



**DESIGNING A
CONCEPTUAL
FLYING-V INTERIOR
WITH VR USER TESTS**

MSc. THESIS BY DANIEL HOUWING

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ABSTRACT

During the redesign of the interior of the Flying-V, especially the Chaise Longue, it is investigated how Virtual Reality (VR) can be used within the design process as an evaluation tool. Can test subjects use VR to provide feedback on conceptual designs? And what are the pros and cons? While these questions are being explored, the results of the testing in VR will be used to redesign the Chaise Longue and combine it with results from other graduate students to create a total configuration of the Flying-V.



Designing a conceptual Flying-V interior with VR user tests

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INTRODUCTION

VR for testing conceptual models

VR has been around for quite some time, but in recent years it has been increasingly used for various purposes, such as simulations, remote assistance, games, but also for design. (XRcollaboration, 2021). For example, Airbus uses VR to show different designs to Airlines (Airbus, 2016). In VR, for example, it is easy to adjust the color of the furniture or the total configuration (moving galleys or chairs). This gives the customer an idea of what he is buying, or what options he has. VR can also come in handy at other times in the design process. Conceptual designs can be tested early in the design process for user perception or ergonomic aspects. In this way, early decisions can be made to the design, and designers can determine which aspects should be optimised and make go / no-go decisions (van Boeijsen et al., 2020).

During this graduation project, VR will be tested as an evaluation tool. It should answer the question of whether VR is suitable for testing user perception; can test subjects use VR, and is it possible for them to say something about the design? It is also looked at what the requirements are for a test in VR and how it can best be set up. The question here is how useful extended reality is to simulate a realistic future setting of the Flying-V interior and to extract relevant data related to ergonomics. To reinforce the test in VR, a design assignment is set up, where the results from the VR test will also be applied to the design.

The design assignment

The TU Delft is developing a new aircraft in collaboration with Airbus and KLM called the Flying-V (see Figure 10). Where Aerospace Engineering takes responsibility for the outside of the aircraft, the Industrial Design faculty develops the inside. Various interior designs have therefore already been made (Peter Vink et al., 2020, Tinie Lam, 2020, Lisa Wamelink, 2021 and more).

In addition, there are also some studies running at the IDE faculty, such as ComfDemo - Digital Twin (Vink, p. et al., 2022), how people experience the chaise longue of the Flying V (Núñez Vicente et al., 2021), and recording human postures in an aircraft seat cushion (Yao, X., 2021).

The design assignment will be creating the next Flying-V interior, which will consist of a redesign of the Chaise Longue and existing designs, to arrive at a total interior that will be put in VR. The aim of the redesign of the Chaise Longue is to make it a realistic concept, taking into account FAA regulations (FAA, 2021) and taking the user into account. The current model of the Chaise Longue (Núñez Vicente et al., 2021) will therefore be tested using VR, the results are used for the first concept of the redesign.

A vision will also be developed that serves as a guideline for choices made within the design process, such as which current designs are included in the total interior, and which end up in the final VR model. Ultimately, this final VR model will be tested with potential passengers next to a VR model of an A350, and the Flying-V interior by Lisa Wamelink (2021). VR should help test subjects to immerse themselves in such a future aircraft. In doing so, results and stimuli from current studies can be used, which are further examined in VR. The results of this test will help to create the final concept of the redesign. The project will be done in collaboration with Airbus, KLM and Aerospace Engineering to have it embedded in their philosophy and possibilities.

00. DESIGN BRIEF

PROBLEM DEFINITION

At the moment several interiors of the Flying-V have been designed, each with a different scope. The interior of Lisa Wamelink (2021) was designed with the idea of creating a comfortable seating area with staggered seats for different group compositions and stimulating walking during flight. The design of W.J. Oosterom (2021) is based on where cut-outs can easily be made for the Flying-V Family. The space has also been arranged as efficiently as possible, in order to maximize the capacity. The capacity is important for aircraft manufacturers and airlines to make the aircraft profitable (Tsai, 2004); the ideal interior for a passenger will therefore look different from the ideal interior of an airline. Yet it is interesting to look beyond these restrictions and to design an interior that is unimaginable today. For example, the interior can consist of a combination of sleeping cabins (Oosterom, W.J., 2021), chaises longues (Nuñez Vicente, A, 2021), a self-service galley (Lam, T., 2020) and flexible workplaces. An experience in which flying does not consist cramped static sitting, but where you can walk around or change seats.

Such a future picture is difficult to imagine, let alone test such a situation without these aircraft existing, and where full-scale models are expensive to make (McGlothlin, 2018). With a view to production, it is important to know as much as possible about the current design, to prevent expensive adjustments in a later stage (McGlothlin, 2018).

Extended Reality should help to solve this problem (Theorem Solutions, n.d.). Futuristic ideas can still be tested by making a model that is as realistic as possible on a true scale. The test will be done in Extended reality and it will be closely examined what the test persons think of the test in extended reality. With the results, a redesign will be made of the interior, based on the designs that have already been made. Also, an evaluation will be provided regarding testing in XR.

ASSIGNMENT

First I will make a vision on the interior based on discussions with stakeholders (Airbus, Aerospace, KLM and suppliers). Using a selection method, interesting elements from the studies and designs are selected that fit into the vision, after which they are combined in an XR model. The XR model will be evaluated with a group of about 20 test persons. In Extended Reality, the test subjects will have to do various assignments and complete questionnaires. With these results a redesign will be made which will be tested in the same way. Subsequently, the redesign will be adjusted based on the results and this will result in a digital model of a final design of the interior, which can also be experienced in XR.

During the test, the test persons will be examined what the test persons think of the test in extended reality. This will result in an evaluation regarding testing in XR.

Initial planning and other aspects of the project brief can be found in appendix 8.



Image made by Henri Werij

01. RESEARCH

To form a basis for the vision, various graduation assignments related to the Flying-V have been thoroughly examined for aspects that are relevant for the redesign. Studies related to comfort in the cabin are also included. The graduation assignments are discussed separately, after which research and discussions with stakeholders that are relevant for forming a vision and the further design process are discussed.

SCIENTIFIC REPORTS & PROJECTS

LISA WAMELINK (2021) - FLYING-V INTERIOR: FLOORPLAN DESIGN FOR IMPROVED PASSENGER COMFORT

Lisa Wamelink researched various designs for the configuration of the flying-V's interior. She looked specifically at the different compositions of groups and staggered seats. She also pays attention to the possibility of walking during the flight.

Because the chairs are staggered, new designs are possible. This has influence on the feeling of privacy, and there is more shoulderspace and an own space at the armrest. The staggered distribution can be disadvantageous for groups because they are now a bit behind each other. To accommodate groups and families, the distance between the seats can be reduced so that they sit closer together. This can be changed for different groups.

Lisa also designed benches for the windows. This should encourage passengers to walk a bit and sit somewhere else for a while.

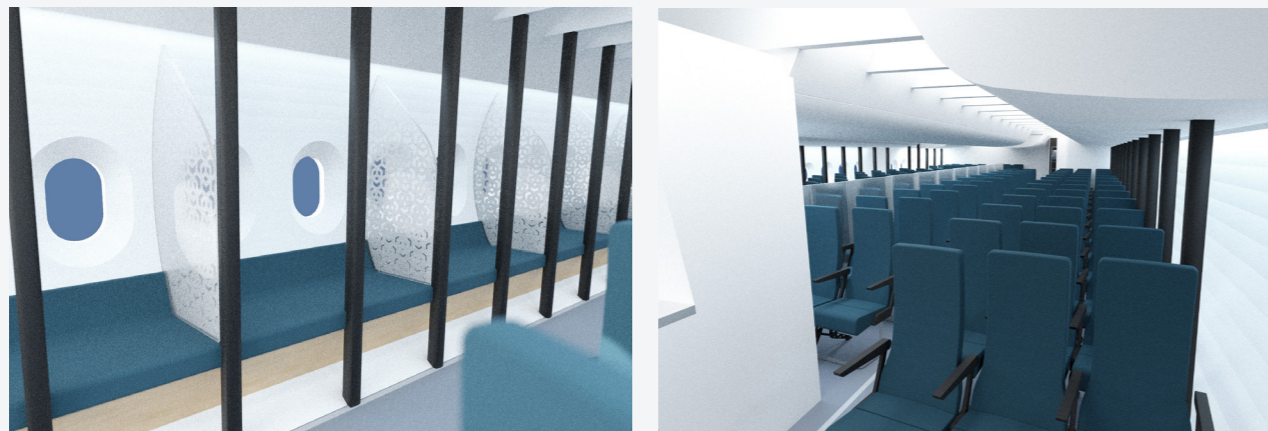


Figure 1 - The interior Design by Lisa Wamelink

ARNOUD MEINES (2019) - SLEEPING ON CLOUDS - ECONOMY CLASS SLEEPING FACILITY

Arnaud Meines designed sleeping cabins for the 'blind' side of the flying-v interior, the side where there are no windows. Up to three beds can be placed on top of each other. This can be combined with a modular design, so that it is also possible to have normal seats which can be switched to beds.

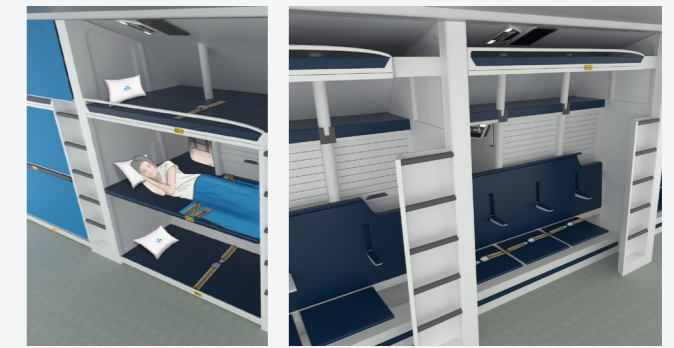


Figure 2 - The design of Arnaud Meines

TINIE LAM (2020) - AIRCRAFT INTERIOR SYSTEMS FOR THE FUTURE ONBOARD SERVICES IN THE FLYING-V

Tinie Lam has made a design for food distribution during the flight. In her design, the passengers can decide for themselves during which meal round they want a meal. They also have the option of self-service for drinks, in this way, passengers can also walk a bit in the plane. She tested the design in VR.



Figure 3 - The design of Tinie Lam

W.J. OOSTEROM (2021) - FLYING-V FAMILY DESIGN

To reduce development costs, three different sizes of the Flying-V are designed at once. These three planes come from the same design by cutting parts from the plane. This must be taken into account when designing the interior because no objects can stand on the dividing lines. In the picture on the right, the cut out parts are marked green & yellow.

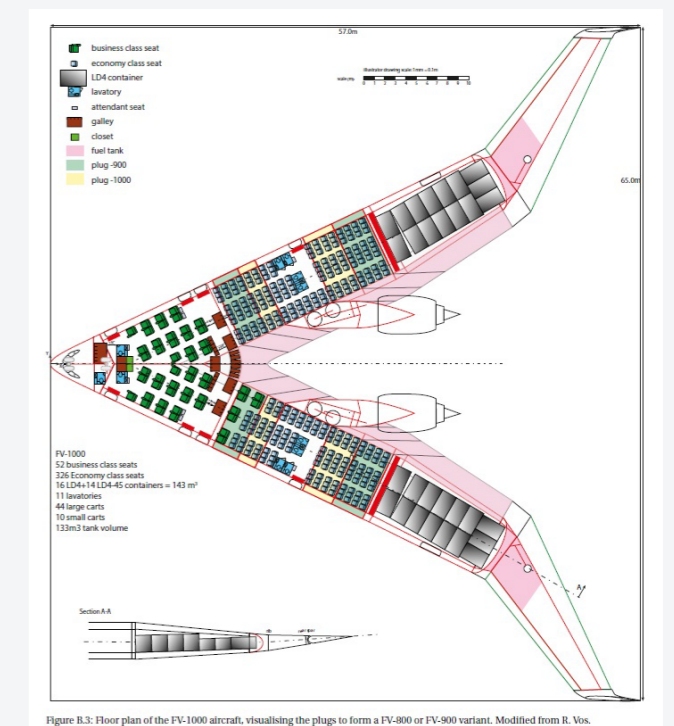


Figure 4 - Schematic of the Family Design, Flying-V

ALEJANDRO NÚÑEZ VICENTE - CHAISE LONGUE

The Chaise Longue is a new concept airplane double decker seat. By using the height, more comfortable chairs can be made with more legroom than the current chairs. The rows of seats are alternately placed high and low, which allows the low row of seats to slide the legs under the high seats. There are also compartments for hand luggage in the seats. The design achieves a weight saving and a capacity increase of 10%.

