expert opinion session. One of them is "staggered eating" - the concept of providing food at different time intervals to reduce the risk of droplets spreading. Another concept was to change the menu to liquid items such as smoothies or shakes that can be consumed through a straw with a mask on. This, however, calls into question their effectiveness on long-haul flights.

Real safety considerations
Research shows that the airflow in the cabin together with the masks is effective in preventing infections. The advantage of the cabin air is its vertical downward flow which continuously transfers exhaled droplets to the floor. There, HEPA filters remove viruses and purified air is recirculated. Therefore, the envisaged product must not affect the air flow by blocking it or restricting access to the head of passengers. Masks, a beneficial layer of protection, are removed during eating. An additional protective layer may be needed to ensure a safe environment while eating. Chu et al. describes that the most infectious places on the human body are the head, mouth and eyes. Therefore, emphasis should be placed on keeping these body parts separate from fellow passengers to ensure safety.

Airlines
Airlines are trying to promote their image as safe. At the same time, social distancing is not profitable for airlines. Therefore, a solution that separates passengers from each other may be desirable to increase the airline's reputation and profitability.

6.4 Design Vision

To inspire the final design, this paragraph summarizes the main conclusions of the literature review, trend analysis, interviews and expert sessions, and creates a vision for the final design.

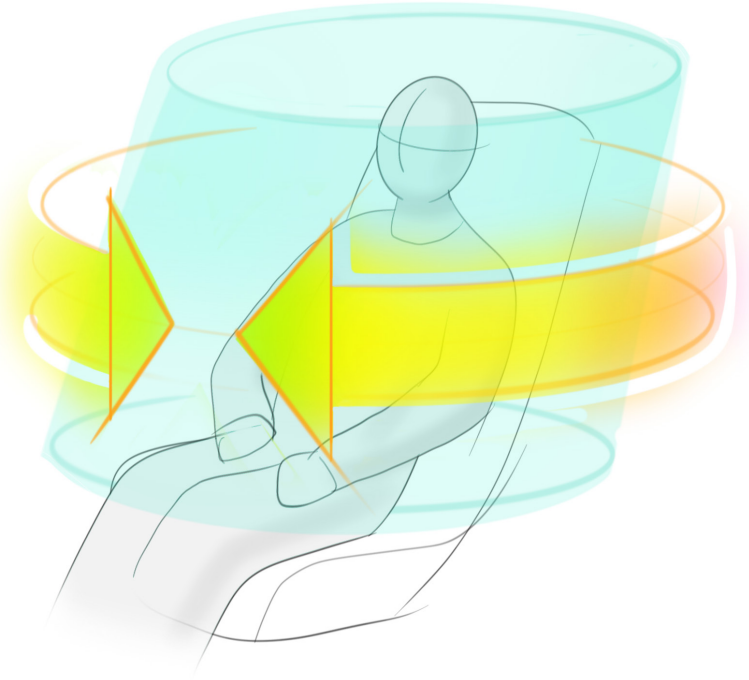
The main issue: Aircraft interior is pereived as unsafe
Embraer: There is a need for providing a sustainable solution to increase perception of safety.
Literature research: Increasing perceived passenger safety is a challenge which will drive the recovery of aviation. Aircraft interiors are relatively safe in reducing the chances of infection.
Trends: The aviation of the future is personalized, digital, hygienic and sustainable.
Airlines: Urgent solutions are needed to increase willingness to fly. Load factor is important for economic viability.
Interviews: Eating is one of the most concerning problems for viral safety.
Expert session: Eating should be revised, alternative methods of providing food and packaging should be considered.

Findings show that there is a clear need to limit physical contact between passengers sitting next to each other, especially while eating. Not only will this reduce passenger concerns, but it can also be beneficial in reducing the spread of droplets in the cabin and potentially increasing privacy. Moreover, the provision of a physical barrier between passengers may enable airlines to maximize the load factor without endangering the health of passengers.

The design considerations are summarized with a description of the design goal:

Develop a proof of concept for the Flying V economy class interior product, which increases the perceived viral safety when consuming food. The product should allow for a comfortable use of the plane interior, without impeding the existing viral and emergency safety. The product should be optimized for low environmental impact. Retrofittable design is preferred for greater versatility.

To inspire the final product, a design vision named "COVR" is created and described in Figure 6.3.



COVR is a personal protector in the aircraft cabin. It gives passengers the feeling of being in their own "bubble" protecting against viral threats. Not only it gives a sense of control over one's safety, but also serves as a beneficial layer of protection in the fight against viruses.

Figure 6.3: Formulated vision of the project and a supplementary sketch.

6.5 Requirements and wishes

Based on the design goal and vision, a set of requirements is developed in Table 3. This allows to define the goals that must be achieved in order for the product to function as intended and address the needs of stakeholders. These guidelines will form the basis of the conceptualization and will be used when assessing performance.

In addition, a set of wishes is created that serve as assumptive guidelines and will not be determinative when testing performance. Meeting with them will be recommended but not required.

Limitations
The interior of the aircraft is a space strictly regulated by safety standards to ensure reliability and a high level of safety. Making a product meet these standards requires extensive efforts that can inhibit innovation. As discussed with Embraer, only selected common-sense guidelines for interior safety have been established. Furthermore, the viral safety guidelines are based on the findings of the SARS-COV 19 virus, and therefore may not be applicable for other types of (airborne) viruses. Moreover, these guidelines are intended to support as much as possible the viral safety characteristics of the aircraft cabin, but are not in themselves a measurable indicator of the actual safety against viral infection.

Table 3: List of requirements and wishes and assessment of performance.

Requirements

Category	Requirement
Passenger experience	The experience should be perceived as safer than the regular setting
	Should be regarded as convenient to use
	Should make passengers more willing to fly during the pandemic
Viral safety	The concept should not hamper the vertical airflow in the cabin
	The concept should not facilitate droplet spread between passengers
Interior safety	Should be made of non-flammable materials
	Should allow passengers to stay informed about the safety procedures
Airlines	Should allow for and withstand the cleaning procedure
	Should allow passengers to communicate with the cabin crew easily
	Should be visually universal to be applicable for different airlines
Supply chain	Should be producible at mass scale
	Should be easy to transport
Sustainability	Should be optimized for low weight
	Should be easy to uninstall
	Should be made with at least 50% recyclable materials
Assignment-specific	Should fit within the physical space available in the Flying-V concept
	Should fit the staggered seat of the Flying V developed by Rebel Aero

Wishes

Category	Wish
Passenger experience	Much safer experience during the entire journey
	Should not make passenger much more claustrophobic
	Should make passengers more willing to fly after the pandemic
Interior safety	Should comply with the current onboard safety standards
Airlines	Should make passengers willing to pay more for the ticket
	Should allow for retrofitting in the current aircrafts
	Should be possible to clean in 10 seconds or less
	Should have a low cost
Supply chain	Should fit within the existing supply chain
Sustainability	Should not use rare earth materials
	Should not be built with “Monstrous Hybrids”
	Should have a defined end-life
	Should be sturdy and long-lasting
	Should have a carbon neutral or carbon positive footprint
	Maintenance should not require detergents or electricity

Takeaways from this chapter

- Perceived viral safety when eating is a scope selected for this thesis assignment.
- If no social distancing is maintained, eating may an activity with the highest risk of droplet transmission throughout the journey.
- Solutions to physically separate passengers without decreasing the load factor could maintain safety while not generating losses, and will be therefore desirable for many airlines.
- The most infectious places on human body are head, mouth and eyes.
- This chapter presented a design vision for “COVR” - a personal cabin protector.
- A set of wishes and requirements was created together with the client.

Chapter 7

Ideation phase

This phase focuses on translating the design vision into tangible product proposals. This chapter describes the design process that included sketch ideation, rapid prototyping , concept selection, and creation of four functional prototypes that will be later tested with users.

7.1 Approach

7.1.1 Introduction

This phase focuses on the product ideation and development of prototypes for further testing. Figure 7.1 outlines the steps taken in this phase.

First, a review of existing concepts was made to provide an overview of the ways to protect passengers. Next, an ideation was conducted with respect to different physical properties of the product. The developed concept matrix enabled to select and and test prototypes in an iterative process. The resulting set of concept proposals was assessed using Harris Profile method, in which project-specific criteria formulated with Embraer were used. This allowed for a selection of four concepts that were further developed in a form of functional prototypes.

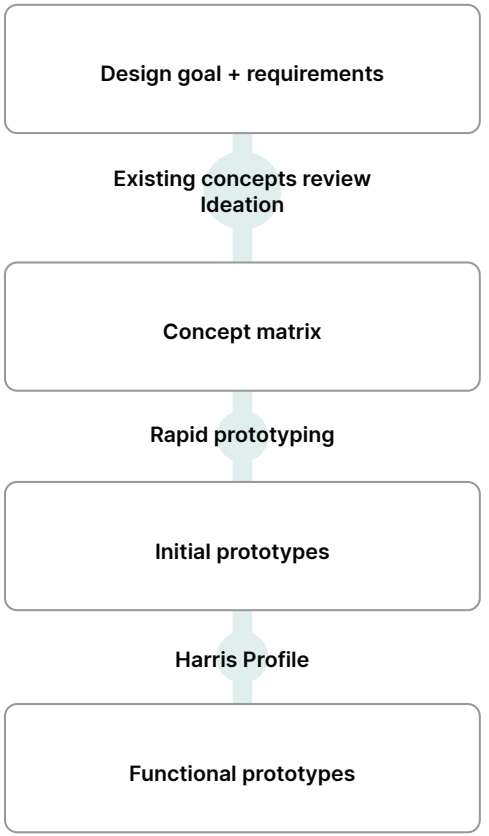


Figure 7.1: Approach used during the ideation phase.

7.2 Existing concepts

7.2.1 Introduction

There are several concepts developed by design agencies, airlines and manufacturers to address the viral safety problem since the onset of the coronavirus pandemic. This paragraph provides an overview on different solutions collected from websites and aviation magazines. At the time of writing, no solutions targeting the eating process specifically have been found. For a full overview, see Appendix H.

7.2.2 Privacy

Greater privacy seems to be an integral part of the proposed concepts. By visually and / or physically separating passengers, it may not only make people feel more safe, but also provide privacy, a feature that may be desirable in the dense arrangement of the economy class seats.

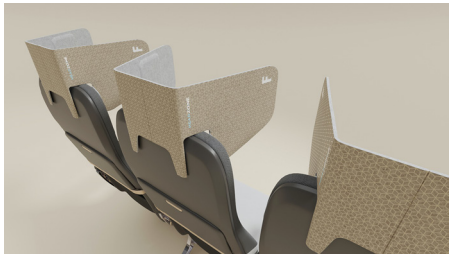
7.2.3 Transparency

An important aspect is how passengers will be able to communicate with cabin crew and other passengers and the cabin crew. Several concepts are made of translucent materials to facilitate communication.

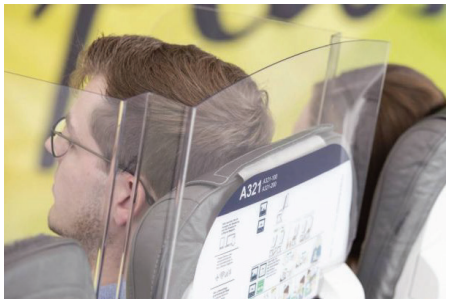
A new seating layout is proposed by Avio Interiors, which eliminates physical contact.

Factorydesign proposes using the middle seat as the convertible space for ensuring social distancing,

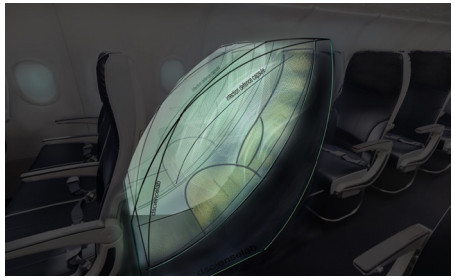
PriestmanGoode imagines the future interior with “gapless” seats, curtain dividers, side covers and several disinfection solutions.



Factorydesign imagines a foldable protection solution that can be easily applied to different types of seats.



Lufthansa Technik developed a head protector that is installed in the middle seat.



Science Lab developed a cocoon protector that provides a complete seclusion from co-passengers.

Different methods of separating passengers ideated by Safran.

Vision Systems developed a lightweight transparent barrier to separate passengers.

AirShield by Teague uses a 3D-printed module to create “air blades” which control droplet spread more effectively.

Figure 7.2: Existing concepts for increasing viral safety.

7.3 Sketch ideation

7.3.2 This section serves as a starting point for final product ideation by considering different physical properties and usage models of the product. This is to generate concepts that consider different usage scenarios and environmental impacts of the end product. For this, a concept matrix has been developed in Figure 7.3, which ranges from “standalone” to “integrated” on the horizontal axis, to distinguish different usage scenarios, and “single-use” to “reusable”, to consider different environmental impacts of the solution as well as hygiene and maintenance.

7.3.2 Expert meeting

To improve idea generation by discussing the physical constraints of the aircraft cabin, an expert from Rebel Aero seat design studio was consulted. During a meeting, several recommendations were made to help with the idea generation process. Solutions that do not require handling by cabin crew or passengers have been recommended as they would be less cumbersome to use in a small interior space. In addition, for objects integrated into the cabin, hard surfaces are preferred to facilitate short cleaning time. Moreover, the importance of interaction with the cabin crew was emphasized, and one of the recommended solutions was the use of translucent materials. To prove viable for the airlines, an easily detachable solution that would not require changes to the interior of the aircraft itself was recommended.

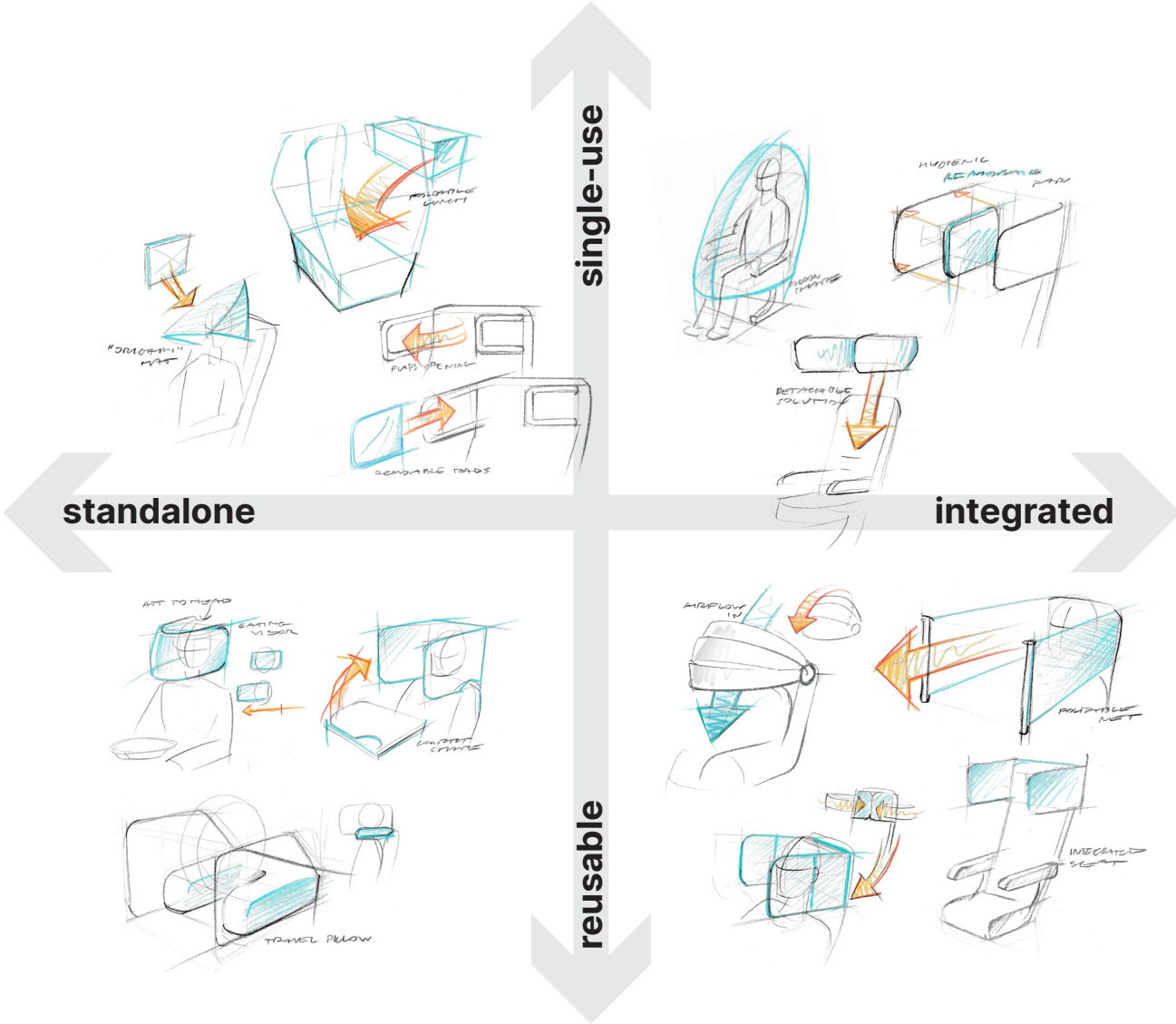


Figure 7.3: Sketch ideation matrix.