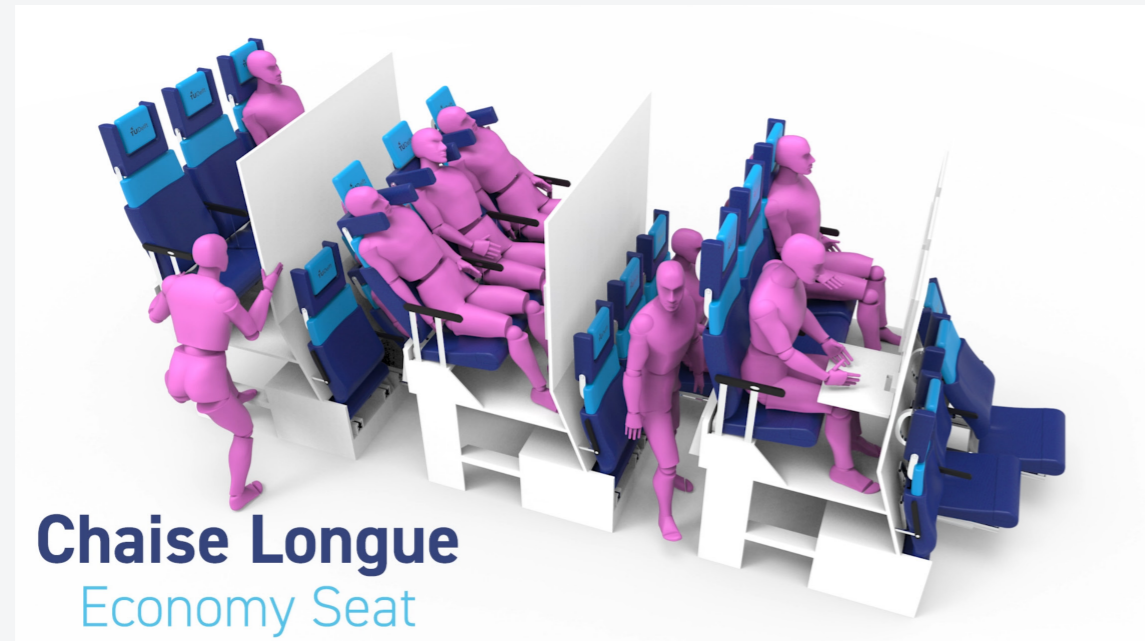


Figure 5 - The original design of the Chaise Longue by Alejandro Núñez Vicente

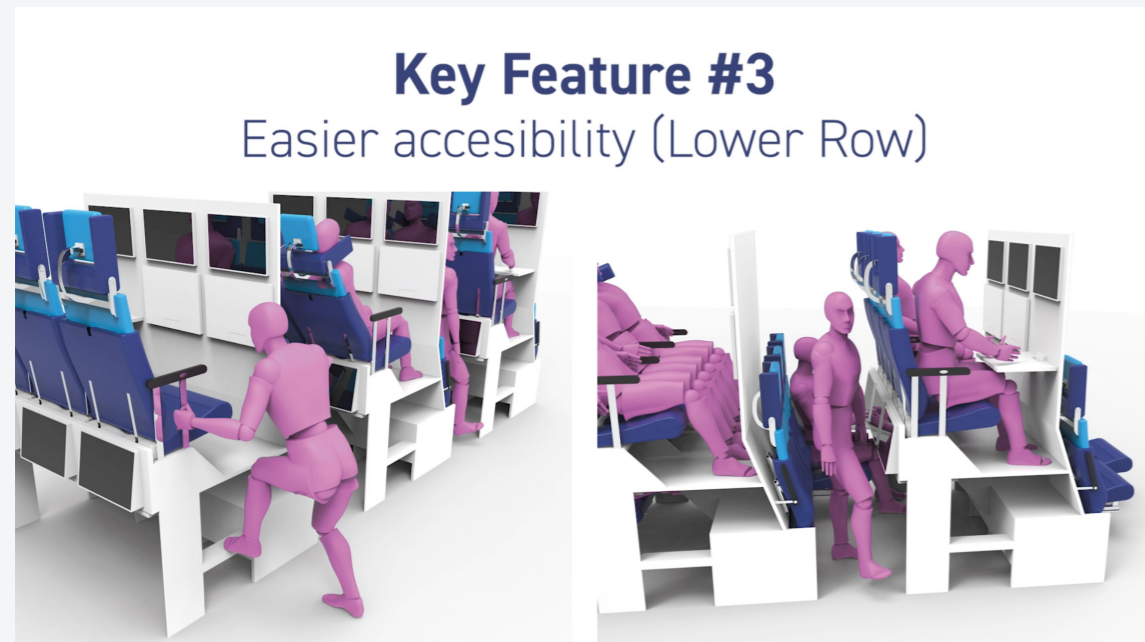


Figure 6 - Key feature #3 Easier accesibility - by Alejandro Núñez Vicente



Figure 7 - Different angles of a newer design of the Chaise Longue by Alejandro Núñez Vicente

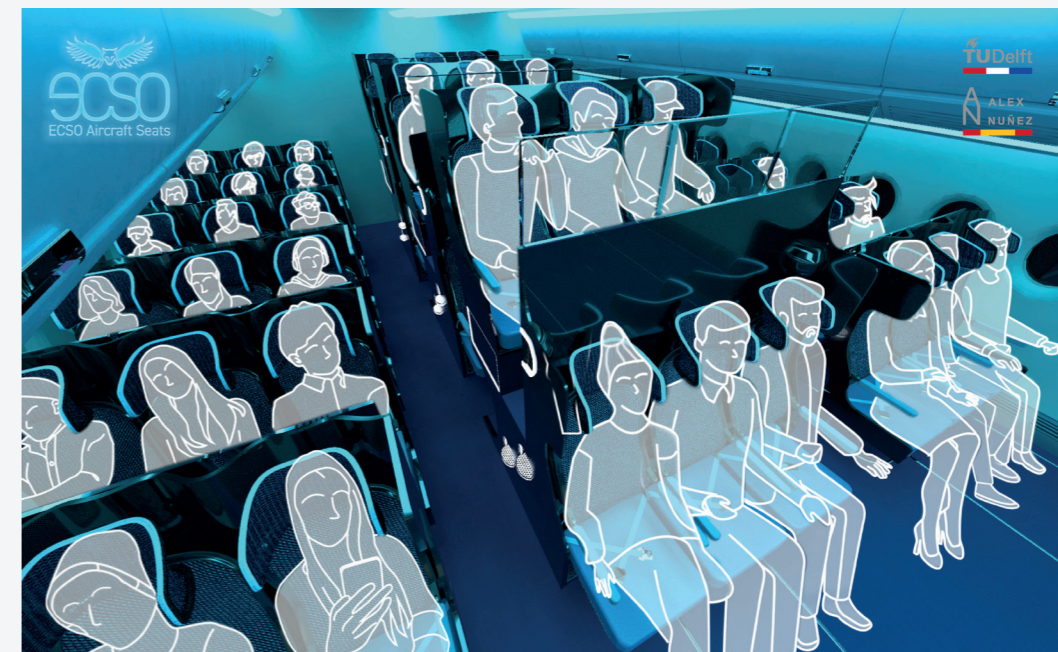


Figure 8 - People sitting in the newer Chaise Longue by Alejandro Núñez Vicente



Figure 9 - The newest prototype at the AIX (Street, 2022) - By Alejandro Núñez Vicente

THE FLYING-V



Figure 10 - The Flying-V (image by Edwin Wallet)



Figure 11 - Scale model of the Flying-V (image by Malcom Brown)

STAKEHOLDERS



KLM - MARK BROEKHANS

KLM emphasized designing for staff. They make the most use of the cabin and have to complete various tasks. They prepare meals in the galley and serve them in the cabins using a trolley. The amount of space in these places influences the working comfort of the staff. Mark Broekhans also indicated that attention should be paid to busy points in the cabin, such as the toilets or self-service. Passengers sitting in the area often suffer from jams that take place here.



AIRBUS - HANS-GERHARD GIESA

Airbus finds it interesting to see a combination of recent designs and studies. They have been involved in the project for some time and are still interested in the design of the Flying-V. The design of the Chaise Longue could also already be applied to the Airbus A350. Ultimately, airlines decide on the interior, while Airbus is mainly concerned with the rest of the aircraft.

By bringing the previous projects together, a total picture is created and a selection can be made in which designs to continue with, so that the development of the interior continues on the basis of previous research and designs.



TU DELFT - ROELOF VOS (AEROSPACE)

TU Delft is the main developer of the Flying-V, with research mainly being conducted at the Industrial Design and Aerospace faculties, with the Industrial Design Faculty focusing on the interior of the aircraft. There is close collaboration between the faculties. Because the Flying-V is still changing after Aerospace research, Aerospace recommended developing the interior in an older model (2019) instead of following Aerospace's developments live. This prevents the interior from having to be constantly adapted to new Aerospace developments. Both can therefore be developed separately, and the details can be looked at at the time of merging.

Roelof Vos indicated he's looking forward to a design he wouldn't have thought of beforehand, that can be conceptual, but keeps in mind the restrictions that come with the Flying-V.

THE USEFULNESS OF A VIRTUAL REALITY MODEL IN CONVEYING CONCEPTUAL IDEAS TO THE USER

INTRODUCTION

In order to receive feedback early in the design process, it is necessary to involve the user at an early stage (Steen, M., et al., 2007). However, early in the design process the ideas can still be in an abstract stage (Kim & Wilemon, 2002). There are still many choices to be made, and the current models can be difficult to capture by the imagination of the test subjects. In order to allow the test subjects to test the early models, the test subject must be included as much as possible in the context of the design, whereby this is already outlined in the design of the test (van Boeijen et al., 2021). This minimizes the differences between the test subjects in how they envision the use of the future product.

A means that designers can use to shape the context and the preliminary design and present it to the test subjects is Virtual Reality (NVIDIA, 2022). This study investigates to what extent Virtual Reality can contribute to conveying designs in an early phase of the design process.

The model used for testing is the Chaise Longue Economy seat (Nuñez Vicente et al., 2021). The Chaise Longue is a new concept airplane double decker seat. By using the height, more comfortable chairs can be made with more legroom than the current chairs. The rows of seats are alternately placed high and low, which allows the low row of seats to slide the legs under the high seats. There are also compartments for hand luggage in the seats. The design achieves a weight saving and a capacity increase of 10%.

The stage where the current design finds itself can be described by the Technology Readiness Level (TRL) (Tzinis, 2021). Testing in VR would be ideal in TRL3 where a preliminary model can be evaluated in a relevant environment. The environment will be simulated in VR. This will be the first time the model operates in its intended environment and will show directly factors that are right or wrong.

For the test an Oculus Quest 2 will be used with a VR model made in Unity.

METHOD

The test starts with a short explanation of what the test persons can expect and how to use the VR headset. They start in VR outside the flying-V where there is a sign with explanation (see Figure 34). When they have read this they can move through the virtual space using the controllers (see Figure 35). When they have walked through the Flying-V they can go to the other hall to look at the chaise longue in an A350. After the test, the test persons complete a short survey with the following questions:

The following questions were asked on a 7 point likert scale:

1. How much did the visual aspects of the environment involve you?
2. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?
3. How nauseous did you feel during the VR experience?
 - 3.1 If you were feeling nauseous, what made you feel nauseous?
4. Do you like to use Virtual Reality to explore conceptual designs?
5. How would you estimate the comfort of the traditional seat (triple near the window)?
6. How would you estimate the comfort of the upper row?
7. How would you estimate the comfort of the lower row?
8. Which of the three seats do you choose for a flight?



Figure 12 - Several people trying the VR experience in Delft and Ras Al-Kaimah.

RESULTS

The group of 16 test subjects consists of different people; people who work in aviation, people who have nothing to do with aviation, and some students. The largest age groups are 20-30 and 40-50. The youngest participant is 20 and the oldest is 80. The male/female ratio is approximately equal.

Looking at the results, those who were willing to participate (sixteen people) enjoyed doing the test (9.5/10) the reactions were also positive afterwards. However, it should be noted that the people who probably didn't appreciate the VR, didn't put on the VR glasses either. This is due to the way the test was administered; namely at events where people have the choice to come by and try the VR.

As far as VR is concerned, the sixteen test subjects feel that they are really present in the virtual space based on what they see (8.6/10). People do give themselves an average of 7.8/10 in how easily they move around. During the administration of the test, the controls caused many problems, a 7.8 is therefore high compared to the observation. The test subjects became more adept at handling the VR when they were longer in VR. Yet most did not last 5 minutes until they indicated that they got nauseous of the VR. This is highly person-dependent, the score is also a 5.0/10. Only four out of sixteen people indicated that they did not get nauseous at all, the other eleven indicated that they were slightly or very nauseous. The main reason is the movement in VR while sitting still called motion sickness (Patrão et al., 2020).