7.4 Rapid prototyping

The concept matrix in the previous chapter served as the basis for iterative prototyping. Several low fidelity prototypes were developed (see Figure 7.4), assessed for aircraft seat usability and progressively optimized. The resulting set of prototypes allowed for the evaluation of concepts in terms of functionality. Personal observations and user feedback were written down to be used later as an aid in the concept selection process. The process of testing the prototypes is visualised in Figure 7.5. For all documented prototypes, see Appendix I.

To assist in making informed choices about individual concepts, a combination of the common sense principles and guidelines from chapter 6.5 was considered:

- The concept should allow for comfortable eating.
- The concept should provide a physical separation for the head and/or food
- The concept should not obstruct the cabin vertical air flow.
- The concept should fit within the Flying V staggetred seat layout and take into account the current aircraft.

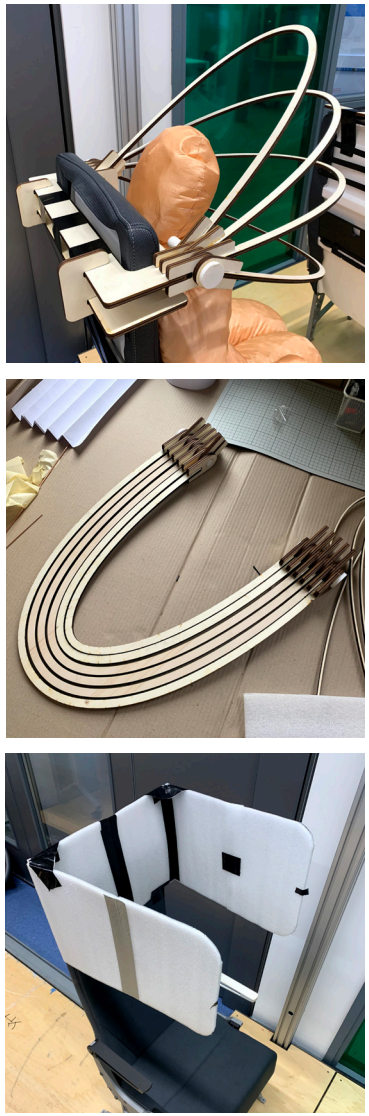


Figure 7.4: Prototypes.

Figure 7.5: Iterative prototyping.

7.5 Concept selection

7.5.1 Introduction

The iterative prototyping process resulted in the development of nine concepts that fit the general criteria. To make an orderly selection of concepts, a combination of the Harris profile (Boeijen et al., 2014) and the Weighted Objective method was used (Roozenburg and Eekels, 1995). The Harris Profile method allows a graphical comparison of strengths and weaknesses within a predefined set of requirements, and Weighted Objective allows to make choices using an overall score. The use of these methods made it possible to select concepts that best fit the criteria, while communicating the process to the client in an approachable way.

The requirements in Chapter 6.5 were translated into seven indicators for the Harris profile, ranked and weighted respective to their importance to the project as discussed with Embraer. The indicators and weights used are described in Figure 7.6:

Indicator	weight
Perceived safety	2
Virus safety	2
Interior safety	1.8
Sustainability	1.6
Maintenance	1.4
Convenience	1.2
Cost	1

Figure 7.6: Criteria and weights for Harris Profile.

7.5.2 Procedure

For each indicator, a set of distinctive criteria have been formulated, allowing for a structured assessment. Concepts have been rated within a range from two minuses (low compliance) to two pluses (high compliance), based on the number of the criteria they meet. Next, total scores were calculated using the Weighted Objectives method. The resulting scores served as a basis for concept selection. For a detailed evaluation using Harris Profile, see Appendix J.

7.5.3 Results

The use of aforementioned methods resulted in a selection of four concepts, as highlighted in Figure 7.7:

- **Headrest**
- **Roller blind**
- **Head Cover**
- **Visor**

Section 7.6 on the next page details selected concepts, including initial design choices, materials, business model and product life, which will serve as the basis for a structured comparison at a later stage. The selected concepts will be further developed and tested with users to determine the final product direction.

Limitations

Harris Profile does not provide a definitive benchmark for performance, but rather serves as a tool to facilitate discussion and communication with stakeholders. It is based on a partially subjective evaluation of concepts using predefined criteria.

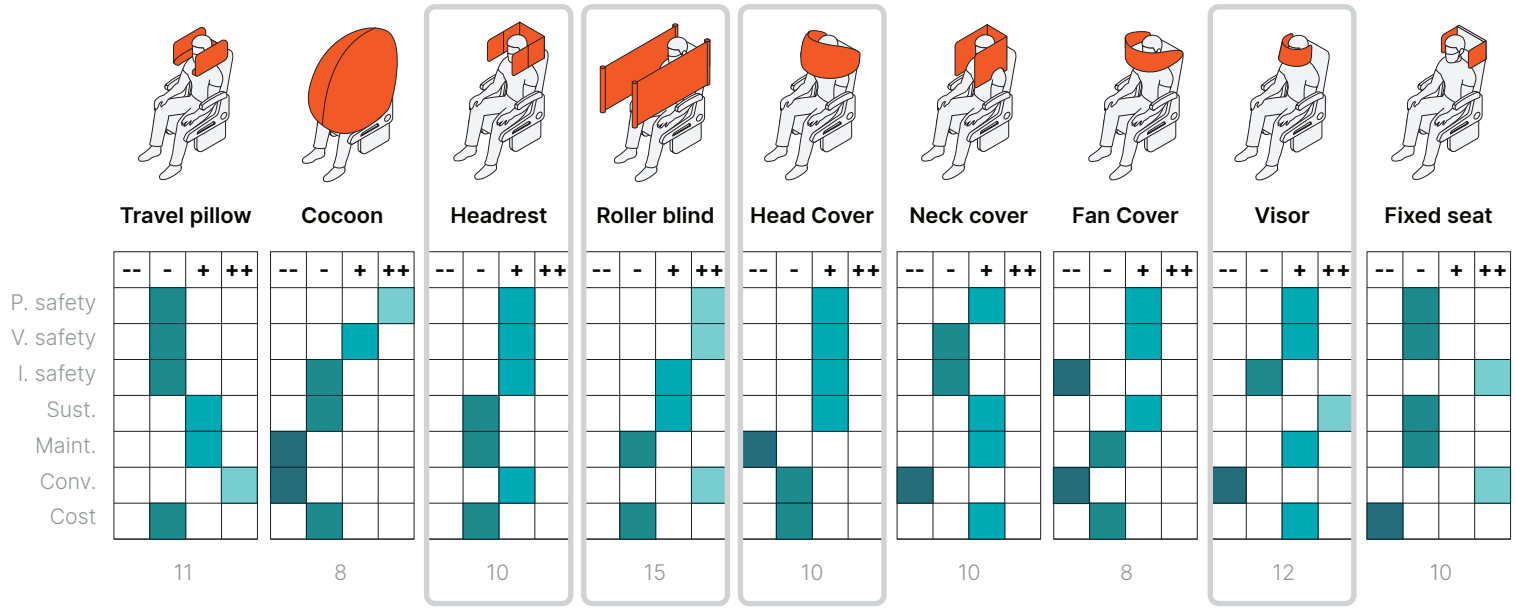
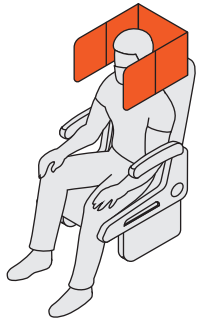


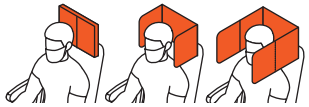
Figure 7.7: Concepts selected using a combination of Harris Profile and Weighted Objective methods.

7.6 Chosen concepts

1

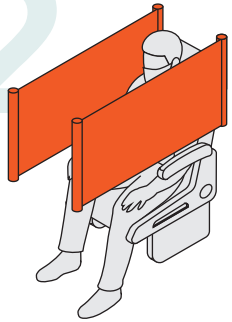


Concept 1: Foldable headrest
A headrest that allows for flexible separation. Side flaps can be expanded to provide different levels of privacy.

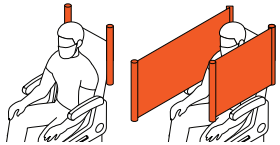


Considered materials: TPU foam, PVC faux leather, aluminium, carbon steel, magnets
Load factor (units/seats): 100% or 66%
Business model: provided by airlines
Installation: Fixed on seat/detachable
Approx. weight: 600g
Approx. product life: 8 years
Maintenance: Airline, same as the seat upholstery

2



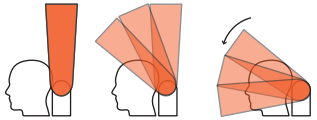
Concept 2: Roller blind
A semi-transparent roller blind that gives privacy and protection.



Considered materials: PET, TPU, nylon, aluminum, magnets
Load factor (units/seats): 66% or 100%
Business model: provided by airlines
Installation: Fixed on seat/detachable
Approx. weight: 600g
Approx. product life: 8 years
Maintenance: Fogging/UV-C/Sanitizing

3

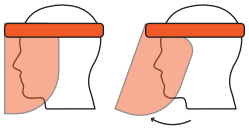
Concept 3: Head cover
A cover that protects the head, additionally limits the access of light.



Considered materials: PC/PET, aluminum, steel
Load factor (units/seats): 66% or 100%
Business model: provided by airlines
Installation: Fixed on seat/detachable
Approx. weight: 600g
Approx. product life: 8 years
Maintenance: Fogging/UV-C/Sanitizing

4

Concept 4: Visor
An on-head visor that can be expanded to provide protection when eating.



Considered materials: PET, TPU, nylon
Load factor (units/seats): 82% (Statista, 2020), based on a typical pre-covid capacity
Business model: provided by airlines/ purchased by the passenger
Installation: Standalone
Approx. weight: 200g
Approx. product life: 1 year
Maintenance: Cleaned by the user

Figure 7.8: Detailed description and early design choices of the selected concepts.

7.7 Functional prototypes

Functional prototypes were developed for the resulting four concepts for further testing, as shown in Figure 7.10. To simulate eating in the Flying V, Rebel Aero was consulted to ideate solutions for the food tray. As a result, an element of the "Joy" seat concept has been adapted which integrates the tray in the armrest. The tray was recreated using rapid prototyping and applied to the Staggered Seat prototype to allow for simulating eating on board the Flying V. A preview of the tray is provided in Figure 7.10.

Figure 7.9: Food tray developed with rapid prototyping.

Figure 7.10: Functional prototypes of the selected concepts.

Takeaways from this chapter

- This chapter explored the existing concepts for separating passengers.
- A sketch ideation was conducted to generate concepts.
- Prototypes were developed in an iterative process.
- A combination of Harris Profile and Weighted Objectives methods allowed for selecting four concept directions.
- Four functional prototypes were developed to be further tested with users.

Chapter 8

User testing

This chapter describes the steps taken to test various aspects of previously developed functional prototypes with real users. To enable the test while adhering to the coronavirus measures, an immersive user experience was developed and provided using virtual reality goggles. The test allowed for the comparison of concepts in terms of perceived safety, comfort and other factors influencing the willingness to fly. The test results were analyzed to determine the final direction for the product.

8.1 Approach

8.1.1 Introduction
The main purpose of this study was to measure the perceptions of safety and preference among users when using the four prototypes. This is to identify the type of passenger protection that best suits the “passenger experience” and “airline” requirements in chapter 6.5. Physical testing of prototypes by users had to be ruled out to ensure compliance with HREC coronavirus safety regulations. To provide a degree of realistic experience of using concepts, Virtual Reality technology was used, which allows multi-directional viewing of the digital environment which is in sync with the user's movements to ensure an immersive experience. 24 participants took part in the study, provided they were 18 years of age or older and had traveled by air in the past two years. For the user test plan, see Appendix K.

8.1.2 Procedure
This study was twofold and consisted of the immersive experience and a survey.

Part 1: Immersive experience
in the first part, participants were invited to watch a set of videos that provide a virtual experience of using prototypes inside the aircraft. The participants were guided by the on-screen and audio instructions. The complete test layout is shown in Figure 8.4 on the next page. To enable the use of virtual reality technology in the user's home, the VR Box set was provided in conjunction with the participant's smartphone and viewed on the YouTube application with VR mode enabled (Google LLC).

Immersive videos
In order for participants to be able to accurately assess the concepts, a realistic experience was necessary. For this purpose, omni-directional videos were created in the cabin of the Boeing 737 using an Insta360 Nano S camera (Arashi Vision Inc.) connected to a smartphone (Apple inc) and attached to the head of the recording person at the eye level. Figure 8.4 shows the recording equipment and Figure 8.6 shows a snapshot of the unedited video created. 360-degree videos were created with Insta360NanoS and later edited with Premiere Pro and After Effects (Adobe).

Part 2: Survey
After completing a test with each prototype, participants were asked to fill in a corresponding part of a survey via Qualtrics XM platform (Qualtrics). The survey consisted of 5-point Likert scale questions as well as open-ended questions for qualitative feedback.

8.1.3 Preventing bias
The use of the virtual reality may be overwhelming for inexperienced participants. In order to familiarize the viewers with this technology, a short introductory video was presented at the beginning of the test, in which users could experience sitting in a regular plane seat. Prior to each video, idle time was provided to give user time to prepare and adjust to the virtual reality. To prevent bias, half of the participants were presented with a different order of concepts.

8.1.4 Research ethics
The study was approved by the TU Delft Human Research and Ethics Committee (HREC). Prior to the interview, each participant completed an online consent form via Qualtrics platform.

Figure 8.1: Insta360 Nano S camera used for recording.

Figure 8.2: Participant using the VR headset.

Figure 8.3: Unprocessed snapshot from the omni-directional camera.

8.2 Test procedure

This page provides an overview of the test procedure. The test began with the instructions on how to set the VR mode on the smartphone and install it in the VR goggles. A short introduction was then presented to familiarize the user with the objectives of the test. Next, the test guide explained different steps of the study. This was followed by an "introductory flight" where users could get used to the immersive experience. This part concluded with completing the first part of the survey with general questions in order to collect demographic data and information about participants' perception of viral safety.

In the second part, users in two groups were presented with prototypes in different order. After completing each experience, the screen prompted the user to complete the corresponding part of the questionnaire. After viewing all experiences, users were asked to complete the final part of the survey where they could select their preferred concept and leave general feedback on the study itself. An overview of the test is shown in Figure 8.4. To preview the experience on a mobile device, the QR code is provided in Figure 8.5.

Figure 8.5: QR code for viewing the experience on a mobile device.

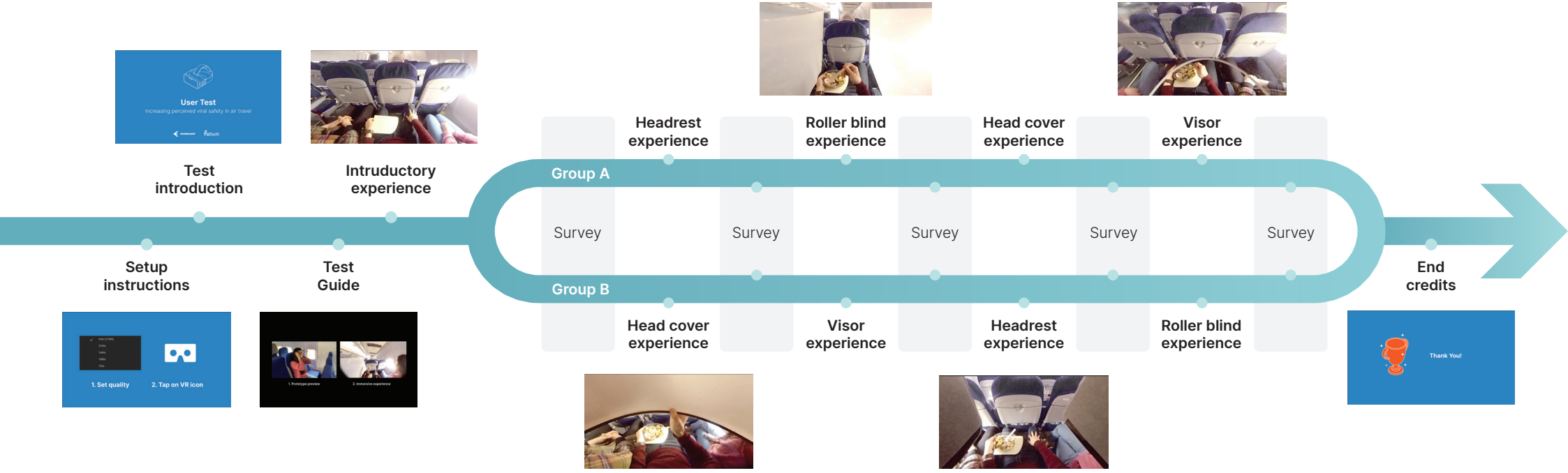


Figure 8.4: An overview of the study procedure.

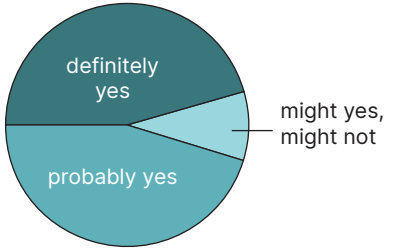
8.3 Test results

This page contains an infographic with the results of the viral safety part of the survey. The next page shows the detailed results for each concept.

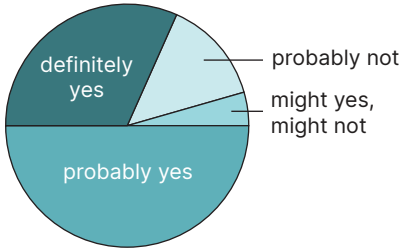
Perceived risk of coronavirus infection

"Do you think there is a significant risk of getting infected by coronavirus in...

Mass means of transport

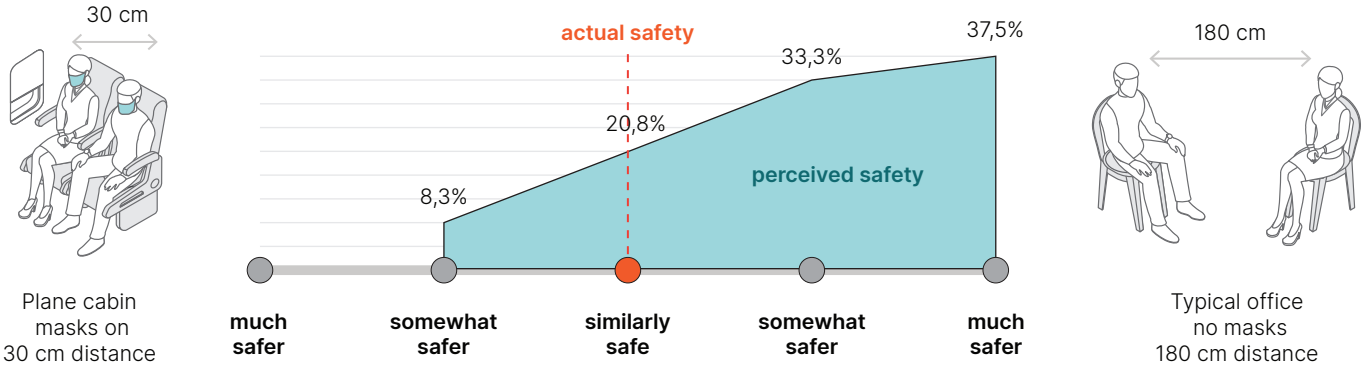


Aircraft cabin



Perceived vs. actual safety

"Which of these settings is safer?" Proportion of choices



The most concerning activities in the cabin

"Which three of these in-flight activities in your opinion pose the highest risk of virus infection?"
no. of mentions in top 3

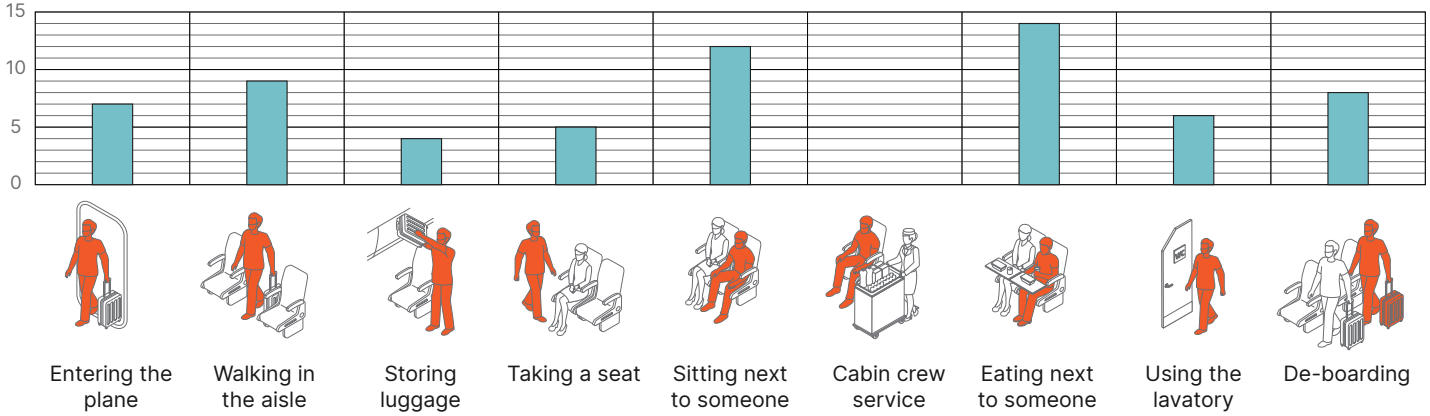
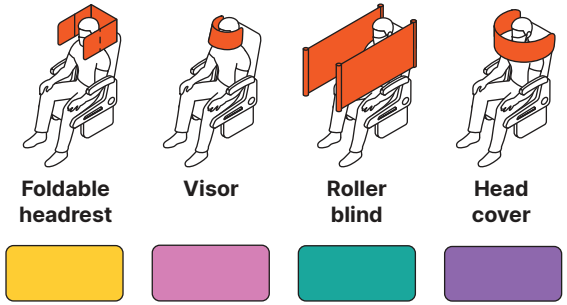
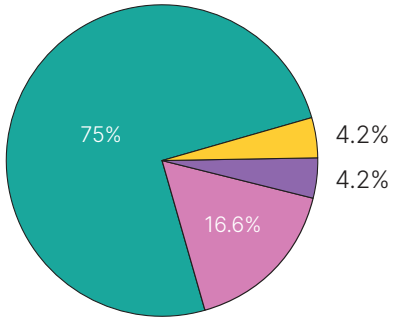


Figure 8.5: Results of the general questions about perceived viral safety.

Preferred concept

Number of participants





Detailed preference

Average scores

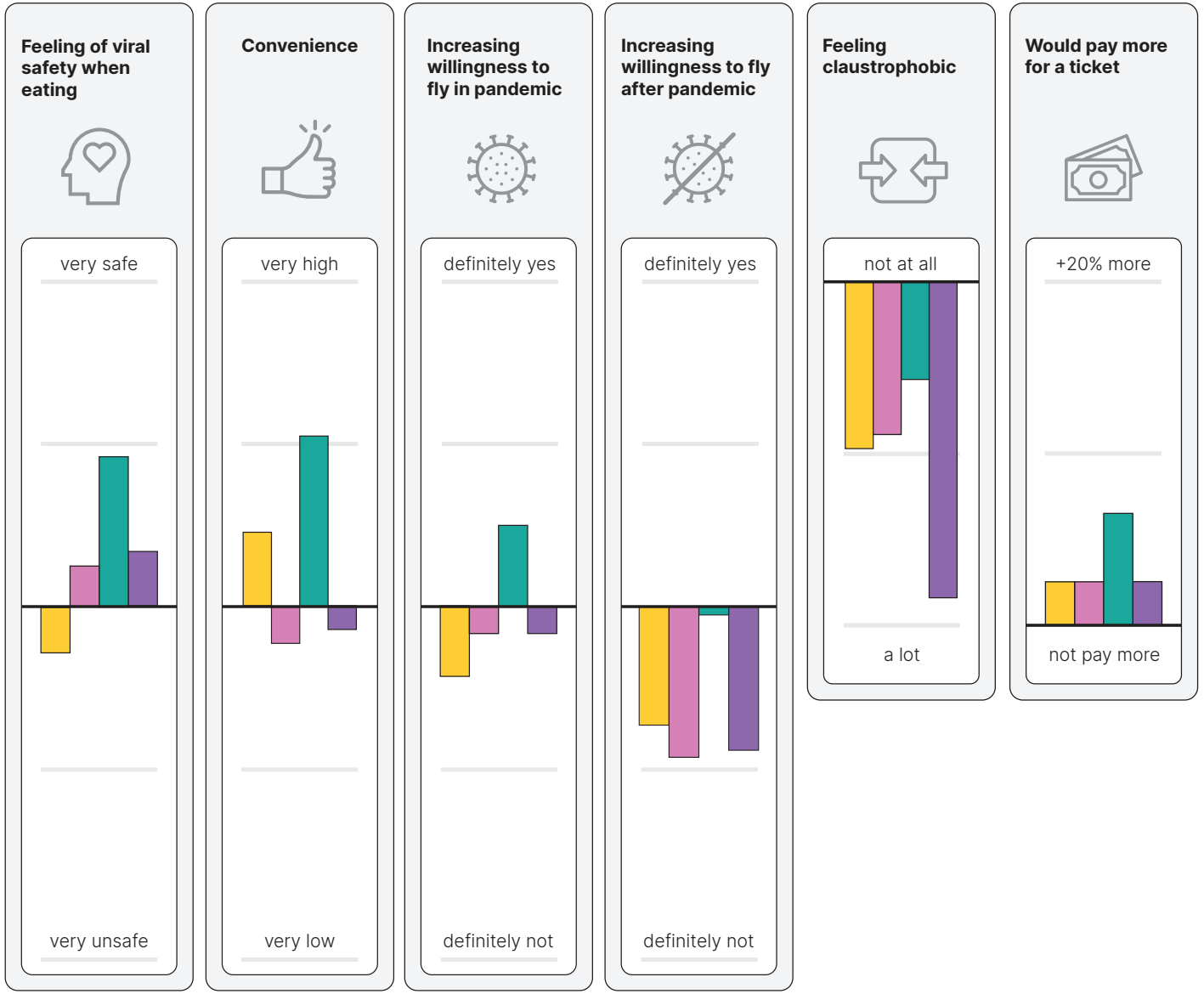


Figure 8.6: Survey results on tested passenger protection solutions.

8.4 Qualitative results

8.4.1 Perceived vs. actual safety

In the survey, participants were asked to rate the likelihood of contracting the virus on an airplane compared to a typical office. This is to identify any potential deviation between objective safety and how passengers perceive it. The benchmark for comparison is the results of CFD simulations conducted by the major aircraft OEMs, which show that the chances of infection while sitting next to someone in an airplane with a mask are similar to those of sitting in a typical indoor environment (Airbus, 2020; Boeing, 2020). One third of respondents chose the office setting as much safer, and none of the participants selected aircraft setting as much safer. Only 1 in 5 participants selected the accurate answer, which is “similarly safe”. The results support the argument that there is a gap between the perceived and objective safety, and that the level of viral safety of the aircraft cabin may be underestimated among travelers.

8.4.2 Concerning activities in the cabin

The survey revealed the main activities where there are concerns about virus safety; In the top three, the most frequently chosen activity was "eating next to someone", which supports the objective of this graduation thesis. The second activity chosen is "sitting next to someone", which partially confirms the IATA finding (IATA, 2020a) that sitting next to someone who may be infected is the most disturbing part of the journey. These were followed by "walking in the aisle" and "disembarking", which were also described as concerning in the interviews in Chapter 3. Three participants used an open-ended response to describe concerns about the efficiency of air circulation in the cabin, indicating that some travelers may base their perception on misjudged or partially incomplete information.

8.4.3 Foldable Headrest

Many respondents were concerned that while the concept provides a degree of protection for the head, the food is not separated from passengers, thus exposed to viruses. Several participants said that the area covered is too small. Regarding convenience, many passengers were concerned that the side flaps may be cumbersome to use and hit other passengers. There was also a concern over the universality of the concept as it only serves people with a certain height. About one fourth of respondents appreciated the privacy and sleeping support it may give. One in six respondents would pay up to 10% more for a ticket with such solution provided.

\+ Convenient sleeping
\+ Gives privacy
\- Not protecting food
\- Cumbersome to use

8.4.4 Visor

The visor is close to the face which made the respondents feel generally safe from viruses. There were, however, many concerns that the food is still exposed, which may render the face protection useless. There were several assumptions that the concept may be inconvenient to use during eating, and simply impractical to have throughout the flight. One participant appreciated the safety benefit of having a personal safety protection, where the owner is the only user. One in five people would pay up to 10% more for a ticket and one person would pay less than a regular price.

\+ Protects the face well
\+ Personal object
\- Not protecting food
\- Impractical to use

8.4.5 Roller Blind

There was a general appreciation of the large area covered, which most respondents believe provides protection and privacy. One in four participants felt that the food was protected and one participant pointed out the good use of the ventilation system. In terms of convenience, respondents said it is easy to use and provides a secluded space. There were few concerns that the solution could be a nuisance when a fellow passenger had to leave the seat. Some participants reported that using it might seem rude or annoying to co-passengers, but it might also prevent awkward conversations. One third said that they would pay up to 10% more for the ticket.

\+ Large area covered
\+ Privacy and protection
\- Rude for co-passengers
\- Cumbersome logistics

8.4.6 Head Cover

Similarly to the concept 1 and 2, there was a concern over food protection, mentioned by about a fifth of participants. There were concerns over the gaps in the cover, where the air may still come through. Some participants appreciated the omnidirectional protection of head. Regarding convenience, respondents appreciated that it gives privacy and looks easy to use. There were, however, concerns over the limited space and inconvenience of eating or watching movies. Two respondents recommended using transparent materials for better visibility. Three out of ten participants would pay 10% more for a ticket, and one in eight would pay less than a regular ticket price.

\+ Full coverage of head
\+ Gives privacy
\- Gaps letting the air through
\- Not profitable for airlines

8.4.7 Test feedback

Positive feedback was received on the study itself. Some users used optional feedback to note that the materials provided were clear and that the use of Virtual Reality allowed for a proper assessment of concepts. Some participants mentioned that they would prefer to use the physical concepts for a more thorough testing. Several recommendations were made for improving the test procedure, such as extending the idle time at the beginning of each video or combining the videos into one for added convenience. See Figure 8.7 for detailed information.

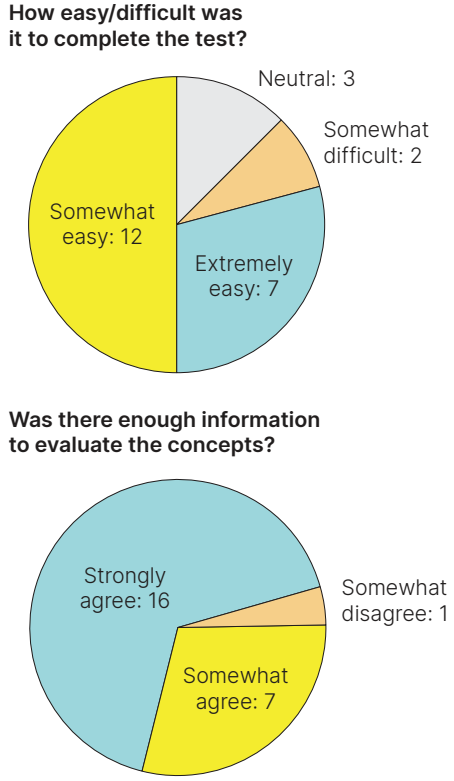


Figure 8.7: Results of the feedback on the study itself.

8.5 Discussion

8.5.1 Introduction
User test results revealed data on preferred concepts and provided quantitative as well as qualitative data on the safety perceptions. In this section, the results are discussed and conclusions are drawn to determine the direction for the final product.