Regarding to the perceived comfort of the seats, all seats score positively with a 7.1/10 for the traditional seat as the lowest. The most popular seat is the upper row with an 8.2/10, slightly higher than the lower row (7.9/10). The fact that these scores are close to each other can also be seen in the result regarding the preferred seat. Five test subjects out of sixteen prefer the traditional seat, four out of sixteen the lower row, and six out of sixteen the upper row. The upper row is therefore the most popular. The traditional seat scores lower in comfort, but is more preferred than the lower row of the double decker. Question 3 and 8 have been visualised below.

3. How nauseous did you feel during the VR experience?

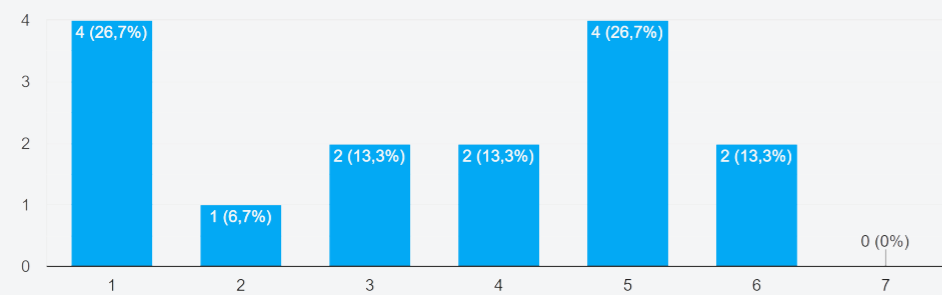


Figure 13 - Result of question 3. Only four people were not nauseous at all.

8. Which of the three seats do you choose for a flight?

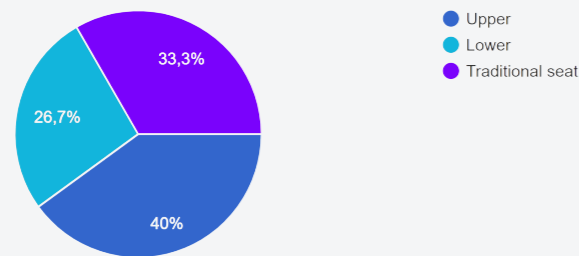


Figure 14 - Result of question 8. The upper seat is most loved.

DURING THE TEST

During the Arab Aviation Summit in Ras Al-Kaimah (UAE), participants of the event were able to test a Virtual Reality model of a new aircraft interior with a Chaise Longue seat. Testing VR at a foreign summit turned out to be more complicated than expected. No fixed place had been agreed in advance and little promotional material was available to indicate what the stand was about. The equipment available were three laptops and 2 VR headsets (HTC Vive Pro & Oculus rift, see chapter 'VR Hardware'). Both headsets had problems while setting up. Ultimately, the Oculus Quest 2 was the most widely used, but often only after an hour of debugging, and many users had already left. While using the headset, the controls turned out to be too complicated for most users. The users who could get along quickly indicated that they had already been in VR before, or that they had played simulations/games more often. When the users were ready, they were asked some questions about VR and how they were feeling. Most of them looked a bit confused when they took off the headset, but indicated they were alright (see appendix ref results test 1). After the VR they quickly walked away, or started talking to the others on the stand about the Chaise Longue. There were also Arab people who hardly spoke English, which made it difficult to ask questions, or to administer a survey.

Contrary to expectations, it was difficult to find people who wanted to try VR. By playing with the VR, attention was drawn to the stand. The others could address the people and entice them for the VR. Older people more often indicated 'that they could also see it on the screen' and rejected the VR experience. The most enthusiastic group to try VR were the (younger) pilots. They recognized the VR and compared it with the simulations they know. They were eager to try it (see photo after this chapter). People did say that the VR model helped them understand the design. It was possible for them to point out things in VR that they wanted to know more about, and they could see the model in an airplane.

This was comparable during an event at TU Delft, (Netherlands). Several people were enthusiastic, and they came to try the VR experience on their own initiative. The same number came to watch but indicated that they were easily sick of VR in general and did not want to try it. A large part watched from a distance but were talking. Those who have tried VR were thrilled with what they saw. They indicated that they found the experience compelling and were able to better understand the design. Two users also indicated that they experienced motion sickness while using the VR.

DISCUSSION

The test at the summit showed that there are several factors that can be improved to do a user test in Virtual Reality. One factor is a missing structure and time during the test. The visitors were often in a hurry and only interested in the VR booth for a few minutes. Probably because there was more to do at the event and visitors didn't want to be stuck in one place for too long.

This could be improved by recruiting test subjects in advance of the test and asking them if they have at least 20 minutes for a user test. The test takes place in a special dedicated location at the university so that the test subjects are not distracted by others. If the location is a summit or congress, a place must be demarcated where it can be tested quietly and where it is clearly indicated what is being tested, and what is asked of the people with the help of banners or posters. It is also advisable to have a tablet to be able to show what the model is being tested and to answer the survey afterwards.

Those who tested VR were very enthusiastic and indicated that the VR helped them to get an idea of the model. Some found the controls too difficult, so a short explanation of the controls in VR will be included within a next model. Others indicated that they suffer from motion sickness. Another option is to remove movement resulting in a seated and static experience. This may help preventing motion sickness from the experience.

Because of the lack of time, only a short survey was held with the people that tried VR. To really understand why people make certain choices, more questions are needed optionally followed by a short interview with more open questions. Also the VR experience itself was distracting people to really look at the new designs. A well designed VR experience is important to make a certain test successful.

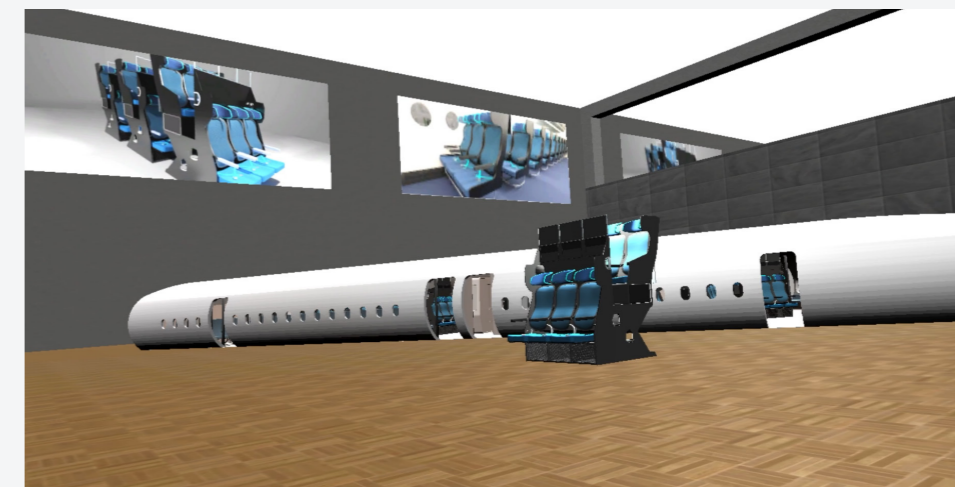


Figure 15 - Overview of the Flying-V hall in the VR experience



TESTING THE INFLUENCE OF A VIRTUAL ENVIRONMENT ON THE PERCEIVED COMFORT OF THE CHAISE LONGUE.

PRE-INTRODUCTION

This test setup was conceived as a backup if the trip to Dubai could not take place. This test requires more preparation than the quick test that has now been conducted during the summit, and probably offers more insights into the pros and cons of VR and the perceived comfort of the Chaise Longue. Although the test has not (yet) been performed, it could still be carried out in the future if it is found to be sufficiently relevant.

INTRODUCTION

In product design, it is possible to build realistic mock-ups early in the design process to test the comfort and perception of the entire product (Van Boeijen et al., 2021). Nevertheless, this can give a distorted picture of the realistic situation where the context (eg. ambient noise, light, other people) has an important influence on the experience of the product (Van Boeijen et al., 2021). To test the influence of the context at an early design stage, Virtual Reality (VR) can be used to simulate the context of the product (Li et al., 2022).

This study aims to answer the question whether the use of context in VR actually influences the user's perception in the sense that a more complete picture of the interior can be achieved. A new model aircraft seat called 'the Chaise Longue' is used as a test set-up. This is a doubledecker passenger seat (Nuñez Vicente et al., 2021).

METHOD

Setup 1.

This is the prototype of the Chaise Longue in a room at TU Delft. The test persons will see the prototype upon arrival and experience the context as it is in the room at TU Delft.

Setup 2.

Also in this setup, the prototype of the Chaise Longue is in a room at TU Delft. However, the test subjects will not see the real prototype, because they will enter the room with the VR headset already on their heads. Visually, they will only experience the Chaise Longue in virtual reality. Physically they sit on the same Chaise Longue as in setup 1.

The test persons are divided into two groups; group 1 and group 2. Group 1 starts in setup 1, group 2 starts in setup 2, after a while the setups will switch. Both groups go through both setups, but do not do this at the same time. Everything is completed with group 1 first, before group 2 starts. The prototype in both setups is the same prototype.

While the test subjects are sitting in the Chaise Longue, they will answer the following questions. They will do this in both setups.

QUESTIONNAIRE

The questions have been derived from Witmer & Singer (1998) and are all validated questions. They are about the VR experience as well as the perceived comfort of the Chaise Longue. The questions should give an insight if users notice other characteristics of the interior or the seat with VR compared to not having VR. The full list of questions can be found in appendix 1.

VIRTUAL REALITY - THEORY

INTRODUCTION

Virtual Reality is a good technology for visually conveying concepts to the customer (Gray, 2020). It takes some effort to put the concepts in Virtual Reality and use them with the available headset. This manual has been written to clarify this process. The headsets used for writing this manual are the HTC Vive Pro and the Oculus Quest 2 (see VR Hardware). The process is described from the modeled concept to a simple scene in Virtual Reality using the Blender and Unity software. A Coca Cola can has been used to show the process (see images in this chapter).

MODELLING THE CONCEPT

Modeling a 3D model can be done in different software packages. For example, Solidworks, Rhino, Blender or Autodesk software can be used (Pickavance, 2022). In view of the entire process, which also involves applying textures to the model, there are several options. Autodesk has an extensive pipeline from modeling concepts to realistic texturing and creating complex simulations (Autodesk, 2022). However, Autodesk is located in the professional segment and therefore also in the more expensive segment. There are also free software available, such as Blender (blender.org). Blender is an open source program with a wide community that allows anyone to model realistic models and give a realistic texture. However, it is less precise than an engineer program such as solidworks (solidworks.com). These software can also be used in combination where the concepts are first modeled in Solidworks after which they are finished in Blender (Carolo, 2020).

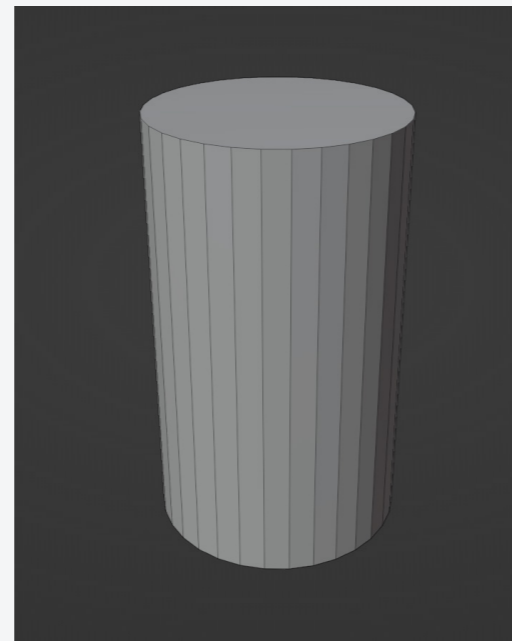


Figure 16 - Start with a base shape to model a can. The black lines are the mesh

THE MESH

The mesh is a mesh of squares (quads), triangles (triangles) or polygons (n-gon) that makes up the model (Turbosquid, 2019). The triangle is the simplest shape, and requires the least computer power to generate. Any shape can be transformed into a triangle (square, hexagon etc.), but a triangle cannot be transformed into a higher order shape (Turbosquid, 2019). This is why game engines like unity use triangles for their shaders (see textures). It is important for the textures that a model has a neat mesh. Inconsistencies in the mesh can cause holes or false reflections and shadows (artifacts) (Turbosquid, 2019).



Figure 17 - Add more detail to get can characteristics. The mesh gets more complicated

TEXTURES

When the modelling is done, and the shape looks right, a texture has to be applied to make it look like a real object. A texture can exist of a shader in combination with images, like the label of the Coca Cola can (Figure 29). A shader is a computer program used to shade objects, like the the principled BSDF shader of Blender (Blender, 2022). To explain a few sliders; Metallic can be set to 1 or 0 to indicate a material is metallic or not. The roughness value determines how shiny a material is. By changing the base color, the color of the material can be changed. An image can be connected to the base color, to project the image over the object (see Figure 22). A normal map can be used to make imperfections to a surface, like the last sphere in the image below (Mikkelsen, 2008).