8.5.2 Perceived safety
Despite being as safe as the aircraft setting, the respondents mainly regarded the office setting as much more safe, which reveals the gap between what is perceived and what is proven to be safe. This supports the argument of this thesis that more should be done to increase the PVS of the aircraft interior.

8.5.3 General feedback on concepts
Many concerns were present regarding the food protection, which indicates that any solution that increases the feeling of safety when eating should cover both the passenger and the area around the food.

8.5.4 Preferred concept
The results show that the vast majority of respondents have a preference towards the ”Roller blind” concept - three in four chose it as the preferred concept. In addition, the collected data shows that it has an advantage over other concepts in each of the categories studied. The quantitative data collected for this concept confirm compliance with the “passenger experience” requirements in Chapter 6.5. Therefore, the "Roller blind" concept was chosen as the final direction for the product developed in this thesis.

8.5.5 Feedback on the chosen concept
Convenience feedback was collected during the user test. User quotes are summarized in Figure 8.8 to serve as recommendations for product optimization in the next phases.

8.5.6 Reflection on the test
This study explored novel virtual reality technology to test different prototypes with users. Thanks to the possibility to perform the test at home, it was convenient and safe for participants and allowed for a high test completion rate. Moreover, thanks to the autonomous and decentralized nature of the test, the study could be performed in a short time with a relatively low time investment of the researcher. Virtual reality goggles in combination with omni-directional camera recordings allowed for providing a realistic aircraft interior experience, otherwise difficult to simulate in the physical dimension. This can be promising for studies on user experience, providing an efficient way of testing that is convenient for users.

8.5.7 Limitations
The test relies on the visual and auditory stimuli only; participants might have had insufficient sensory input to assess the concepts thoroughly; limited freedom of movement and interaction with prototypes might have reduced the accuracy of the assessment. In addition, immersive video combined with VR goggles could distort object proportions and distance perception. The lack of direct supervision by the researcher may have resulted in the participants not performing the test properly.

“The roller blinds are not high enough to provide me with a feeling of safety.”
“I'd be worried that someone wants to use the toilet or buy something from the trolley, reducing the protection .“
“Might seem a bit rude for the other passengers.”
“Would not like to be the person in the window seat, how does he/she get out?”
“I would imagine that these things get quite dirty when people use them and spill food and drinks, etc.”
“The magnetic fixating mechanism looks pretty easy and convenient.”

Figure 8.8: Qualitative feedback from users on the selected concept.

Takeaways from this chapter

- The use of Virtual Reality technology allowed for testing prototypes with participants while complying with the HREC measures.
- Half of the participants said the test was “somewhat easy” and two-thirds said there was enough information to assess concepts.
- The collected data supports the argument that there is a gap between perceived and real safety.
- Roller blind is the most preferred concept among the models developed in this project.

Chapter 9

Product embodiment

In the previous chapter, prototypes were tested with users to identify the product direction that best gives a sense of safety from viruses. This chapter outlines the steps that were taken to translate these findings into a feasible product proposal, that will be the end result of this graduation assingment.

9.1 Approach

In this chapter, the selected concept of increasing the perceived viral safety shown in Figure 9.1 will be further developed and presented as a proof of concept.

The first step towards a successful design is the application of the requirements and wishes set out in chapter 6.5 regarding the physical and functional properties of the product as well as its impact. For this, relevant requirements have been grouped into clusters in Figure 9.2.

The steps taken to develop a proof of concept are described in Figure 9.3. Requirement symbols are assigned to indicate which stages of product development will apply to a specific requirements cluster.

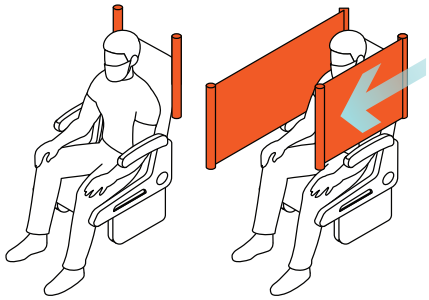


Figure 9.1: The working principle of the developed concept.

Usability
Should be regarded as convenient to use
Should not hamper the vertical airflow in the cabin
Should allow passengers to communicate with the cabin crew easily

Safety
Should allow passengers to stay informed about the safety procedures
Should not hamper the vertical airflow in the cabin
Should not facilitate droplet spread between passengers
Should be made of non-flammable materials

Sustainability
Should be lightweight
Should be made with at least 50% recyclable materials

Feasibility
Should be producible at mass scale
Should be easy to transport
Should be optimized for low weight
Should be easy to uninstall
Should fit the staggered seat of the Flying V

Airline
Should be visually universal for different airlines
Should allow for and withstand the cleaning procedure
Materials and colors should convey hygiene and calmness

Wishes
Should allow for retrofitting in the current aircrafts
Should be possible to clean in 10 seconds or less
Should have a low cost
Should fit within the existing supply chain
Should not use rare earth materials
Should not be built with “Monstrous Hybrids”
Should have a defined end-life
Should be sturdy and long-lasting
Should have a carbon neutral or carbon positive footprint
Maintenance should not require detergents or electricity

Figure 9.2: Product requirements, grouped.

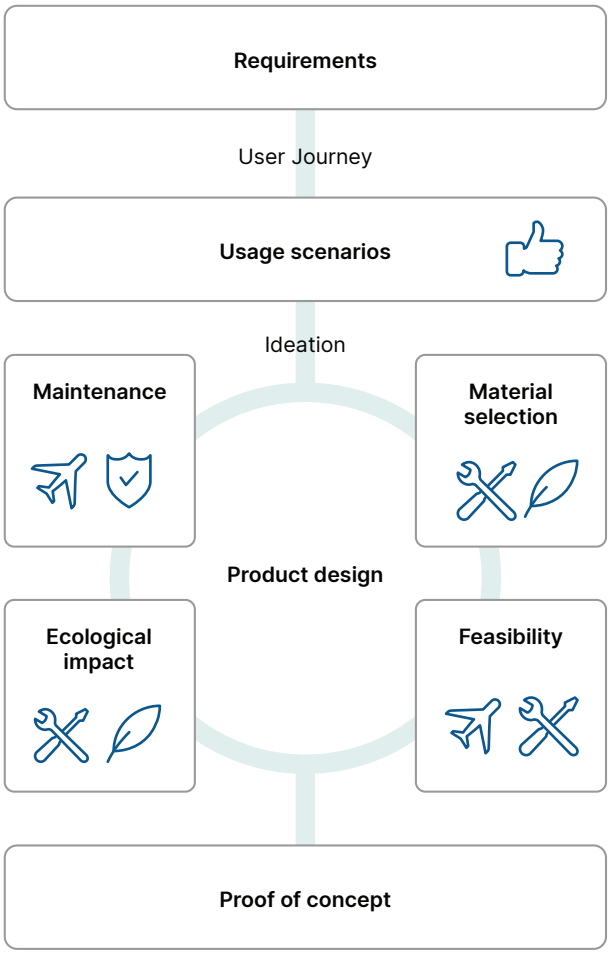


Figure 9.3: Steps taken to develop the proof of concept.

9.2 Usage scenarios

In this section, different product usage scenarios are analyzed to take account of the typical needs of the airplane cabin users. Furthermore, emerging sub-goals are formulated that will be taken into account during the ideation phase. Figure 9.4 visualizes typical activities when using airplane seats and describes the formulated sub-goals. Goals are supplemented with exploratory sketches for initial ideation.

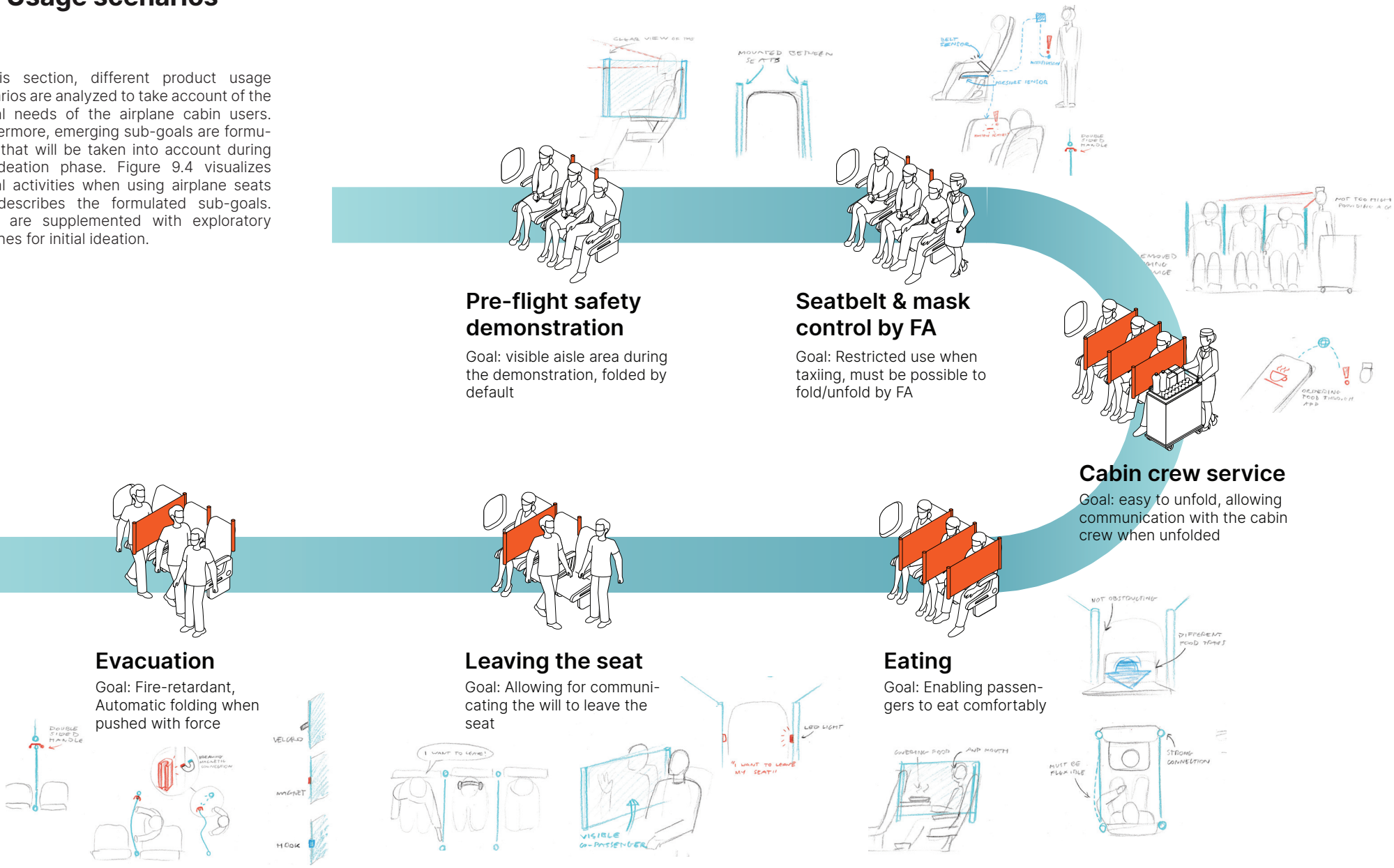


Figure 9.4: Usage scenarios of the product with complimentary sketches.

9.3 Maintenance

9.3.1 Introduction

Interior components, especially those that come into contact with passengers, require regular cleaning by the airlines. Since the COVID-19 outbreak, there has been an emphasis on disinfection procedures to ensure a high level of hygiene for travelers. Doing this in the shortest possible time shortens the turnaround time (TAT) and is therefore desirable for airlines. Figure 9.5 provides an overview of existing and new cleaning procedures along with an assessment of the relevant aspects of the product, namely cost, TAT and hygiene. The selection of cleaning techniques was based on desktop research and articles from an aviation magazine (Aircraft Interiors International, 2021). This paragraph concludes by proposing a maintenance model that takes into account different ways of cleaning the product in order to ensure a sufficient level of hygiene and the shortest possible TAT.

9.3.2 Maintenance model

After comparing different maintenance methods, it became clear that each solution adds time or cost, which affects the profitability of the product for airlines. On the other hand, hygiene should not be compromised. Therefore, solutions that do not require intensive care while maintaining hygienic properties are desirable. This may be possible by using an antimicrobial material that reduces the need for disinfection due to its tendency to kill bacteria and / or viruses. However, no reasonable proposal can be made without further testing that goes beyond the topic of this thesis. To enable further product development, Figure 9.5 proposes a 3-step model involving different degrees of hygiene and using different cleaning techniques to aid in a procedure that can be used to support the antimicrobial properties of the material.

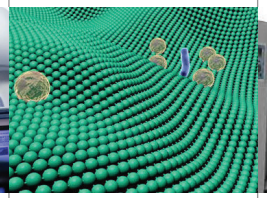
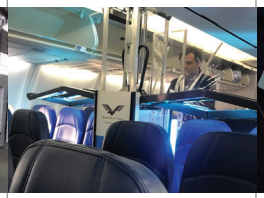
Fogging	Antimicrobial material	Washing	UV light	Manual disinfection	Protective coating
					
Description: Generating a disinfecting fog in the cabin	**Description:** Using a material with natural antimicrobial properties.	**Description:** Washing of textiles in an industrial laundry	**Description:** Disinfecting with the UV light	**Description:** Manual cleaning by cleaning staff	**Description:** Applying the solution to the surface that lasts up to 10 days
Cost: ●○○ **TAT:** ●●○ **Hygiene:** ●●●	**Cost:** ●●● **TAT:** ●●● **Hygiene:** ●●○	**Cost:** ●○○ **TAT:** ●○○ **Hygiene:** ●●●	**Cost:** ●○○ **TAT:** ●●● **Hygiene:** ●●○	**Cost:** ●●● **TAT:** ●○○ **Hygiene:** ●●○	**Cost:** ●●● **TAT:** ●●○ **Hygiene:** ●●○

Figure 9.4: A chart presenting different maintenance options for the product.

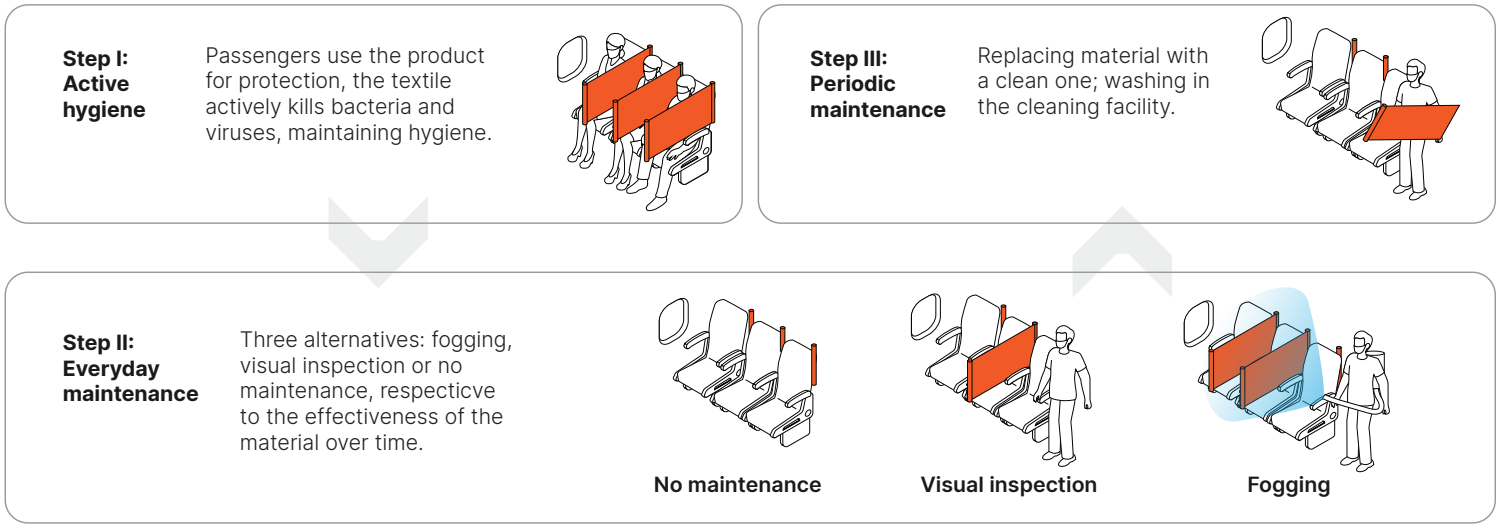


Figure 9.5: A proposed maintenance model of the product.

9.4 Embodiment ideation

The usage scenarios as well as maintenance model provided a basis for a sketch ideation. Different properties of the envisioned product are considered through ideation sketches in Figure 9.6.

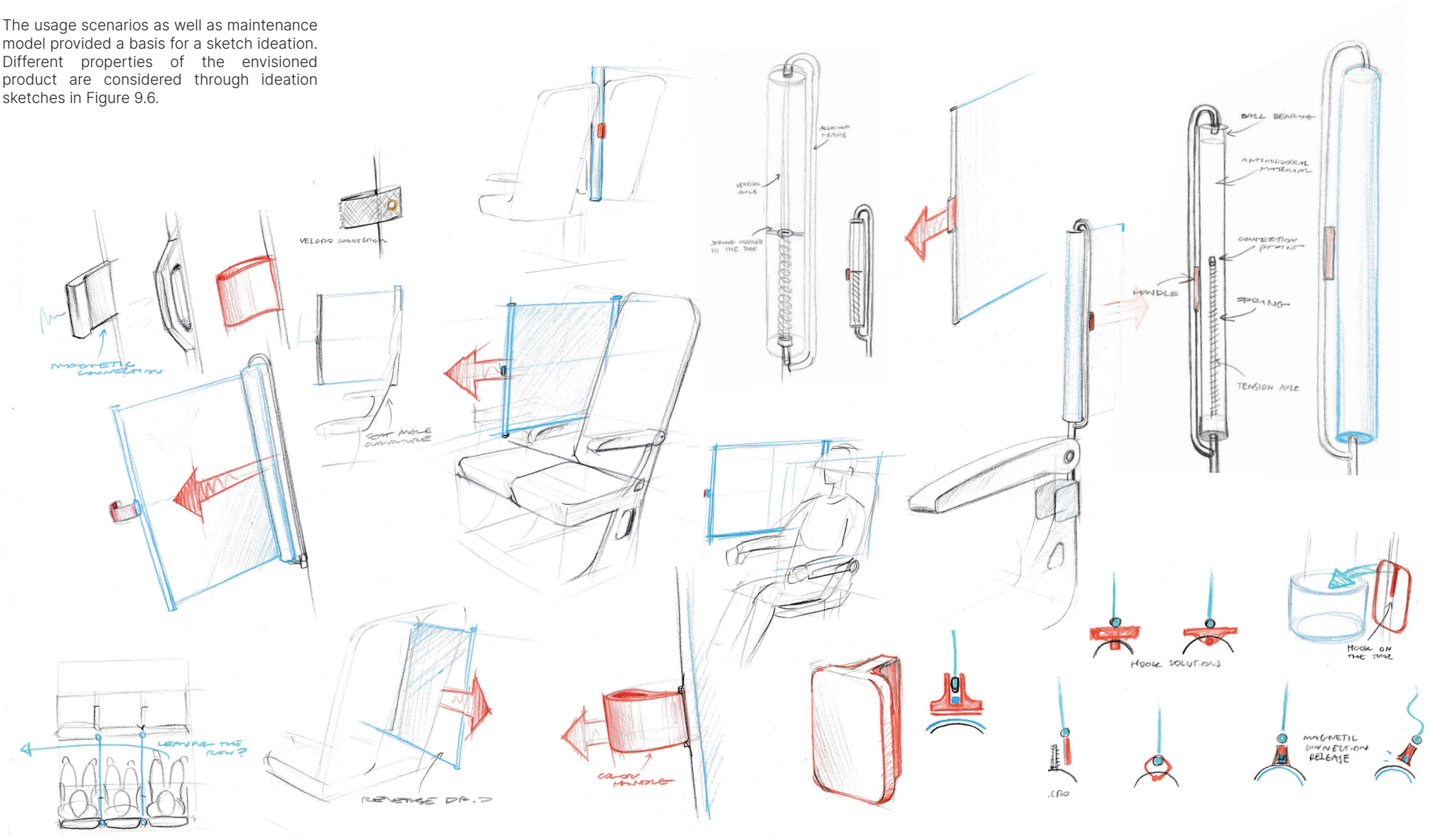


Figure 9.6: Sketch ideation of product properties.

9.5 Dimensions and ergonomics

9.5.1 Introduction

With a general direction for a product embodiment from the sketch ideation, steps are taken to define the physical dimensions and properties of the product. This paragraph explores the possibilites of embedding the product in the cabin environment and refers to human dimensions to ensure sufficient coverage and comfort for different body types. The seat used as the base is the Joy by Rebel Aero, which is applicable to both regular airplanes and the Flying V concept.

9.5.2 Ergonomics

the human population varies in body size, which must be taken into account to ensure inclusive design. As described in section 6.3, the mouth and eyes are the most contagious parts of the body that need to be covered. In addition, as user testing showed, it is advisable to use a separator that covers the food and reaches above eye level to create a sense of security. To determine the size of the product that suits most users, the dimensions of Dutch adults aged 31-60 were obtained from the DINED website (Molenbroek, 2018). In order to determine the extreme dimensions of the height of the eyes that must be covered by the blind, the body sizes of women in the 5th percentile and men in the 95th percentile were used. The height of the divider was calculated by subtracting the height of the elbow from eye level at the 95th percentile. The resulting dimension of 572 mm is rounded to 600 mm. shoulder breadth and seat dimensions were used to determine the installation options of the divider. For a preview of all dimensions, see Figure 9.8.

9.5.3 Embodiment

The generated sketches provided a basis for creating dimensional drawings of the product, provided in Figure 9.7. The seat pitch of 31” is selected, which is used in the economy class of KLM airplanes (Skytrax, 2018). An initial frame shape is defined to fit the Rebel Aero Joy seat.

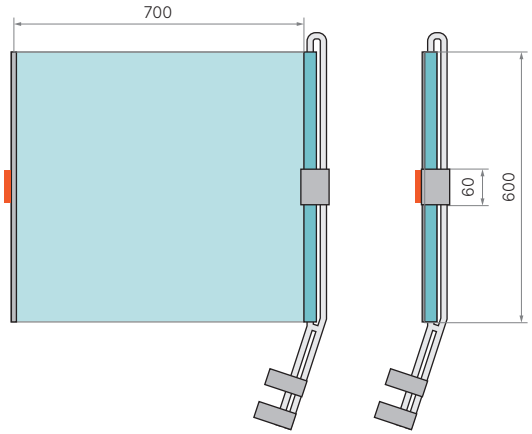


Figure 9.7: Product dimensional drawings.

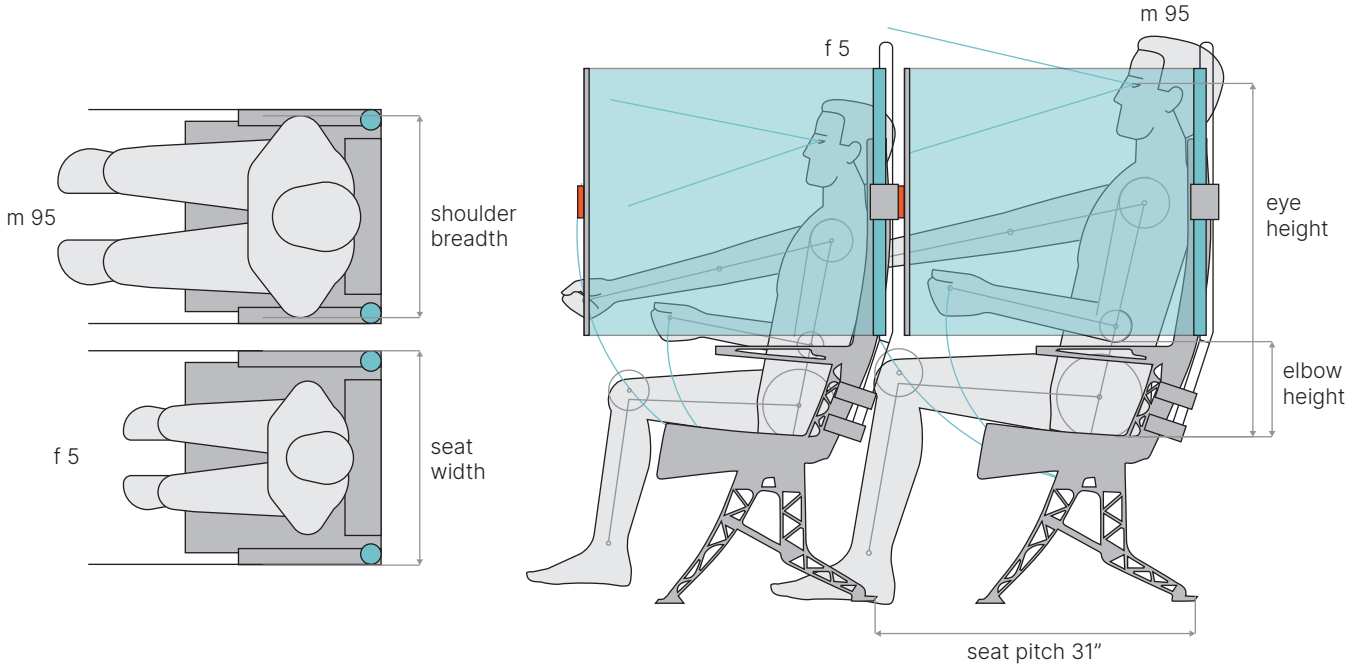


Figure 9.8: Ergonomic dimensions used to determine the physical properties of the product.

9.6 Product embodiment - Iteration 1 and 2

9.6.1 Introduction

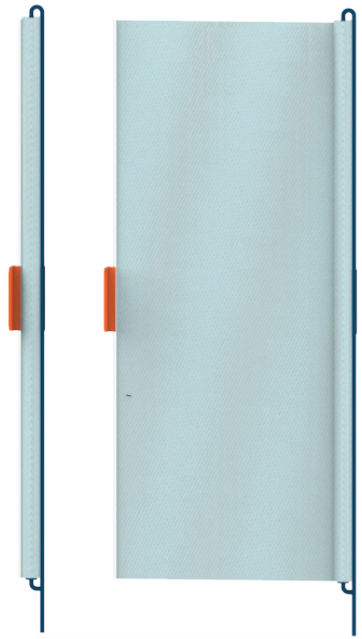
The previous steps allowed to generate the first iteration of the product. For this purpose, CAD models were developed and visualized. Preliminary design choices were made regarding product appearance, materials, and the mechanical properties. This allowed the product concept to be communicated to the expert (Appendix L) and optimized in the second iteration. For a preview of the first product iteration, see Figure 9.7.

9.6.2 Expert meeting

In the meeting with Embraer's interior product designer, several optimization points were proposed for the initial design. It was recommended to provide a more robust frame that would provide structural strength and withstand heavy use by passengers. It was advised to focus on making sure that the fabric always folds as intended, as it may warp due to improper use and thus hamper the disembarkation procedure. Moreover, it was recommended to explore ways to protect the cover fabric and consider a guide nozzle that will evenly distribute the fabric. Regarding mounting, it was advised to study the existing seats of major manufacturers and look for common mounting points. It was also recommended to focus on a mounting solution that requires no special tools to disassemble. It was appreciated that the divider was opened in a forward motion, which the expert regarded as more intuitive than in the opposite direction. It was recommended to investigate ways to improve communication, for example by using transparent material and embedding seat belt sensors, to allow personnel to check the seat belts faster. Finally, advice was given on commonly used materials in the aircraft cabin.

9.6.3 Second iteration

The insights collected during the expert meeting allowed for the development of the second iteration of the product, presented in Figure 9.8



Iteration 1

Figure 9.7: First iteration of the product.

Iteration 2

Figure 9.8: Second iteration of the product.

9.7 Materials and processes

9.7.1 Introduction

The choice of materials is an important aspect of product development that determines its physical properties, enables different production methods and allows for a more structured assessment of its environmental impact. This section presents material selections resulting from expert consultation and desktop research. The main materials are detailed below.

9.7.2 Screen fabric

The proposed maintenance model in section 9.3 considers the use of an antimicrobial fabric. Furthermore, a transparent textile is preferred, which would facilitate communication. In a desktop search for suitable materials, two types were found:

TORAY Makspec V

Makspec V is a novel antiviral polyester textile, which has proven effective in reducing concentrations of SARS-COV 2. Tests have shown shown a 99.9% reduction of the virus over the time of two hours (Toray, 2021). The material shows the same properties after 50 commercial washing cycles, which proves its potential for commercial use.

Trevira Bioactive CS

Trevira Bioactive CS is proven to kill bacteria efficiently. However, no tests regarding the COVID-19 virus are available. The fabric maintains properties after 50 washing cycles. The material is flame retardant, which shows promising in implementation in the aircraft cabin.

Frame and structural components

The frame will provide a structural strength and will allow for a stable attachment to the seat. In an expert meeting, aluminum alloy 2024 was recommended, which is one of the most commonly used alloy types in aircraft interiors (Smye, 2018), having an excellent cyclic fatigue resistance and low weight.

Plastic parts

Different types of plastics are used according to different desired mechanical and aesthetical properties of the part (Williams, 2020). The plastics used are PMMA, PP, ABS and TPU for the screen fabric. For an overview, see Figure 9.9.

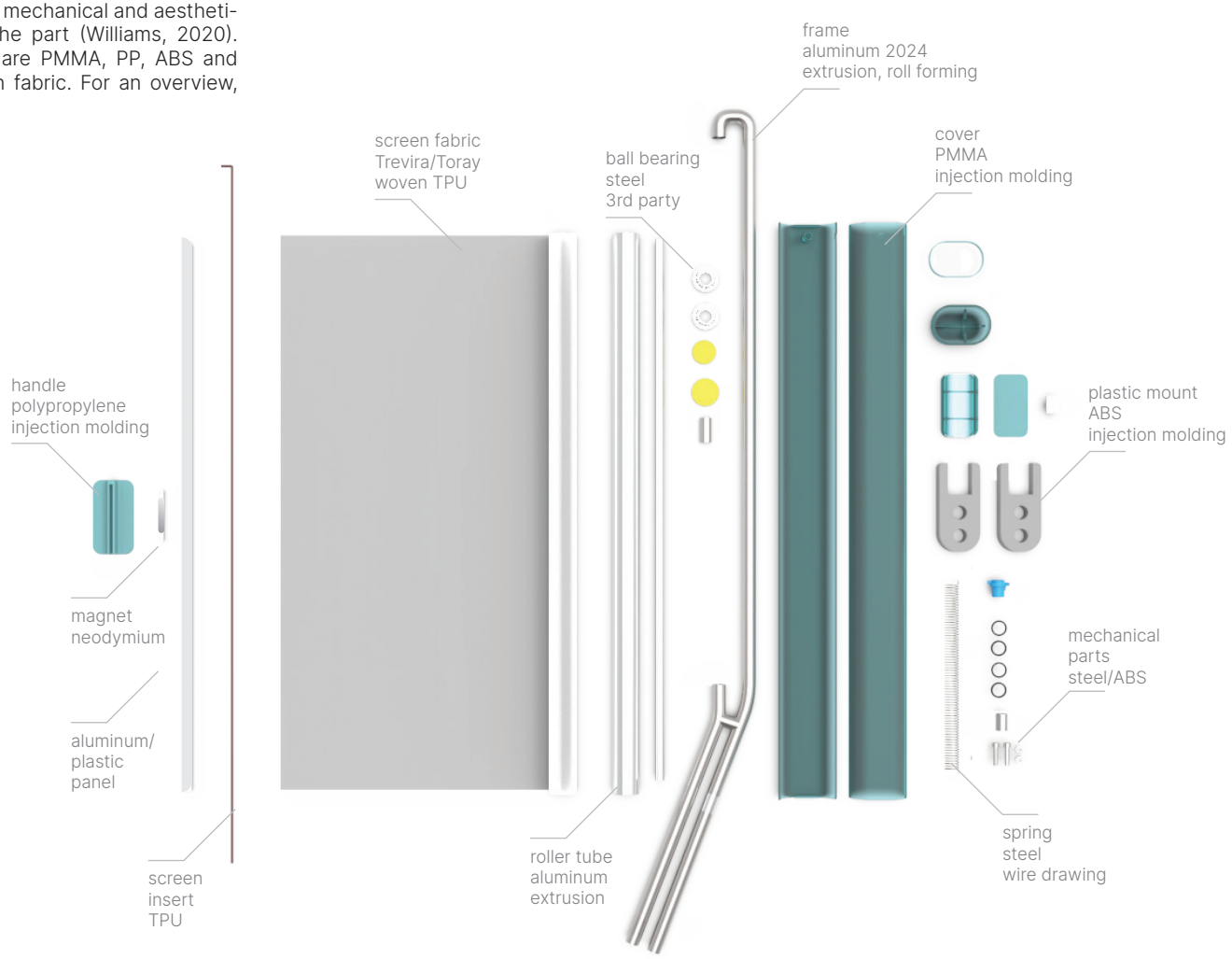


Figure 9.9: Product components resulting from the selection of production processes and materials.