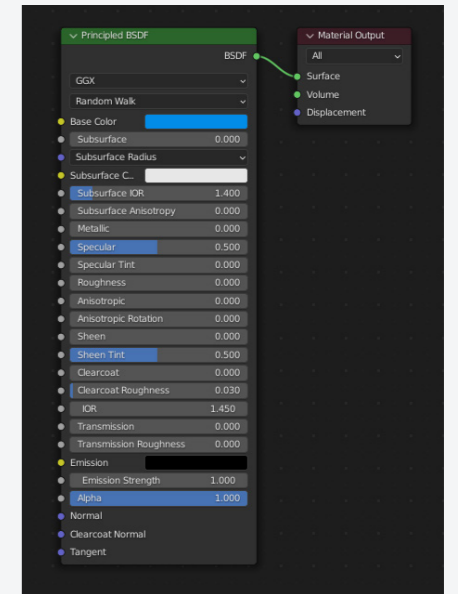


Figure 18 - Principled BSDF shader from Blender with sliders to change the values.



Figure 19 - Example of applying texture maps

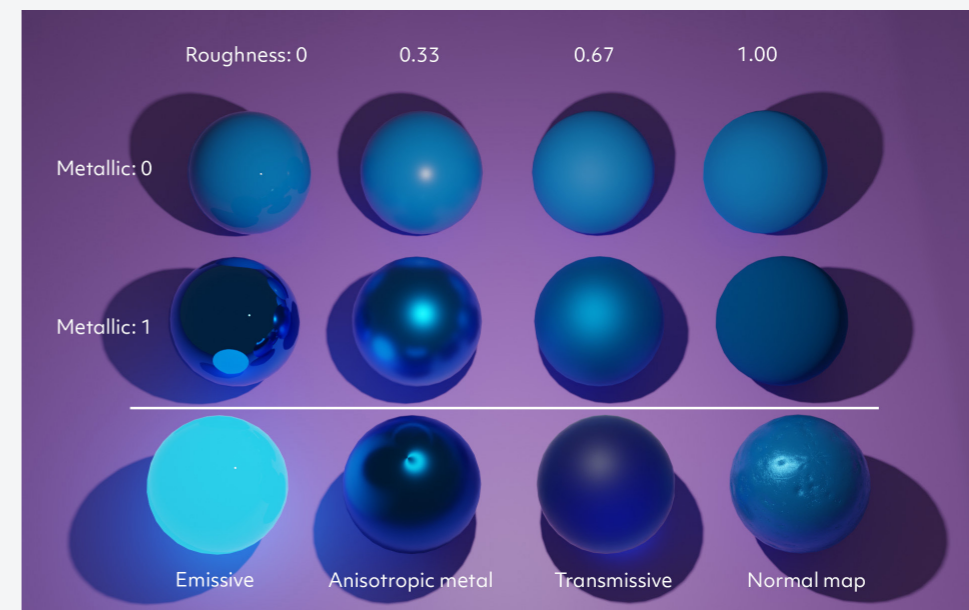


Figure 20 - Example of different shader values

Instead of using the sliders of the shader, also an image can be used as an input. The images hold a combination of coordinate and intensity data, so that different spots on the material can have a different roughness value (Adobe, 2018). The image below shows how it works. An aluminum texture build up like the wooden texture has been applied to the can.



Figure 21 - Can with aluminum texture

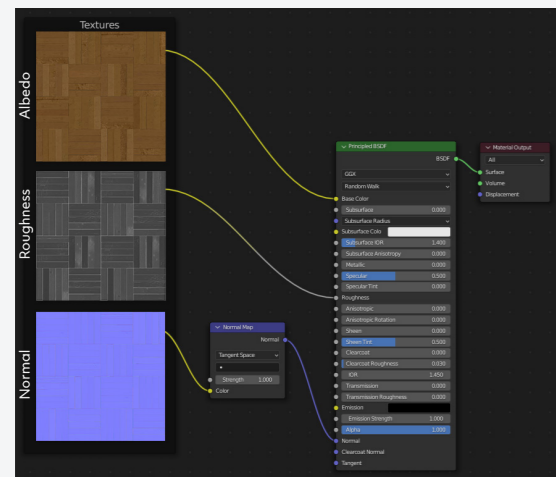


Figure 22 - Adding image maps as an input for the shader (Blender, 2022)



Figure 23 - Result of the material on a cube

UV MAPPING

When the label of the Coca Cola is projected, it is not aligned properly. This is because the software makes an estimation on how the mesh has to be straightened out. It is like a dice made out of paper; from a flat projection you can fold a 3D dice (see image).

In computer graphics this flat outline of the dice would be called an UV map (Mullen, 2010). It is a coordinate map of the surface of the object. In this case, the UV map is not placed properly over the label. By adding so called seams to the model you indicate where the software needs to 'cut' the model to get the flat projection (Blender, 2022c). In this way you will get a proper UV map that can be placed over the label.

When all the nodes are connected properly, the seam is marked, and the object has been unwrapped resulting in a flat UV map, the label will align properly to the can, as seen in the images on the next page. With complex models it can be hard to see if every surface has been unwrapped properly. A special texture has been developed called an UV test grid (Blender, 2022d) which makes it easier to see if surfaces are stretched or contain artifacts (see Figure 31).

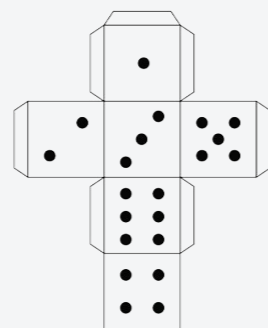


Figure 24 - Flat projection of a paper foldable dice



Figure 25 - The UV map of the selected mesh on the label

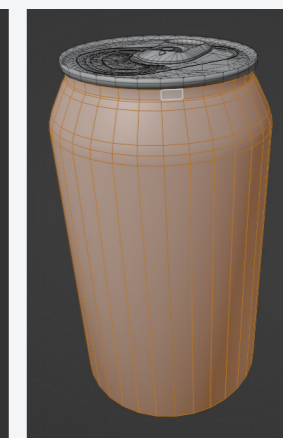


Figure 26 - Selected mesh



Figure 27 - Result of the mapped label over the can

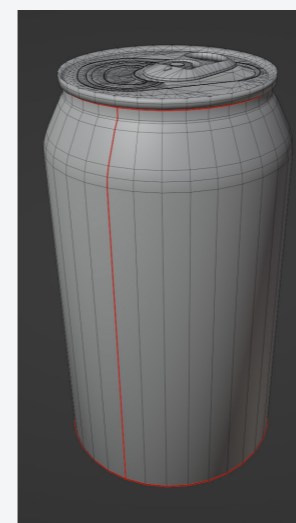


Figure 28 - Marking seams (red) on the mesh so Blender knows where to 'cut'.

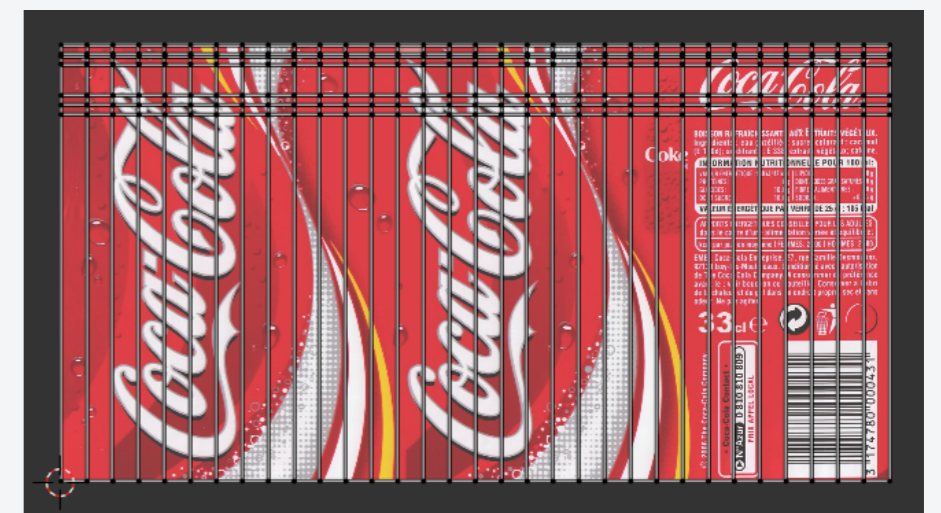


Figure 29 - The UV map is straightened out and placed over the label.



Figure 30 - The result of the can fully textured

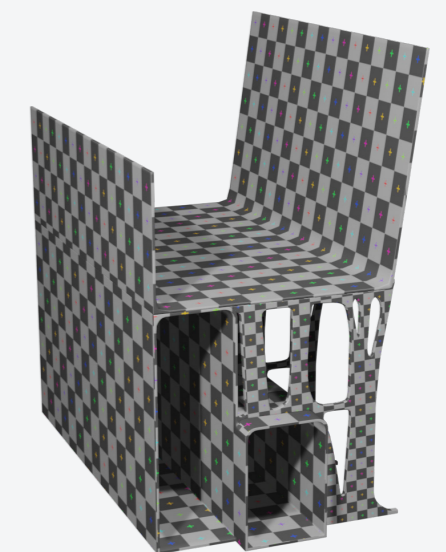


Figure 31 - A model with an UV grid applied to it (Blender, 2022)

VIRTUAL REALITY - UNITY

Now the model is ready, it can be exported as an .fbx or use the .blend (Unity, 2022b) and be imported into Unity. Having the CAD model fully textured is a big part of creating the VR experience. When the model is imported into Unity, the experience is almost ready (Unity, 2022). The last thing to do is telling Unity how to handle the VR headset and the controllers that will be used. Luckily, Unity has some ready to go presets made for this and can be directly imported as a template (Unity, 2022). Just open a Unity VR project, and the XR rig, existing of a camera and the controllers will be present. Go to edit>project settings>XR plug-in management and check the provider that is suited for your headset (Unity, 2022). Headsets come with their own software that Unity also needs to debug your new experience on the headset (Oculus, 2022). For example, the HTC Vive Pro is run by Steam VR. The file is setup probably and you are ready to go and try your own experience.

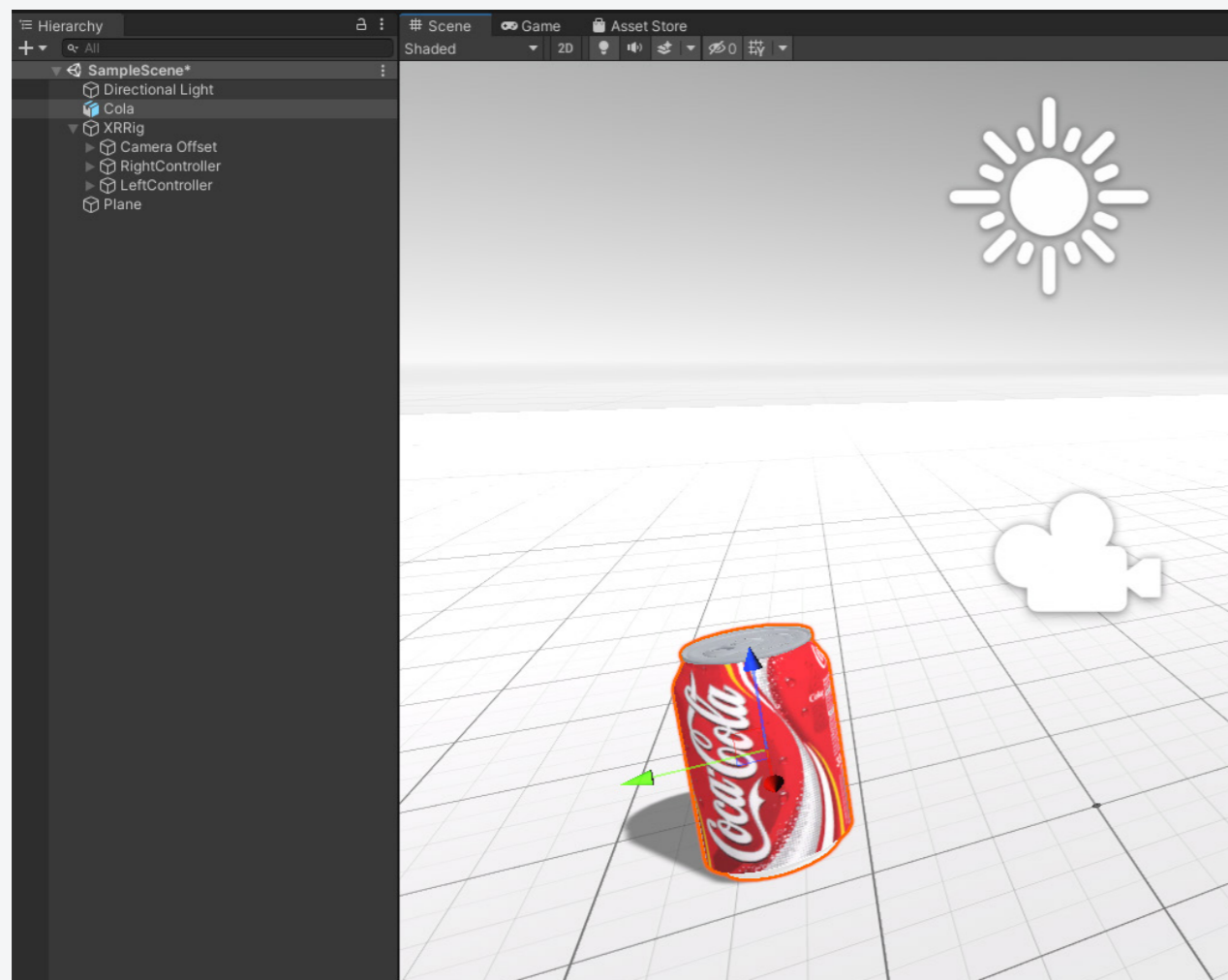


Figure 32 - The unity editor with the can placed in the scene. On the left all the assets that are currently in your scene are visible, like the XR rig that controls the VR headset and controller movement.