9.8 Environmental impact

9.8.1 Introduction

This project aims to develop a product that will have the lowest environmental impact possible throughout its lifetime. In this chapter, different aspects of a product's life are assessed using the Fast-track Life Cycle Assessment (Muralikrishna and Manickam, 2017) and EcoDesign (Sanyé-Mengual et al., 2014) methods to provide a structured estimate of its environmental impact and identify opportunities for product optimization. The overview is shown in Figure 9.10.

9.8.2 Procedure

The following methods were selected to assess and communicate the environmental impact of the concept (I. de Pauw, personal communication, March 3, 2021):

Fast-track Life Cycle Assessment

The Fast-track LCA method allows for the quantification of the environmental impact by assessing the materials used, the processes needed and their impact at different stages of life (Muralikrishna, 2017). This allows to make more informed design decisions and provides meaningful optimization strategies. First, an inventory was made based on design considerations and weight and dimension figures from CAD models. This included a selection of materials, manufacturing processes, component weight, and usage patterns. A complete inventory is provided in Appendix M. As the product will be transported in an airplane which uses fuel, the estimated product life of seven years is selected with an average of 3000 flying hours per year (Stagliano, 2016).

The information collected was used to conduct an EcoAudit with CES EduPack (Granta) software. It allows for a numerical estimation of the impact using two commonly used environmental stressors - energy consumption and carbon footprint. The results of the assessment are shown in Figure 9.11. The comparison of impacts for two iterations, see Appendix N. For the entire EcoAudit report generated by CES EduPack, see Appendix O.

Discussion

LCA allowed the quantification of impacts and the identification of the most unsustainable phases of a product's life. An important finding is that using the product in an airplane has an overwhelming share of the overall impact on the life of the product. This is because the airplane uses fuel to carry the extra weight generated by the product. Optimizing weight, and hence reducing impact, can be twofold; first by reducing the weight of a single unit, and then by optimizing the load factor per seat in the airplane cabin.

Ecodesign Checklist

To support product optimization, further evaluation was performed using the EcoDesign Checklist (Brezet and Hemel, 1997). It supports the analysis by providing a set of questions about the different stages of a product's life. This allows the identification of potential environmental bottlenecks and provides room for improvement. Selected solution spaces are shown in Figure 9.13 on the next page. The full EcoDesign checklist is included in Appendix P.

EcoDesign Strategy Wheel

Assessment results are visualized by the EcoDesign strategy wheel in Figure 9.12 on the next page.

9.8.3 Product optimization

The conclusions from LCA and EcoDesign highlight the possibilities to redesign the product and optimize its use on the plane. Based on the findings, a new design is proposed In section 9.10. The strategy of weight optimization by reducing the number of units in an airplane is presented in section

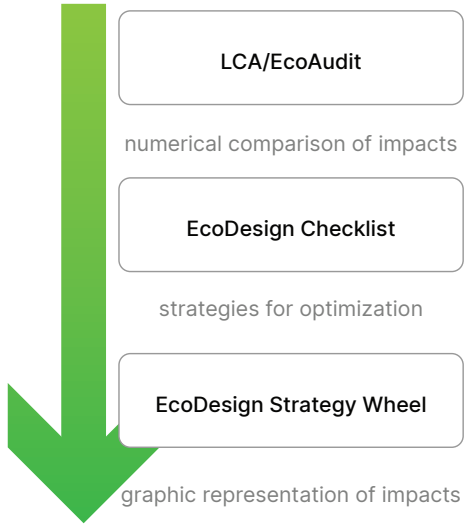


Figure 9.10: Approach for assessing the environmental impact.

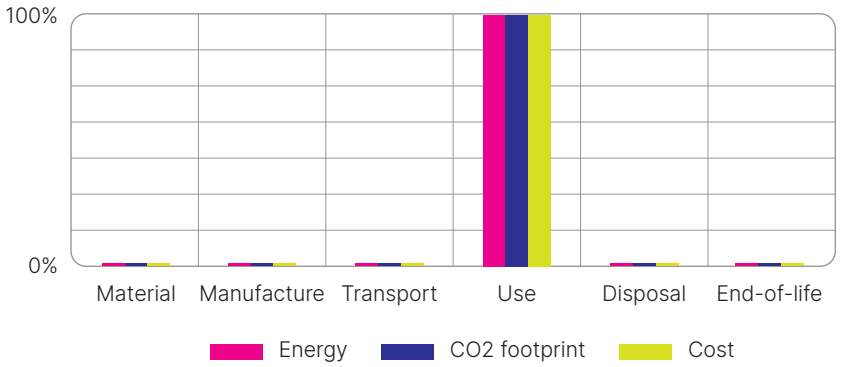


Figure 9.11: Relative contribution of different life phases on the overall impact.

9.9 Optimizing the impact

The EcoDesign checklist allowed to define areas for improvement in various aspects of product life. The EcoDesign strategy wheel in Figure 9.12 visualizes the results of the assessment presented in Figure 9.13, as well as the areas for product optimization and strategies for future improvement.

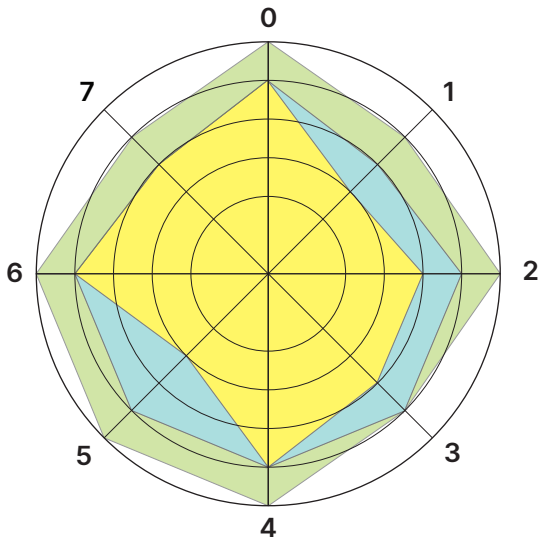
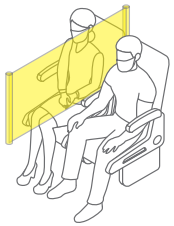
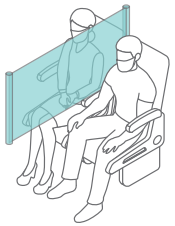


Figure 9.12: EcoDesign Strategy Wheel showing an evaluation of the current concept and two strategies for product optimization.





EcoDesign strategy	Current design	Optimized design	Future improvements
0 **New concept development**	Fullfills the need for virus safety, as well as gives an additional benefit of privacy	A new function added - seat number indicator.	Providing a flexible space division, adaptation for other modes of transport
1 **Selection of low-impact materials**	Materials relatively hard to recycle; uses materials from Critical Elements List	Using recycled plastic for the casing, eliminating neodymium magnets	Using novel sustainable materials; all materials recycled/recyclable
2 **Reduction of materials usage**	Irregular frame shape, relatively heavy unit, little packaging needed	Less weight achieved by reducing the cover size, more compact design	Using parametric design to optimize weight, remove parts, foldability
3 **Optimization of production techniques**	Many processes needed to make the frame; energy-intensive injection moulding	Less plastic elements; Simpler frame shape, greener materials used	Considering less production steps, further optimization to reduce plastic
4 **Optimization of distribution system**	Product transported from factory to OEM, no further distribution required	A more foldable design, less packaging volume, weight reduction	Improved packaging, green or no packaging, further weight reduction
5 **Reduction of impact during use**	Does not use energy directly; high indirect consumption; hard to disassemble	Reduction in weight, easier to disassemble; reduced use in the aircraft	Cleaning only in the aircraft; optimizing of use in aircraft with AI/big data
6 **Optimization of initial lifetime**	Relatively easy to repair, easy maintenance, similar to current solutions	More reliable attaching; optimized for easy disassembly	Modular design, easier access to the mechanism
7 **Optimization of end-of-life system**	Materials generally recyclable; controlled process; relatively easy to detach	Faster detachability; simpler design for easier disassembly or repurpose	Using more recyclable materials; repurposing or remanufacturing plan

Figure 9.13: Highlights from the EcoDesign Checklist.

Optimized design - iteration 3

In the third iteration, the optimization strategies are implemented in the new design shown in Figure 9.14. The second EcoAudit was conducted for the new design and the obtained numerical values are compared with the previous product to show the improvements in Figure 9.14. such

Embodiment improvements
The product is optimized to provide the same functionality with less plastic and aluminum. The result is a weight reduction of 0.2 kg from the previous 1.3 kg. An additional function has been added to indicate the seat number in an accessible way. The frame has been redesigned in a way that shortens production steps and facilitates dismantling.

New materials
In order to reduce the impact of the plastic used in manufacturing, an innovative type of material is used, Ecothylene (Vanbriel, 2020), which uses scrap plastic for production, and can be recycled again after use. The magnetic handle was replaced with a metal hook, which excludes the use of neodymium, a rare earth material.

Discussion
The sustainability methods used to optimize this product have facilitated eco-innovation and resulted in an improved design. A new feature has been added to improve the passenger experience. Less plastic is used, which has a significant impact on weight reduction and thus CO_2 emissions. More environmentally friendly materials were used and one rare earth material was excluded. The resulting product, in addition to having a lower environmental impact, is lighter, simpler and more functional.

-15%
weight reduction

-69%
less plastic

€56
savings per unit/year

2t
less CO_2 per unit in 7 years

~~Nd~~
excluded rare earth materials

easy
to disassemble

eco
recycled plastic used

Figure 9.14: numerical comparison of the improved product's impact.

9.10 Airline viability

9.10.1 Background

The airline will be the main entity responsible for handling this product. Therefore, a need was identified to develop an implementation strategy that would be satisfactory for customers and, at the same time, profitable for airlines. In this chapter, different usage scenarios are considered with a goal of developing a model that takes into account the interests of the airline, considers different needs of passengers and ensures a low environmental impact.

9.10.2 Perception of safety and viability

During a pandemic, when the feeling of safety is crucial for passengers, providing a divider for every flyer may improve the airline's image as a safe carrier. However, as the confidence in flying is likely to increase after the pandemic, there might be less demand for virus protection on the future flights. This is supported by a large study by Inmarsat (Inmarsat, 2020) in which 27% of the respondents showed confidence in flying again six months after the pandemic subsides. Furthermore, one in five of all participants stated that they are very satifsied with the current airlines' response to the pandemic. This indicates that not all passengers will need a divider to feel safe in the aircraft cabin. This is important for the implementation strategy, as optimizing the number of dividers saves costs and limits the CO2 emissions.

9.10.3 Financial incentive

Airlines strive to provide good service for passengers to attract customers and generate profits. One such practise is providing various paid benefits, such as seat selection or increased legroom, which improve the travelling experience. A personal divider, which gives a sense of safety and privacy, may be one of such products offered by an airline as an option for customers seeking a safer or more private flying experience. In the user tests conducted in chapter 8, participants were asked whether they would be willing to pay more for a seat with the divider installed. Over a third of participants claimed that they would be willing to pay up to 10% more for a ticket, which indicates that apart from increased reputation, airlines may have a financial incentive to implement such a solution. The data on willingness to pay from user tests is used to estimate a proposed fee for the "safe seat" for a reputable and budget airlines (Statista, 2020b). Next, the estimated profit generated from the fees is extrapolated for a regular flight scenario to indicate the potential total profit on the total ticket sales for a flight. The results are presented in figure 9.16.

9.10.4 Sustainability

The results of the sustainability assessment provided insight that the greatest environmental impact of this product occurs during the use phase. This is due to the consumption of fuel and energy to carry the extra weight. Consequently, it can be concluded that any strategy that minimizes the number of dividers per seat will yield a smaller footprint and savings for the airline. This is especially relevant after the pandemic, when airlines are likely to re-focus on lowering costs and reducing CO_2 emissions on each flight.

9.10.5 Willingness to fly

A potential benefit for an airline from introducing such product is an increased willingness to fly among customers. One in three test participants claimed that they would be probably more willing to fly during a pandemic with this solution and one in six claimed that they would be definitely more motivated to do so. This indicates that airlines that implement this solution in their aircraft may contribute to restoring confidence in flying, and in consequence, support the recovery of the aviation industry.

9.10.6 Stages of perceived safety

In order to propose a strategy that addresses different levels of perceived safety, three stages are distinguished in Figure 9.15. Each stage describes the likely attitudes of passengers towards viral safety at different stages of the virus outbreak and the approach that the airline can take to address them. The division of the strategy into three stages allows for the creation of a model that adapts to the current needs of passengers, balances profits while respecting the airline's reputation and optimizes load per seat to reduce CO_2 emissions in the long term. Figure 9.17 on the next page shows the resulting three-step product implementation strategy for the airline.

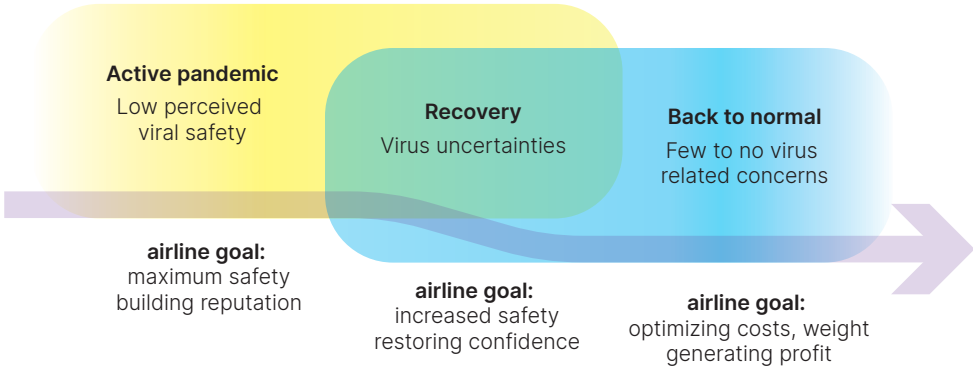
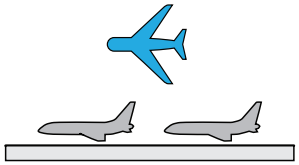


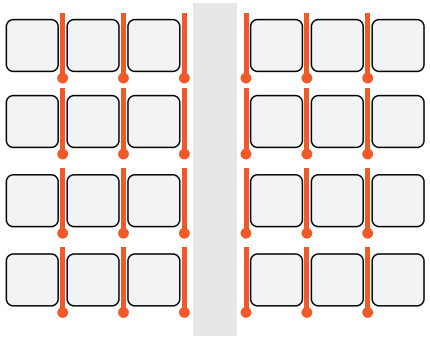
Figure 9.15: A proposed strategy for airline operations recovery.

Figure 9.16: Potential profits from ticket sales for different airlines.

Scenario 1: Pandemic

Low air traffic, increased disinfection, travel restricitons, low perceived safety





Density per seat: 100%

One divider per one seat; each passenger is covered from both sides; no fees.

Airline strategy

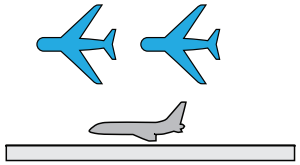
"Providing highest safety for each passenger"

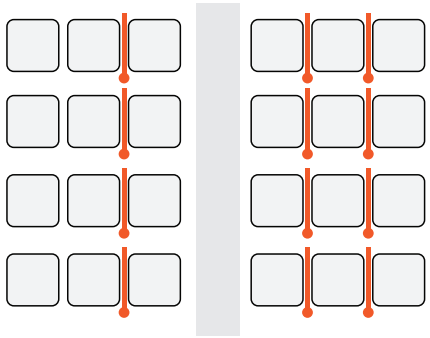
Safety+

Product proposal: divider as standard on each flight to give extra safety, increase the willingness to fly and improve airline reputation.

Scenario 2: Recovery

Increasing air traffic, increased disinfeciton, lifting travelling restricitons, rebuilding confidence





Density per seat: 50%

Every second seat equipped; twice as many airplanes; flexible arrangement of dividers; aisle side not covered; a minimal or no fee.