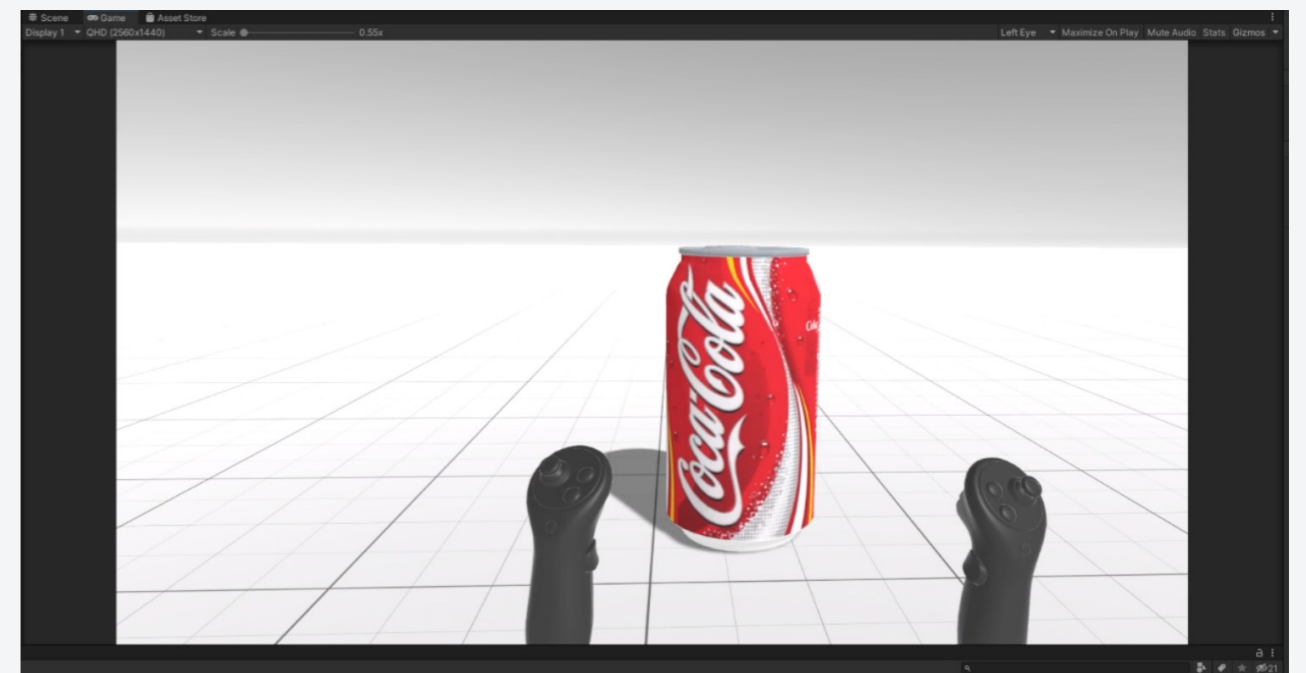


Figure 33 - Looking at the can in Virtual Reality

THE VR EXPERIENCE

This chapter will be used to show the VR experience used for the test. You will see the interior of the Flying-V and A350 from a VR perspective. In addition, some interactions are also shown with the Chaise Longue in VR.



Figure 34 - Overview of controls used in the VR experience



Figure 36 - Standing in the front of the Flying-V with the Chaise Longue of Alex Núñez

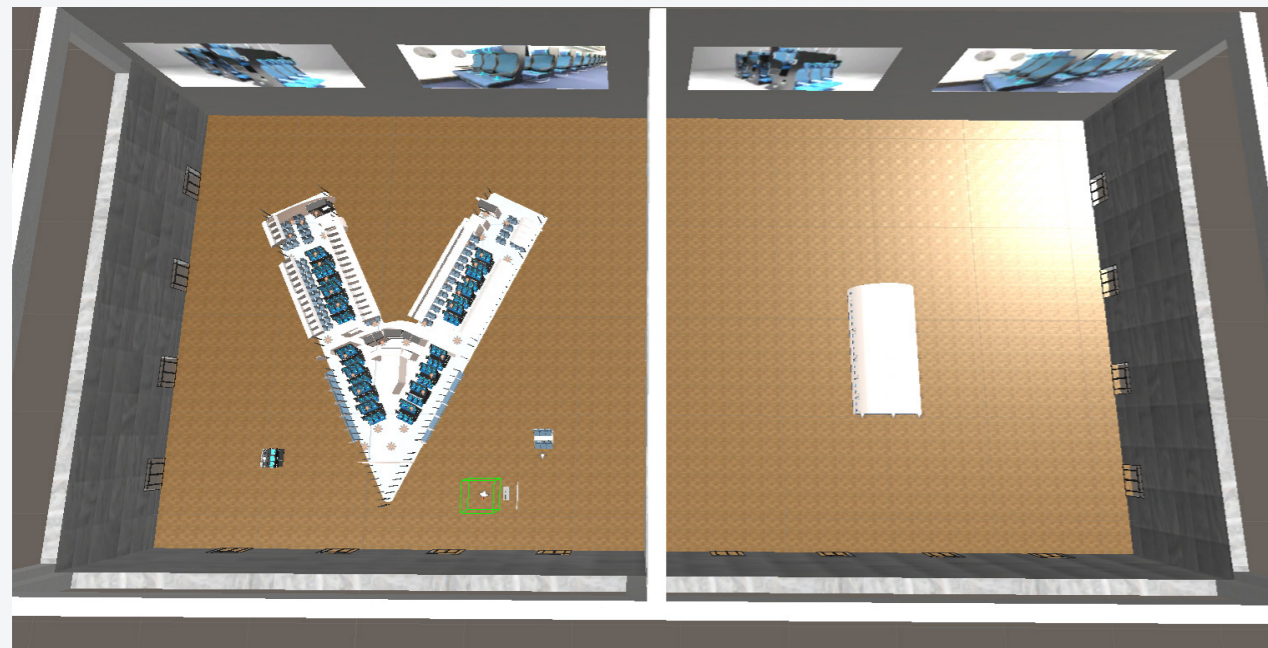


Figure 35 - Top view of the VR experience

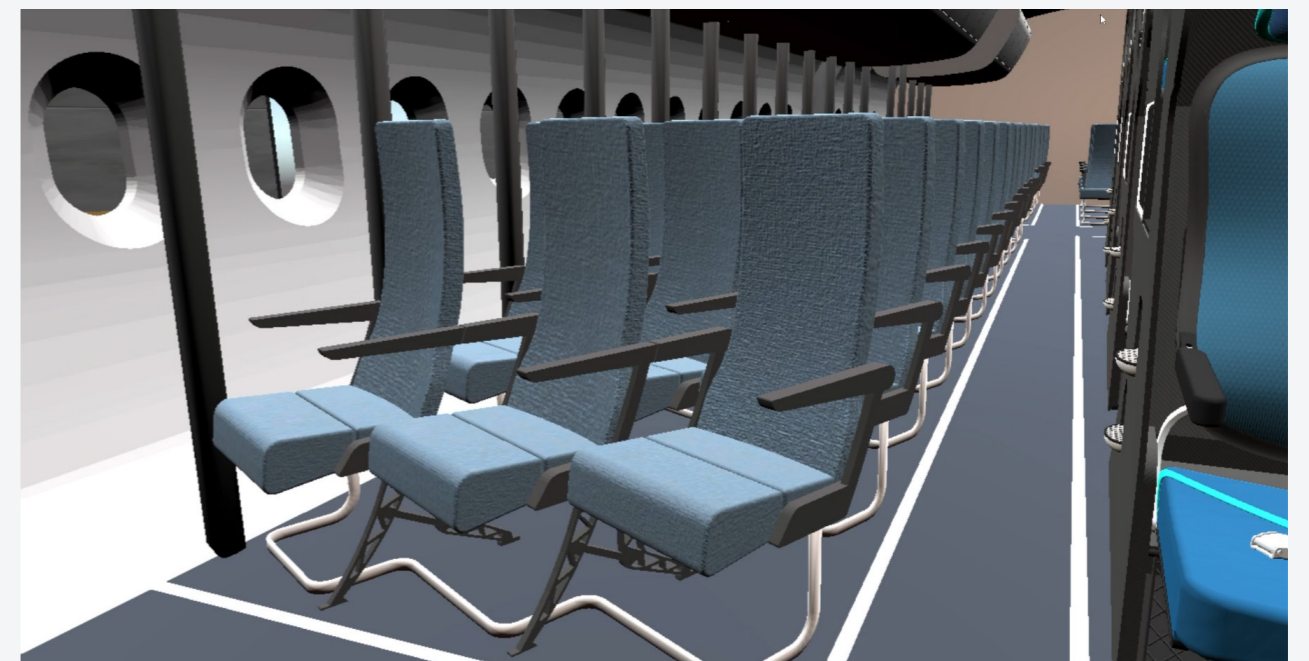


Figure 37 - The staggered seats of Lisa Wamelink in the Flying-V



Figure 38 - Grabbing and moving the tray in VR



Figure 39 - Pushing the drink icon on the touchscreen gives a Cola



Figure 40 - The Chaise Longue seats in an A350

INTERACTIONS

To give users a more immersive experience, interactions can be added to the VR experience. For example, in the first test (see Figure 38 & Figure 39) it is possible to open and close the tray, start and stop a video, and get a drink by pressing a touchscreen. The reactions to the interactions have been mostly positive, although they can be confusing if it works poorly.

Adding interactions in Unity is done using the C# programming language, Unity offers a manual at <https://docs.unity3d.com/Manual> (Unity, 2022) in which the code is explained. Unity also offers tutorials for beginners (<https://learn.unity.com/>).

Looking at the button that gives the cola can, the procedure is as follows:

Table 3 - Diagram of Cola can interaction

	Action	Trigger	Reaction
For the user	Hand touches drink button	Button is pressed	Cola pops out
in Unity	Collider of hand (controller) touches collider with trigger of the screen	check if object tag is "hand" When tags are okay the button is pressed This is printed in the console	Check if amount of drinks is lower than five A model of the Cola can is instantiated on a specified location
Code C#	<code>void OnTriggerEnter(Collider other)</code>	<code>if (other.gameObject.tag == "hand") Debug.Log("Pushed the Button!");</code>	<code>a = GameObject. FindGameObjectsWithTag("Clone").Length; if (a < 5) GameObject Clone = Instantiate(ColaCan, location1.position, location1.rotation); Clone.gameObject.tag = "Clone";</code>

The whole code can be found in appendix 7

By adding so-called colliders (see Figure 41) to the objects, an action can be started with the help of code. The colliders touching each other is the trigger, the reaction is the Coke can which spawns at a specific location. Table 3 shows an overview of the actions with the associated code. To ensure that cola cans are not added indefinitely, a maximum of five cans has been set in this example. This has also been done for the video. Instead of spawning a can, the button spawns the video which starts immediately with playing. Another push on the button stops the video. This is done by checking if there is already a video playing. If this is true, it destroys the current videoplayer instead of opening a new one. The code of the videoplayer can be found in appendix .

Grabbing objects is handled through the XR Interaction toolkit (plugin) (Unity, 2022c). By adding a XR Grab Interactable component the object can be grabbed.



Figure 41 - The collider is visualised with the green lines surrounding the cola Can.



VR HARDWARE

During the project, two headsets were used with different advantages and disadvantages. In this chapter, the two headsets used are compared. It concerns an HTC Vive Pro and the Oculus Quest 2.

HTC Vive Pro must be connected to a computer in order to use it. Also, the bases need to be set up for headset tracking (HTC VIVE, 2022). The bases must be connected to mains power, so using the HTC Vive requires multiple sockets. If the controllers also need to be charged, the headset uses a total of 6 power outlets (two controllers, two bases, the headset and the laptop or computer). You also need a good computer to use the headset. The minimum requirements are (HTC VIVE, 2022):

- Processor: Intel® Core™ i5-4590 or AMD FX™ 8350, equivalent or better.
- Graphics: NVIDIA® GeForce® GTX 970 or AMD Radeon™ R9 290, equivalent or better.
- Memory: 4 GB RAM or more
- Video out: DisplayPort 1.2 or newer
- USB ports: 1x USB 3.0 or newer port
- Operating system: Windows® 7, Windows® 8.1 or later,

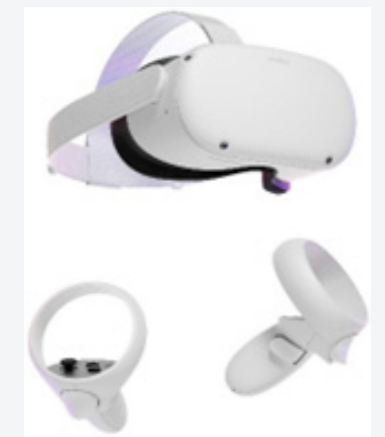


Figure 42 - Oculus Quest 2



Figure 43 - HTC Vive Pro (full kit)

This differs from the Oculus Quest 2. The headset has a memory through which apps can be placed on the headset. No computer is required, and the headset can be used without wires. However, the limit of the complexity of the apps is lower than when the headset is used via the computer. It is important to keep the vertices as low as possible, with a maximum of 750k-1.0m (Oculus, 2022b).

VR OPTIMIZATION

To be able to put the VR models on the Oculus Quest 2, the models had to be optimized. The model can be optimized in a few ways. Figure 44 shows the differences in the number of vertices. The complete models have been remodeled to reduce the amount of vertices, which gives a big performance improvement (Google, 2019). Combining loose parts with separate meshed into one part with one mesh reduces the amount of draw calls, what also improves the performance (Google, 2019).

When it comes to lighting (and shadows), real-time lighting costs a lot of power, instead it is possible to bake lightmaps if shadows are necessary (Unity, 2022d). The information lighting and thus shadows will be printed on a texture image so the PC doesn't have to compute it real-time. See Figure 45 for a light bake.

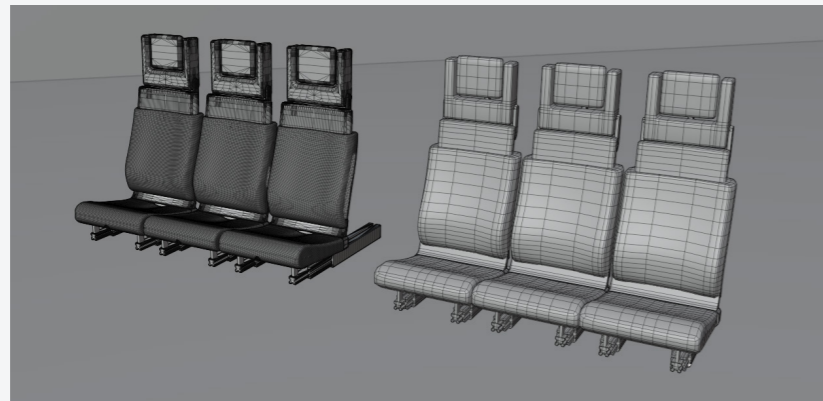


Figure 44 - The old model (left) has approx. 500.000 vertices. The optimized model (right) has around 20.000 vertices.

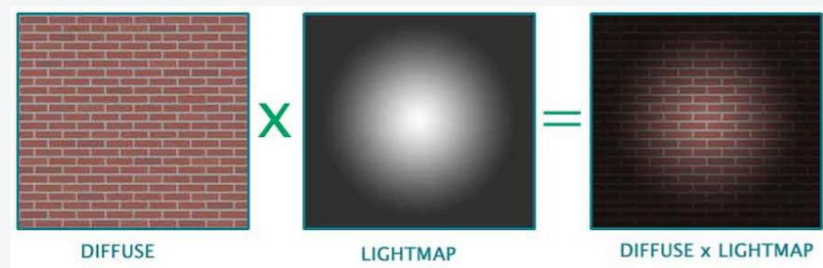


Figure 45 - Visualisation of a light map (visual by Keshav Channa - flipcode.com)



02. VISION

To create a vision, elements of the VIP method were used (Van Dijk & Hekkert, 2011). Trends and mutual connections were investigated. The trends showed that there are differences between flying individually or as a group, so the needs differ. Also when we look at future needs, these can be divided into two groups; Hardware oriented needs (such as the chairs or sockets) and service oriented needs (such as arranging when the food comes or turning on entertainment). These relationships are named and form a matrix with the following axes: Future Needs (X) and Consciousness & Inclusion (Y). The interests of the various stakeholders is also investigated. The most important stakeholders are the passengers and crew, who are directly related to the new design. The airline, manufacturer and educational institution come next. In this respect, it is possible to design for two groups: the passengers or the crew. It has been decided that the focus will be on the passenger in order to keep the design brief manageable. The crew is not forgotten here; in the design choices, what this means for the crew will be considered in the design choices. The following vision statement flows from the stakeholder analysis (next page) and the VIP method: This statement means that the passengers themselves are in control of their flight and can do the same things as they can do at home; sleeping, turning on a movie, comfort, coziness, deciding for yourself when you want to eat or go for a walk.

I WANT EVERY PASSENGER IN THE CABIN TO FEEL AT HOME WHILE ENJOYING THE AUTONOMY OF THEIR OWN FLIGHT

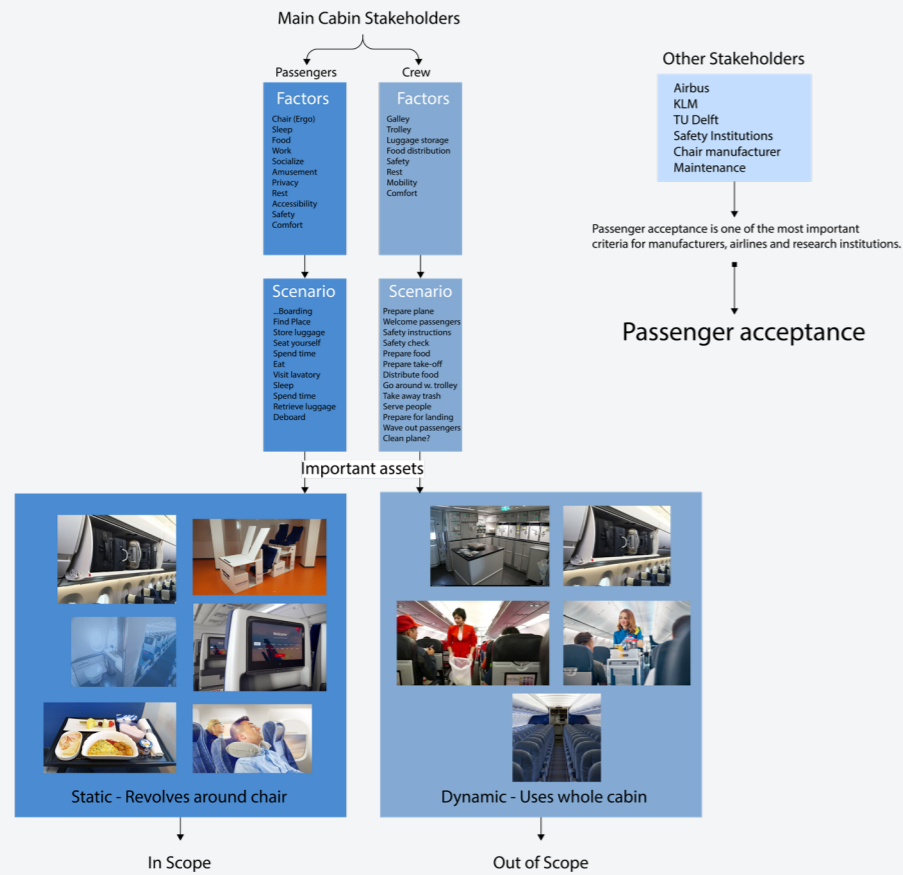


Figure 46 - Future world view matrix, ViP method

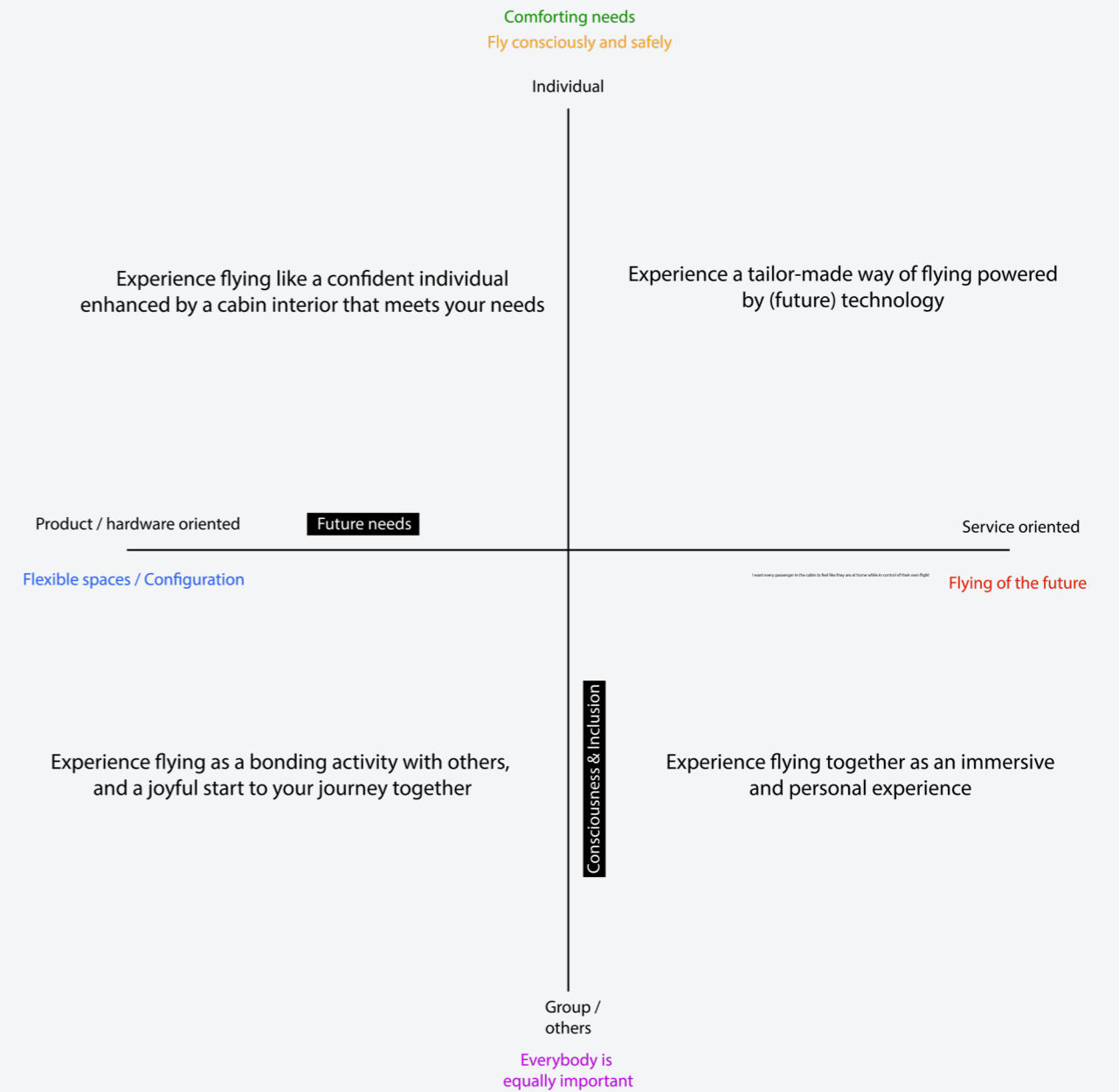


Figure 47 - Overview of key stakeholder analysis



03. REDESIGN

INTRODUCTION

To see how Virtual Reality can help early in the design process, a redesign of the existing Chaise Longue will be made (see Figure 5), and it will be tested with different test persons. Further adaptations and changes will result from this for the final design. The aim of the redesign of the Chaise Longue is to make it a realistic concept, taking into account FAA regulations (FAA, 2021) and taking the user into account. A number of requirements have already been drawn up for the redesign that the design must meet (see below). For the test in VR at an early stage of the design process, a design in TRL 3 (Tzinis, 2021) is sufficient. According to NASA (Tzinis, 2021), at this stage a design is tested to see if it is viable, and a proof-of-concept model is created.

This is also reflected in the requirements, and these are therefore limited. For example, distribution, packaging or end of life are not considered (Pugh, 1990). However, the rules of the FAA (see appendix 5) are taken into account, because the goal is ultimately to work towards a realistic design. However, in order to meet these requirements, research and many specific tests are required (FAA, 2021), which are only applicable at a later design stage (Tzinis, 2021).