Airline strategy

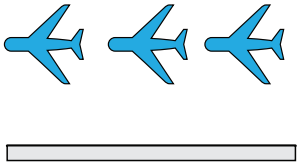
"Flexible options for privacy and limiting physical contact"

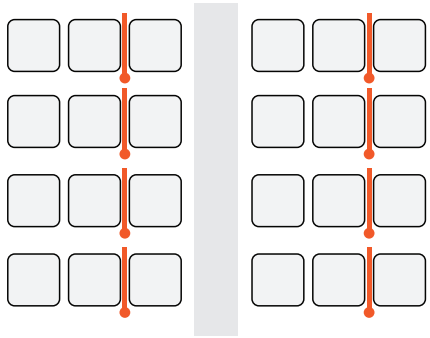
Privacy+

Product proposal: Different arrange-ments in the interior to provide safety as an option for customers that need it.

Scenario 3: Back to normal

Regular air traffic, regular maintenance, no travelling restrictions, confidence in flying





Density per seat: 33%

One in three seats equipped. 3x more planes; divider as a paid feature, up to 10% of ticket; privacy is the primary focus.

Airline strategy

"Privacy on demand"

PrivateZone

Product proposal: PrivateZone; divider as a paid feature to give privacy for the passengers that need it; a choice of a single or double seats for different types of flyers.

Figure 9.17: The proposed three-step implementation strategy of the COVR product.

Takeaways from this chapter

- The product has been optimized for compliance with the requirements in three design iterations.
- Various aspects were considered including usage scenarios, maintenance, ergonomics, materials and production techniques, environmental impact and cost effectiveness for airlines.
- The sustainability assessment allowed the product to be improved and the environmental impact to be reduced.
- An implementation plan was proposed that distinguishes between three stages of perceived safety in order to optimize the load factor of the product in the aircraft.

Chapter 10

Final design

This chapter aims to introduce the final product that emerged from this graduation assignment and explain its key features.

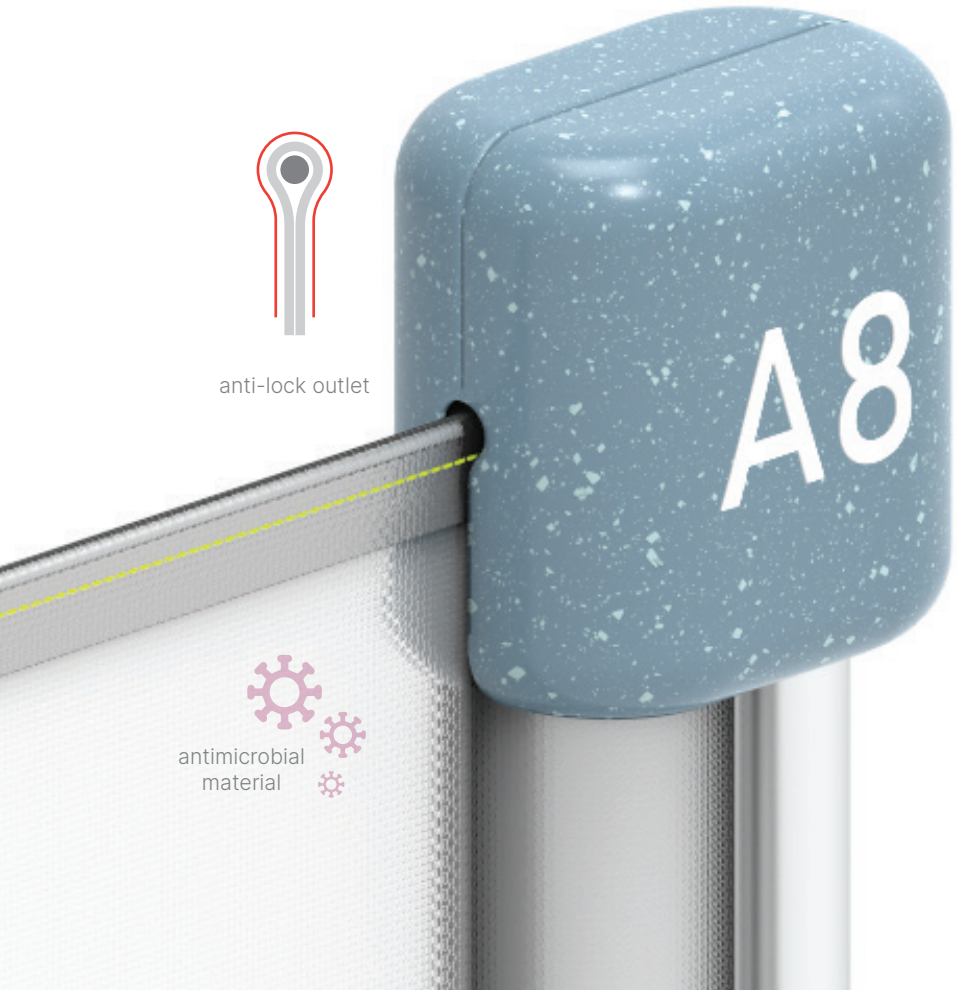

A8

Got you covered.

COVR not only provides a sense of safety, but also aims to reduce the risk of infection. The screen divider serves as a physical barrier that limits contact between passengers. The antimicrobial fabric reduces the spread of droplets to other seats and kills over 99.9% of COVID-19 viruses. An open top can promote favorable airflow characteristics in the cabin*. All this so that you can relax and get to your destination safely.

*futher tests required.

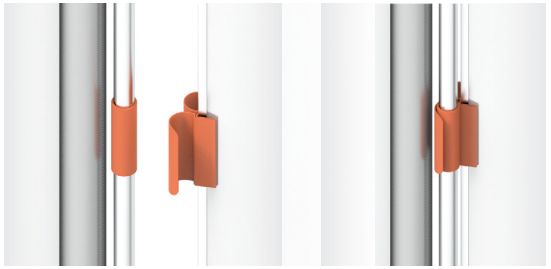
Noble in purpose, clever in detail.



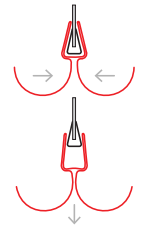
anti-lock outlet

antimicrobial material

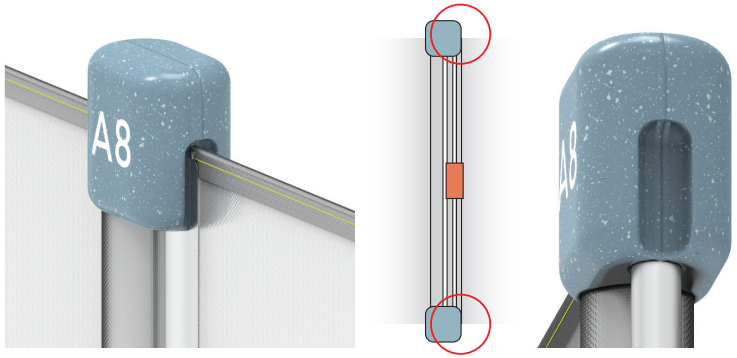
recycled Ecothylene plastic



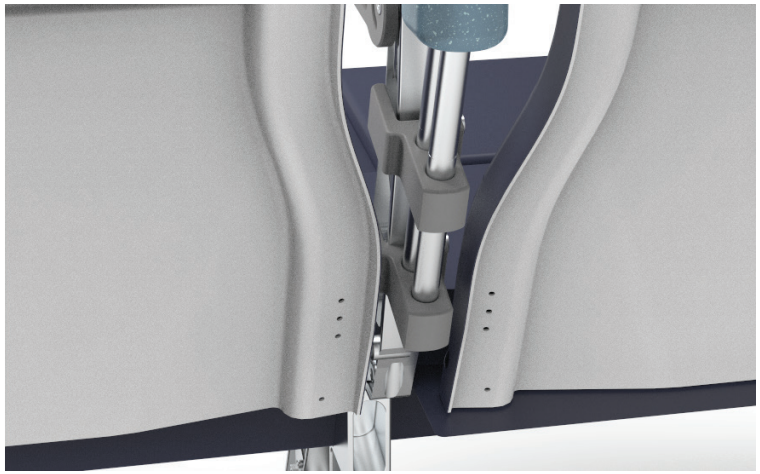
two-sided attachment handle



quick fabric release for easy maintenance



anti-warp screen stabilizer



interchangeable mounting to fit different types of seats

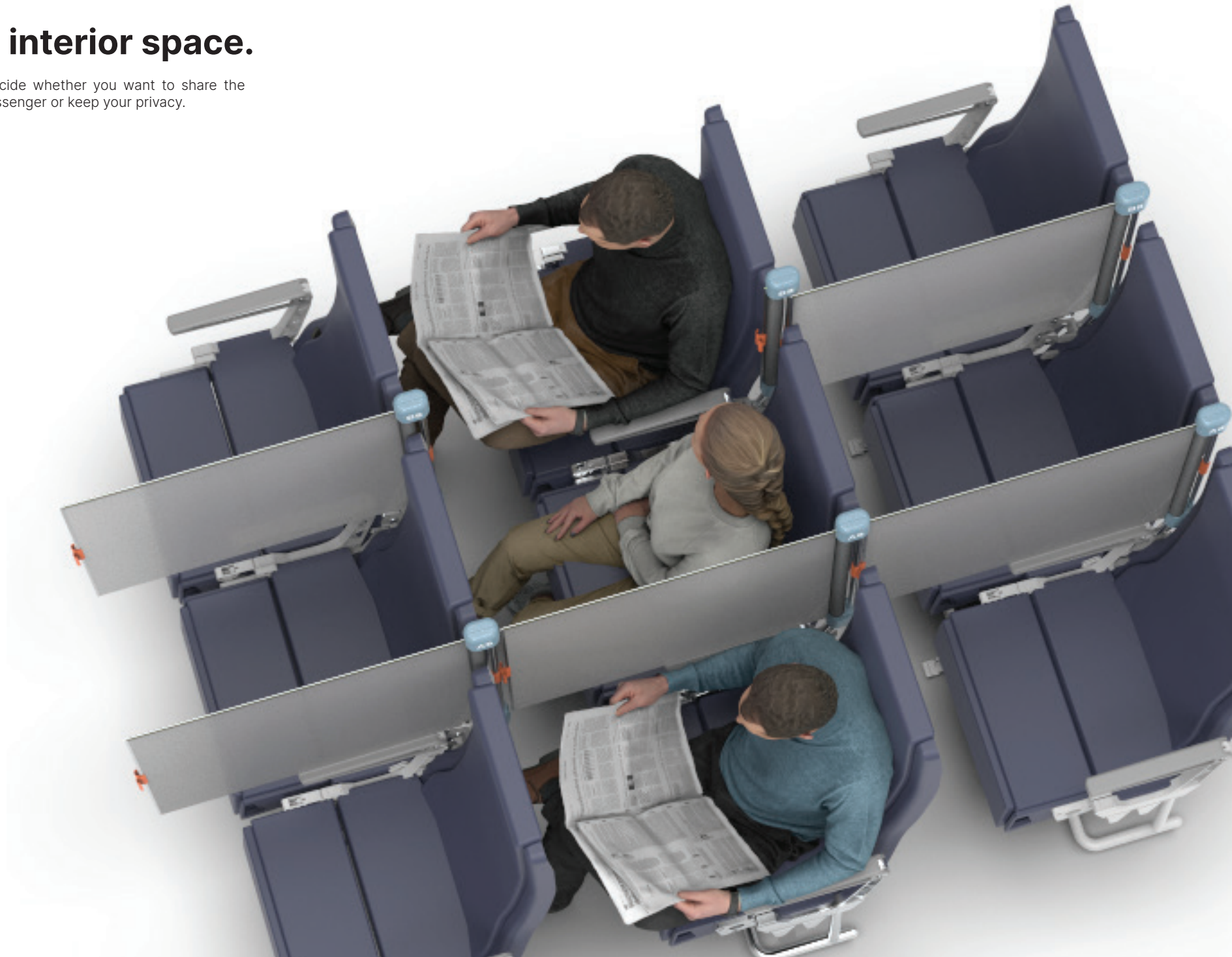
Integrated.

Low weight and compact size for application in various types of cabins.

Seat number indicators for finding the seat quicker

A flexible interior space.

COVR allows you to decide whether you want to share the journey with another passenger or keep your privacy.



COVR.
Have a safe flight.

Chapter 11

Expert validation

The previous chapters focused on product embodiment, considering its use, environmental impact and implementation strategy. However, a need for an expert evaluation was identified to understand if the developed design was feasible and desirable, and to explore possibilities for further improvement.

11.1 Introduction

11.1.1 Introduction

In order to assess the key aspects of the concept developed in this graduation project, experts from relevant fields were invited to share their views on the project results. In total, five meetings with eight experts were held. Embraer's cabin safety expert was consulted to assess the product's compliance with the safety regulations in the aircraft interior. Furthermore, experts from KLM Cityhopper were invited to evaluate the airline's maintenance and implementation strategy. Finally, an assessment of the product's impact on cabin airflow was consulted with an Environmental Control specialist from Embraer, and feedback on the use of environmental optimization methods was collected from a sustainability professor at the Delft University of Technology.

11.1.2 Procedure

Experts were contacted with the help of Embraer. To keep the consultation confidential, experts were selected on the basis of a confidentiality agreement with Embraer. The list of experts is presented in Figure 11.1. An individual digital presentation was prepared for each expert. Each presentation contained a brief summary of the concept, detailed information on the aspects assessed in the area of specialization, and a set of discussion points to facilitate the conversation. See Figure 11.3 for a preview of the presentation slides.

Expertise	Organization
Airline fleet manager	KLC
Maintenance and operations expert	KLC
Interior systems engineer	KLC
Interior systems engineer	KLC
Sales director	Embraer
Airworthiness & Cabin Safety expert	Embraer
Environmental Control System expert	Embraer
Sustainability expert	TU Delft

Figure 11.1: List of experts consulted to evaluate the final concept.

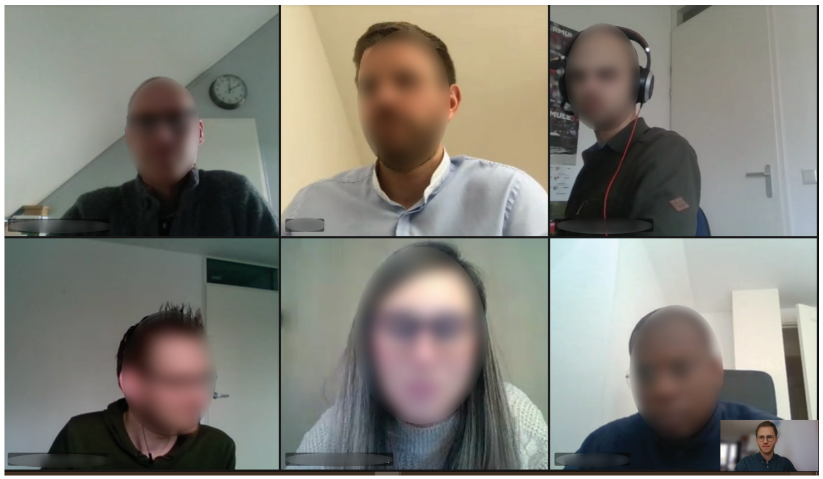
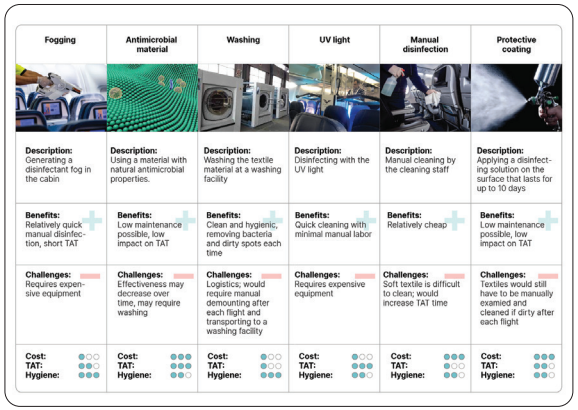


Figure 11.2: An online meeting with airline experts to evaluate the proposed strategies for maintenance and implementation.