LIST OF REQUIREMENTS

Requirements

- Structurally correct
- Place for 6x hand luggage (50cm x 45cm x 25cm) (IATA, n.d.)
- Space for life jackets
- Passengers below must be protected from passengers above
 - When a beverage falls over, the contents may not reach a passenger in another row
- Space for reclining seats or for Aero seats which are in a reclined position.
- Overview for cabin personnel, are able to look to the back of the aisle. (FAA, 2021)
- Every seat has a screen & tray
- Legroom advantage compared to 'normal' setup at 32"
- Three people can sit above and three people can sit downstairs.
- No more than 18 degrees out of the direction of flight. (FAA, 2021)

Wishes

- As few sharp corners as possible due to crash safety
- Easy to get in top
- Easy to get in downstairs.
- Meets the structural requirements of the FAA (FAA, 2021)
- Amount of material used similar to material used for stowage boxes.
- Round & Friendly design, passengers need to feel themselves at home.

See Appendix 5 for an elaborated table of the list of requirements of the FAA and the status of the other requirements.

REQUIREMENTS FAA

The FAA (Federal Aviation Administration) has extensive rules regarding requirements that an aircraft interior must meet during a crash or evacuation. Appendix 5 lists the FAA requirements relevant to this design (FAA, 2021).

FORM EXPLORATION

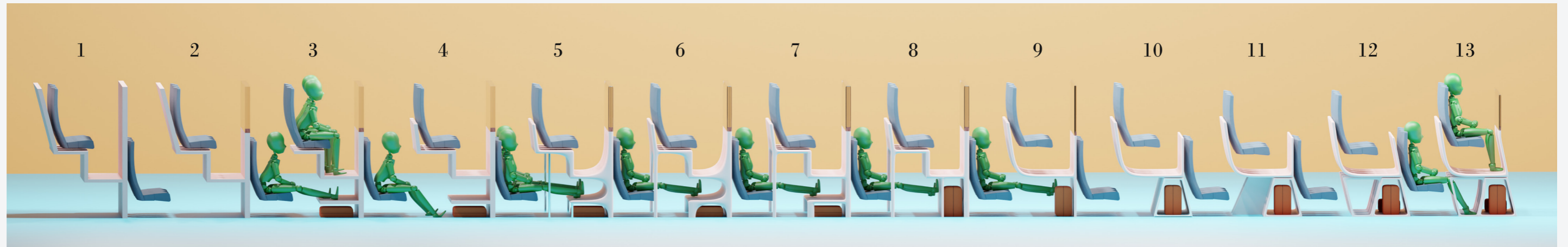


Figure 48 - The iterations during the form exploration

ITERATIONS

In the form exploration, the starting point is to hold up two rows of chairs, and new requirements are added in each iteration, in order to arrive at a final shape. The numbers in the image above refer to the steps below. Number 13 is the starting point for moving forward in Solidworks and adding realistic measures. This creates a realistic picture of the proportions.

1. Basic shape, plate material holds upper chair and protects the lower seat.
2. Transparent to board has been added for crew overview.
3. Foot rest has been added, which creates a place for luggage.
4. Board in the back has been added as protection for the lower seat.
5. Corners are rounded, pole has been added for the structure.
6. Metal poles replaced with same material as the frame, one piece.
7. Sharper corners, still rounded.
8. Luggage straight up, using unused space above luggage.
9. Creating space under upper seat for life vest by changing the plate shape.
10. Creating a closed space for the hand luggage, making it two pieces.
11. Adding structural plates, also the create a private feet space.
12. Changing the structural plates to create more open space.
13. Put back the transparent board.



Figure 49 - 3D printed mannequins on the Aero seat in a double decker configuration

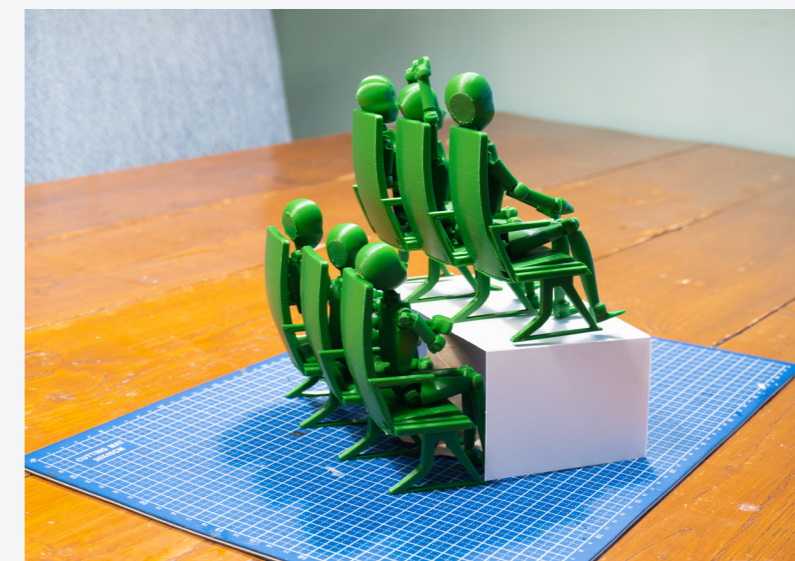


Figure 50 - 3D printed mannequins on the Aero seat in a double decker configuration

MEASUREMENTS

Human sizes from DINED.nl (TU Delft, 2020) are used as reference for the dimensions of the frame. Because the frame has to fit in place of current seats, the distance between two frames, the pitch, is 62 inches. When these measurements are applied in Solidworks, the model is created as can be seen in the image on the top of the next page. The overall width of the frame is 1514 mm, so it fits exactly 3 Aero seats (Liu et al., 2021).

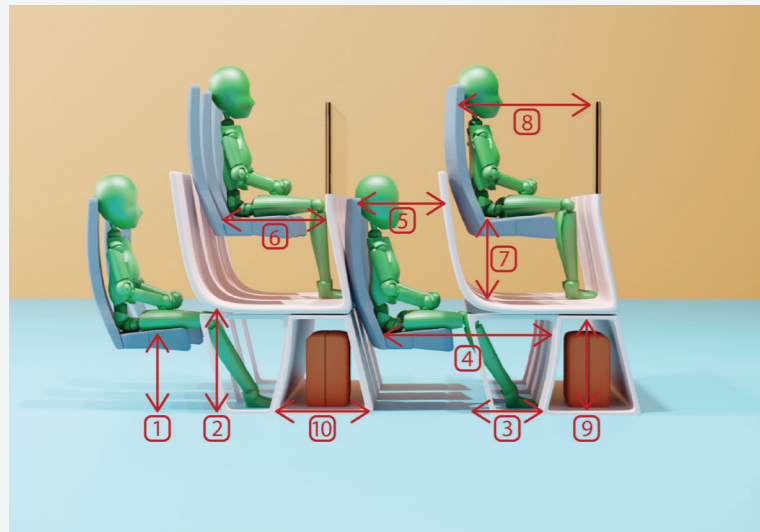


Figure 51 - Important human measurements for the design of the frame. The mannequin is P88 Dutch Adult m+f (DINED 2004)

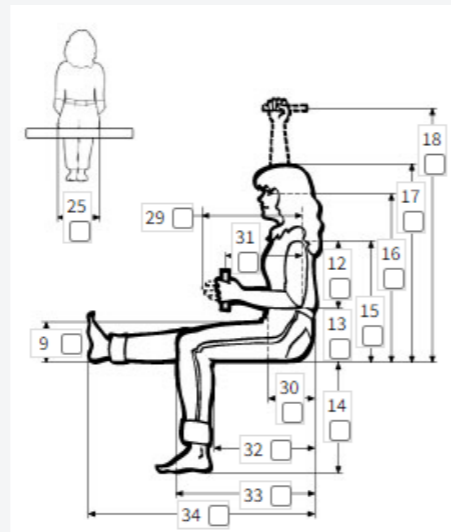


Figure 52 - Reference of measurements from DINED

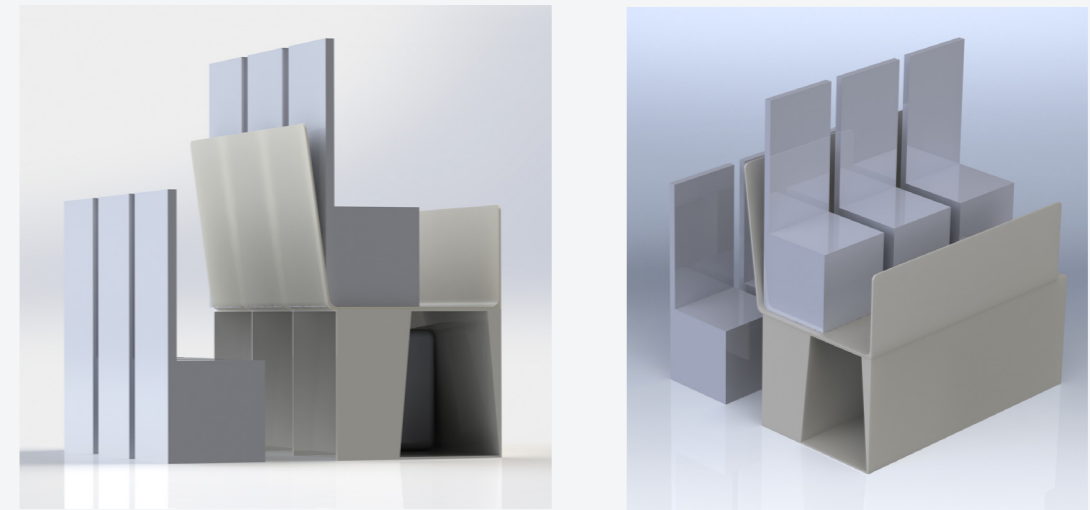


Figure 53 - The concept modelled in Solidworks with the real measurements. The chairs represent the overall volume of the Aero seats.

The image below shows the final measurements of the legroom. The lower seats have the most gains when it comes to legroom. The upstairs seats especially have more room at the knees, but are less able to stretch their legs. The other dimensions can be found in Appendix 4.

Table 1 - Frame sizes with corresponding human sizes.

#	Frame	DINED
1	Seat height lower seat	Popliteal height (14)
2	Height frame bottom	Popl. height + Thigh clearance (14 + 9)
3	Leg space bottom seat	$\sqrt{(\text{Popl. height.high})^2 - (\text{Popl. height.low})^2}$ *
4	Depth lower seat	Buttock-knee depth (33)
5	Headspace lower seat	
6	Depth upper seat	Buttock-knee depth (33)
7	Seat height upper seat	Popliteal height (14)
8	Headspace upper seat	
9	Stowage height	IATA Baggage rules (56cm x 45cm x 25cm)
10	Stowage	IATA Baggage rules (56cm x 45cm x 25cm)
	Overall width	3 times the Aero chair. (1514mm)

for the maximum sizes, the Dutch male up to P95 was chosen as the population. For the dimensions of the seat, the dimensions of the Aero seat are leading (Liu et al., 2021).

*The legspace is calculated as the short side of a triangle, with the long straight side as the P.low and the P.high for the slope.



Figure 54 - Mannequins sitting in the final concept, with dimensions of the pitch and legspace.

TOPOLOGY OPTIMIZATION

Topology optimization can be used to cut away redundant material (Bendsøe and O. Sigmund, 2003), while creating an interesting shape for the design, which may seem more natural (Vincent, 2021). Various starting points have been taken to arrive at a design. Parameters that can be adjusted are the initial shape, the forces, and the places where the model is attached to the aircraft (Dassault Systemes, 2021). An adjustment in one of these factors creates a different shape that flows from the simulation. See the images below for different simulation results when different initial shapes are chosen.

A composite was chosen as the material for the simulation (SMC BMC Alliance, 2016), the specifications are shown in table 2. The force placed on the model is 3200N (800N per partition), the green arrows indicate where the model is attached to its environment.