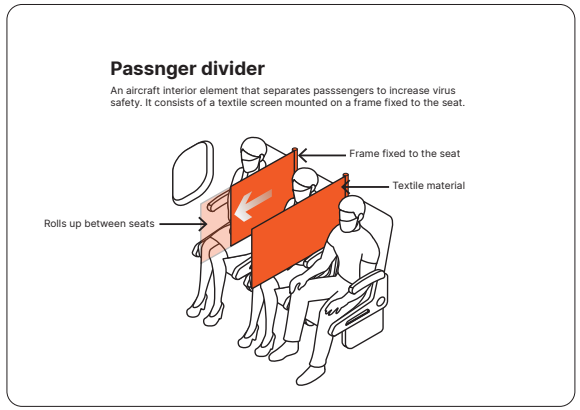


Figure 11.3: Preview of selected slides sent to the experts before the meeting.

11.2 Results

11.2.1 Cabin safety expert

A meeting with an expert on aircraft cabin safety brought an overview of the challenges related to safety certification required to bring the product on board of an aircraft. During the meeting it became clear that assessing a product's compliance with safety requirements requires a series of extensive tests that would have to prove that the concept is reliable and intuitive in everyday use, and also safe during an evacuation or in the unlikely event of an accident.

Several regulations have been identified by an expert as crucial for implementing such a product:

Emergency landing conditions (crashworthiness)

Static load test (25.561) - test where forces are applied to the seat. Since the divider will be mounted on the seat, it has to take part in this test.

Dynamic Load Test (25.562) - A test performed to determine whether a product could injure passengers when high force is applied.

Physical Injury test (25.785) - a test that ensures that the passenger will not be seriously injured during an emergency landing as a result of the inertia forces.

Evacuation

Each new element of the cabin can slow down the evacuation time and therefore requires testing. There must be a guarantee that the product will not prevent any passengers from properly evacuating. This can generally be proven by analysis. Moreover, a re-run simulation of the entire evacuation procedure may be required to prove that the product does not significantly impede the process.

In addition, it was emphasized that the design would need to be tested to withstand abuse loads - forces resulting from improper use by passengers.

Recommendations

The expert made some comments that could potentially improve the feasibility (certifiability) of the proposed divider:

- Improving the screen rolling mechanism to allow the curtain to self-fold for increased reliability during evacuation.
- Identyfying and eliminating any sharp edges from the product to prevent physical injury.
- Placing a safety placard in a visible location, informing passengers about proper use and instructing to fold the divider during taxiing.
- Optimizing the screen connection, which needs to be strong enough to withstand normal use, but also fragile enough to self-retract when pushed so as not to jeopardize evacuation.

When designing a new device for the interior of an aircraft, several tests must be carried out to confirm certification. The specific certification for this type of product would include flammability assessment, static and dynamic load tests, and evacuation analysis. Possible improvements could include a redesign of the retraction mechanism, adding a safety placard, and optimizing the connector for reliability in the event of an evacuation.

11.2.2 Cabin Environmental Control expert

In the consultation with environmental control expert, which specializes in the airflow and temperature exchange in the cabin, various challenges and recommendations were identified. The main conclusion is that it at this stage of development it cannot be assumed whether the product improves or reduces the risk of infection by assisting the airflow in the cabin. This is due to the fact that the airflow in the cabin is a highly controlled environment, tailored for the current shape of the cabin interior. Therefore, the introduction of any physical product into the cabin will promote the new airflow behavior, which will impact the distribution patterns of droplets among passengers. One consequence of disturbing the current air flow may be the formation of a specific microclimate around the passenger, in which the air, instead of being frequently exchanged, remains in the passenger's personal space or in the worst case is dragged upwards due to the temperature or air velocity differences above the divider. The air outlets located above the passenger's head only play a minor role in the airflow in the cabin and therefore cannot be relied upon to effectively remove air droplets from the personal space.

Recommendations

One recommended method of proving the effectiveness of the divider is to run tests with an optical particle generator that measures the concentration of particles in adjacent seats. Other tests can be performed using smoke and odor generators, which may be less reliable but more cost effective. Another long-term solution that can be costly but will prove most effective is to redesign the way air is introduced into the aircraft cabin. Possible improvement could include a more individualized airflow for each passenger which, in combination with the divider, could focus on creating a favorable microclimate for eliminating the risk of viral infection.

The introduction of a divider in the cabin of an airplane will undoubtedly cause disturbances in the flow of air, which may prove either beneficial or deteriorating for the viral safety of the cabin. No assumptions can be made about the advantageous droplet propagation properties of the device without thoroughly testing with particle generators and / or CFD simulations. These may indicate possible product design improvements or an adaptation of the airflow in the aircraft cabin to work effectively with the distributor.

11.2 Results

11.2.3 Airline experts

During the meeting with aviation experts, the maintenance plan and implementation strategy were reviewed. This is to identify the market opportunities for the product and anticipate the real challenges that the product concept may pose before implementation.

During the meeting, an issue was raised that it is very difficult to provide a reliable cleaning method that will prove profitable for the airlines, as each new cleaning element increases the downtime for the aircraft. There have been concerns about the reliability of the antimicrobial fabric, which, if not cleaned after each flight, may not fully prevent the spread of the virus. This is especially important for airlines that strive to minimize turnaround times, for which the 2 hours tested, which the fabric takes to remove all viruses from the surface, would not guarantee hygiene. Therefore, more careful maintenance would be necessary, most likely involving manual work or fogging / UV C equipment, which could be an additional burden in time and cost.

"As an operator, you want the least maintenance for the for the most yield. That's why it is so important to know what the fabric maintenance requirements are; is it necessary to replace or wash it weekly, monthly? This simple variable can have a decisive influence on the viability of the concept."

Experts agreed that a short-haul carrier such as KLM Cityhopper may not find such a solution feasible as the potential benefits will not outweigh the emerging challenges. However, experts concluded that this product has the potential to prove beneficial on long haul flights where cleaning is less frequent and more thorough, and the need to eat is more common among passengers. The added privacy provided by a partition may also be desirable on longer flights, while on short haul routes where eating and privacy are less desirable, the benefits of such a partition may not be sufficient. In terms of the implementation strategy, the further optimization of the product offering was proposed to make it clear to passengers traveling without a divider that they are not necessarily more vulnerable to viruses as this could backfire on the airline's reputation. In order to further develop the product, it was advisable to consult the consumer relations department to make sure that the plan for introducing this product will be prepared in accordance with consumer expectations and that it will be clearly stated what exactly benefits the product brings during and after the pandemic, so as not to cause confusion.

11.2.4 Sustainability expert

Consultation with a sustainability expert was aimed at assessing the use of the methods and obtaining general feedback on the approach to product development. In order to facilitate the assessment, the Expert was asked to leave feedback directly in the prepared document in the form of comments. The approach was generally appreciated and the use of the fast-track LCA method to narrow down the scope of impacts to focus on was appreciated. Some comments have been made regarding the presentation of the optimization results, namely to provide a benchmark for comparison, for example by using percentages instead of numbers, as it may be unclear for many people what percentage of the overall impact certain improvements have. The approach to addressing every strategy from the Eco-Design checklist was questioned as it is recommended to put greater focus on the biggest product bottlenecks that generate the highest environmental impact. By focusing the scope of optimization to weight reduction, potentially even greater weight cuts can be achieved and thus an even lower impact.

Chapter 12

Discussion and recommendations

This chapter aims to summarize the developments of this graduation assignment. The first part provides answers to research questions. Next, the project requirements and wishes are considered to evaluate the success of the project. A set of recommendations is then provided which summarize the improvements identified during this project. This chapter ends with a discussion on the project itself and a personal reflection.

12.1 Answers to research questions

What perceptions of viral safety are present in typical activities in the cabin during a pandemic?
Chapter 3 describes the interviews that were conducted to determine the level of perceived safety during various activities in the cabin. By gaining qualitative feedback from recent flyers, it was possible to determine which moments in the cabin of the aircraft caused the greatest concern about catching the virus. This allowed the scope of this thesis to be narrowed down to the most relevant moments that affect the perception of viral safety.

During which activities the feeling of viral safety is the lowest?
The interviews revealed different attitudes towards viral safety in common activities while traveling in an airplane cabin. The most concerning were eating, disembarking, using the lavatory, and walking in the aisle.

Which activity is the most critical for passengers to tackle for increasing perceived viral safety?
As not all activities are always performed by all passengers, criticality was also measured. By identifying the top three activites that need to be tackled, it was possible to determine the overall significance of the problem for passengers. As the interviews have shown, disembarking is the most critical task, followed by eating.

What factors inside the cabin decrease passengers' perception of viral safety?
It became clear in the interviews that there are many aspects to low viral safety. In order to structure the findings, the participants' responses were analyzed using the Quirkos software. This made it possible to compile a list of the most recurring issues for viral safety, presented in section 3.4.

What undesired on-board behaviors occur among passengers when flying during a pandemic?
The literature research provided an insight that behavior of other passengers may be important for the perception of safety. Data colected from recent flyers as well as flight attendants allowed for defining several on-board behaviors most recurrently mentioned by participants as affecting their perceived safety. The results are provided in section 3.4.

What are the features in the interior that increase the perceived safety among passengers?
An ideation regarding the product embodiment allowed for providing a set of solutions for separating passengers while eating. In order to define the physical properties that a product should have to improve the feeling of safety, user tests with virtual reality technology were conducted. Likert Scale ratings revealed the most preferred concept, and open-ended answers highlighted the importance of covering both food and head to improve perceived safety.

12.2 Requirements and wishes

12.2.1 Introduction

The requirements and wishes in Section 6.5 have been formulated with the client to provide guidance on product development and performance evaluation. Table 4 on this page reflects on the requirements and wishes in the form of a checklist that indicates whether the goal was achieved. A short description is also provided for each requirement.

12.2.2 Discussion

The product developed within this thesis meets 11 out of 16 predefined goals, two partially and for the remaining two further tests are needed. The expert consultation revealed that the requirements regarding the spread of virus in the cabin cannot be concluded without analysis with particle generator. As no real-life testing with the cabin crew was possible, no conclusins can be made regarding the communication. Finally, the requirement of fitting the Flying V concept's physical space was not tested due to a shift of focus to current aircraft. However, the presented product is designed to fit the Joy seat by Rebel Aero, which is currently adapted as the Flying V economy seat, indicating that this goal is partially met.

Table 4: List of requirements & wishes and an assessment of performance.

Requirements

Requirement	Met?	Description
The experience should be perceived as safer than the regular setting	yes	As stated in user test, see chapter 8
Should be regarded as convenient to use	yes	As stated in user test, see chapter 8
Should make passengers more willing to fly during the pandemic	yes	As stated in user test, see chapter 8
The concept should not hamper the vertical airflow in the cabin	unknown	Further tests required as discussed with expert
The concept should not facilitate droplet spread between passengers	partially	Antimicrobial physical barrier, further tests required
Should be made of non-flammable materials	yes	Flame retardant textile; aviation-grade materials used
Should allow passengers to stay informed about the safety procedures	yes	Unfolded during cabin safety demonstration
Should allow for and withstand the cleaning procedure	yes	Permanent animicrobial properties, chapter 9
Should allow passengers to communicate with the cabin crew easily	unknown	Translucent material not yet developed
Should be visually universal to be applicable for different airlines	yes	The appearance can be adapted to the specific airline
Should be producible at mass scale	yes	Commonly used manufacturing techniques selected
Should be easy to transport	unknown	A detailed prototype may provide results
Should be optimized for low weight	yes	Weight optimized by 15%, or 0,2 kg
Should be easy to uninstall	yes	Optimized mounting for easy detachment
Should be made with at least 50% recyclable materials	yes	Cover, blind and frame, at least 72% of weight
Should fit within the physical space available in the Flying-V concept	partially	Designed to fit the Flying V economy seat
Should fit the staggered seat of the Flying V developed by Rebel Aero	yes	Designed to fit the Rebel Aero Joy seat

Wishes

Wish	Met?	Description
Much safer experience during the entire journey	unknown	Not tested in the user test
Should not make passenger much more claustrophobic	yes	As stated in user test, see chapter 8
Should make passengers more willing to fly after the pandemic	no	Not more willing to fly on average from user tests
Should comply with the current onboard safety standards	unknown	Further tests are needed to check compliance
Should make passengers willing to pay more for the ticket	yes	As stated in user test, see chapter 8
Should allow for retrofitting in the current aircrafts	partially	Retrofitting requires adapting to a specific seat
Should be possible to clean in 10 seconds or less	unknown	Further tests needed
Should have a low cost	unknown	Cost estimation needed
Should fit within the existing supply chain	partially	Ecothylene and Trevira are not widely used in aviation
Should not use rare earth materials	yes	Product does not use rare earth materials
Should not be built with “Monstrous Hybrids”	yes	No organic compounds are used
Should have a defined end-life	no	A definition of the end-life strategy needed
Should be sturdy and long-lasting	unknown	Further tests are needed to prove durability
Should have a carbon neutral or carbon positive footprint	no	Production and use generates CO2 emissions
Maintenance should not require detergents or electricity	no	Maintenance requires detergents and/or electricity

12.3 Recommendations and reflection

12.3.1 Introduction

This section provides a set of recommendations for further product development as well as a reflection on the methods used and the project itself.

12.3.2 Further improvements

Collected data

As previously mentioned, all studies involving participants conducted in this project were developed during an ongoing pandemic. This may affect the reliability of the data as their attitudes at a given point in time may not reflect them at other stages of the pandemic. Studying a larger sample of the population at different phases of the COVID-19 pandemic may help identify changing attitudes to virus safety, and propose a more accurate product implementation plan.

Virus safety

It is recommended to run a CFD analysis of the airflow in the aircraft cabin with dividers installed to verify the assumptions made about the antiviral properties of the product. Another test for the build-up of viruses and bacteria on the fabric surface during daily use can provide more reliable data to support the development of a feasible maintenance strategy.

Airlines

A detailed plan for the product launch is necessary so that passengers, on the one hand, would appreciate the increased sense of security and privacy, and on the other hand, would not misjudge the benefits of the product. Trials with real users can reveal more information regarding customer attitudes towards the product.

Materials

The development of a translucent version of the antimicrobial fabric is recommended to improve communication with cabin crew.

Other recommendations

Several recommendations emerged throughout the report. See specific sections:

Improving perceived safety - chapter 4.2
Optimizing for sustainability - chapter 9.9
Safety compliance - chapter 11.2
Airline viability - chapter 11.2

12.3.3 Reflection on the project

Methods used

This project demonstrated the usefulness of sustainable development methods in improving the design. The use of Fast-track LCA and EcoDesign strategies not only allowed for a significant reduction in weight and carbon footprint of the product, but also resulted in a more useful and efficient design. Moreover, insights from the sustainability assessment allowed for developing a strategy for the airline that brings a significant reduction in weight and costs by minimizing the number of dividers per seat, which can increase viability for the airline.

Due to the new constraints imposed by the pandemic, many of the commonly used design methods could not be used to their full potential. This made it challenging to ensure the quality and accuracy of the data collected. On the other hand, adapting some methods to the new context created space for innovation. A good example of such a feat was the adaptation of virtual reality technology to conduct the User Test. The generally positive feedback received indicates that this testing method may prove to be a valuable tool for designers by allowing them to reach a large group of desired participants and introducing time and cost savings due to its decentralized nature.

12.3.4 Personal reflection

Working in a dynamic context

This project started with the goal of envisioning a more resilient, safer and sustainable future for aviation. For this, the main focus was on the Flying V concept. However, throughout the project it became clear that aviation may not develop properly without first overcoming the crisis caused by a pandemic. This has influenced the shift of the focus of the project into the present context, which anticipates the challenging near future of aviation recovery. Adapting the project to current context required flexibility in project planning and execution, but resulted in an outcome that may be more relevant for aviation recovery and thus contribute to a better development of this industry in the future.

Coronavirus implications

The coronavirus pandemic undoubtedly influenced the course of this project. The psychological challenge was to stay motivated when there is little social interaction and limited workplace opportunities. Another limitation is the changing state of the pandemic, with various events affecting the availability of reliable information. Therefore, in order to increase the credibility of the project, gathering the most up-to-date information was an additional time burden which had to be taken into account when planning.

A major drawback has been the scarcity of previous research into the effects of a pandemic of this proportion, and little research into the phenomenon of perceived viral safety. This made it difficult to draw reliable conclusions about improvements.

Interest of the industry

This project was met with considerable interest from widely recognized aviation firms and organizations. During the course of the project, many valuable links were established that may result in further progress of this project beyond this graduation project.

Opportunities for the product

The safety and privacy benefits COVR brings may prove useful in other modes of transport such as shared vehicles, trains, buses, as well as in public spaces such as stadiums and cinemas. Further research may reveal more implementation possibilities.

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