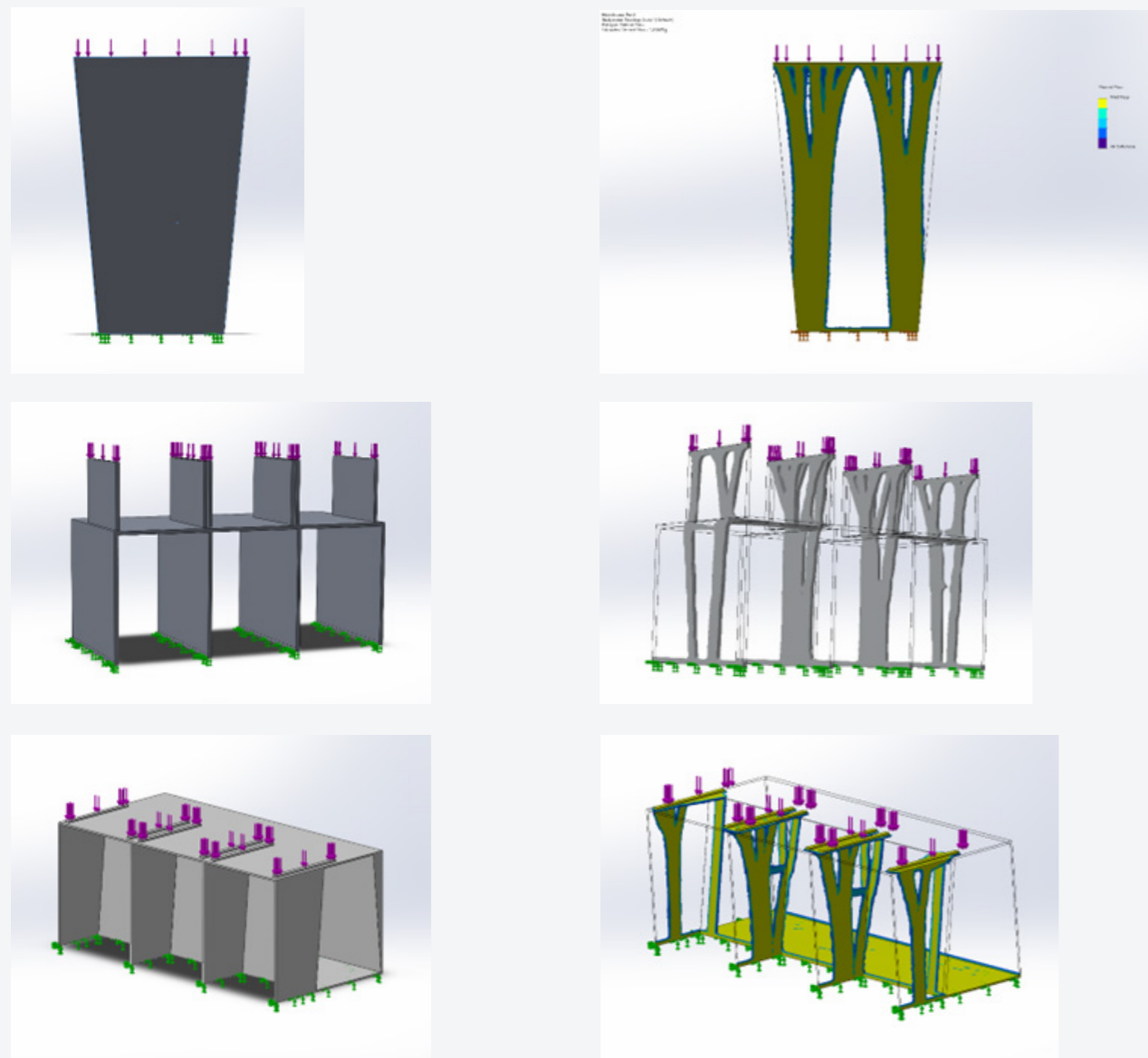


Figure 55 - Three different CAD models with their optimized topology.



Figure 56 - This model has been modelled after the topology result of the model on the bottom of the left page.

Table 2. The specifications of the materials used in the topology optimization simulation (SMC BMC Alliance, 2016)

Property	Value	Units
Elastic Modulus	3000000000	N/m ²
Poisson's Ratio	0.394	N/A
Shear Modulus		N/m ²
Mass Density	1400	kg/m ³
Tensile Strength	20000000	N/m ²
Compressive Strength		N/m ²
Yield Strength	15000000	N/m ²
Thermal Expansion Coefficient		/K
Thermal Conductivity	0.2256	W/(m·K)
Specific Heat	1386	J/(kg·K)
Material Damping Ratio		N/A

FIRST CONCEPT

The first concept roughly consists of three parts; A storage for the hand luggage, a curved plate to accommodate the seats above, and four structural parts resulting from the topological optimization. Every form has arisen from the function or requirement (see list of requirements) it has to fulfill. For example, there must be room for six pieces of hand luggage, and the storage is closed by a gate, which is also the step for the upper part. The gate can be slid open to the seat in front. In this way, it never blocks an escape route, even if it slides open during a crash.

The plate in front of the seats above mainly offers protection and privacy for the people who sit downstairs. It provides a closed compartment, where things or food and drinks cannot just reach the people below. A transparent screen provides the staff with an overview and makes the downstairs seat less closed. All chairs are equipped with a screen and a tray (although this is not shown in the images).

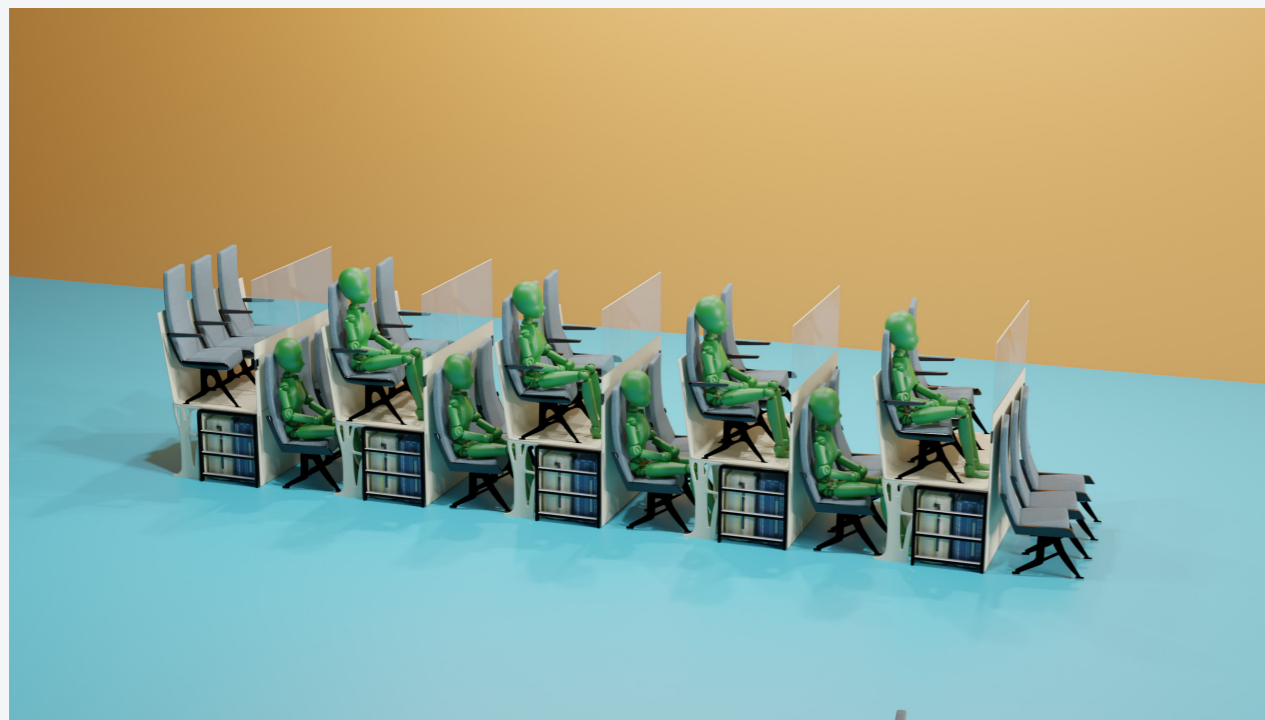


Figure 57 - Mannequins sitting in a row of double decker seats, enjoying their flight.



Figure 58 - Picture above shows a sideview of the double decker seat, one luggage fence has been opened.
Figure 59 - Picture below shows the double decker seat in more detail.



FIRST CONCEPT

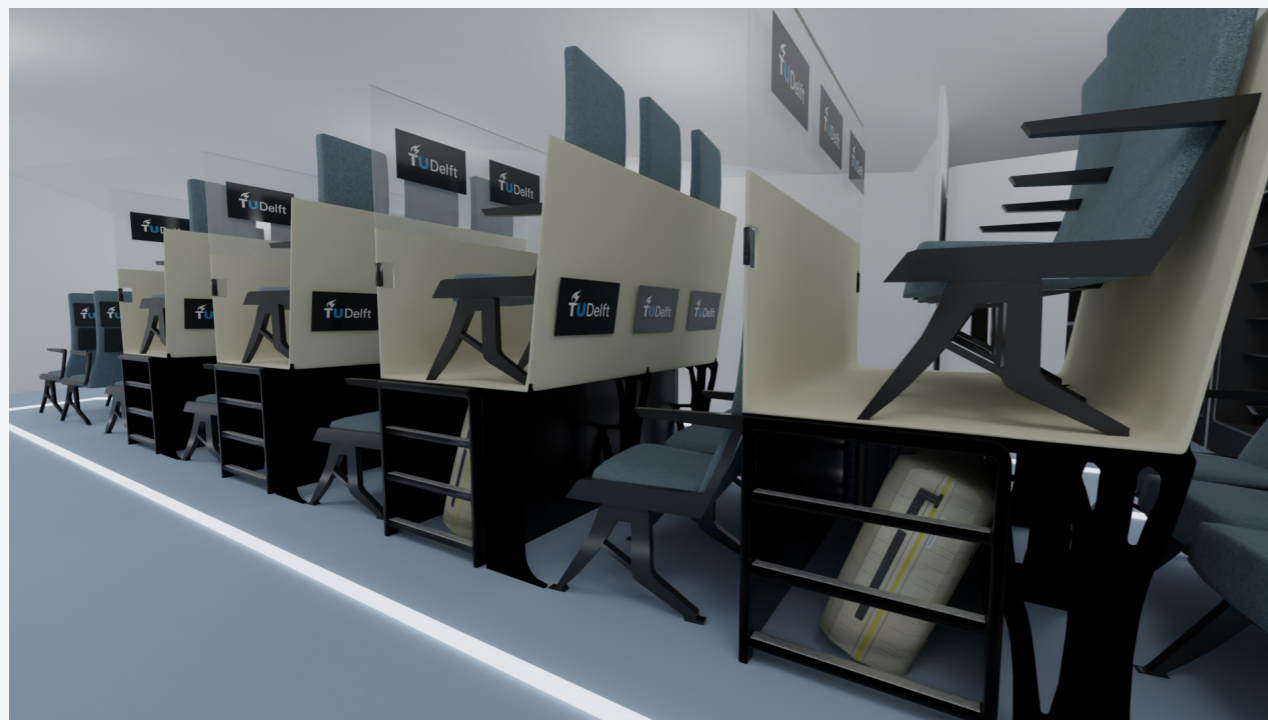


Figure 60 - Two pictures of the double decker seat in the Flying-V.



Figure 61 - Above: The double decker seat in the back of the Flying-V.
Figure 62 - Below: An exploded view of the main parts of the double decker seat.

MATERIAL

The material of the double decker frame shall for the most part consist of a composite. These are light materials with great stiffness. In addition to carbon fiber, SMC/BMC would also be an option (SMC BMC Alliance, 2016). It is a material that is already used for various products such as the plating of trucks or cars (the rear trunk lid of Mercedes), but it is also used to make seats (SMC BMC Alliance, 2016).

According to Glenn Johnson, of Collins Aerospace (the leading seat designer of one of the three largest aircraft seat manufacturers), composites and thermoplastics are now being used for seats in aircraft such as Kydex. Metals are also present, aluminum alloys, but also titanium in some parts. Collins manufactures own thermoplastics in the Netherlands (Collins Aerospace, 2021).

When it comes to materials, careful consideration must be given to where the greatest stiffnesses are needed, so that composite components can be reinforced with metal parts when necessary. This way, weight is only added when it is really necessary.

The flammability is also an important selection criteria for materials that are used in a plane cabin. The FAA states rules for the flammability requirements for materials in CFR 14. 25.853 (FAA, 2021).

EXTRAS

To return to the vision, mood-enhancing parts can be added, to make the passengers feel like they are at home. The mood board below gives an idea of the atmosphere. Natural elements can be added or elements from the country of origin of the airline, such as Dutch paintings for KLM, which are depicted on the trays. Also, the shape of the chair can create a greater sense of home. This is already partly achieved by the topology optimization structure, which has the shape of a tree and gives a sense of nature (Vincent, 2021).



Figure 63 - The eggchair by Arne Jacobsen transferred to the doubledecker design. A tray with the girl with the pearl embossed into it. A moodboard of 'feeling at home'.

SMC and BMC are everywhere (without you noticing)



© GSI



Great in Lightweight

Property	Steel	Aluminium	SMC	Carbon SMC
Density (g/cm ³)	7.8	2.7	1.8	1.4
Tensile strength (MPa)	365	483	80	200
Tensile modulus (GPa)	200	70	13	30
Specific tensile strength (MPa)	4.6	17.8	4.5	14.3
Specific tensile modulus (GPa)	2.6	2.6	0.7	2.1



Figure 64 - Slides from a SMC/BMC alliance presentation



04. TESTING THE REDESIGN

3 SCENES TEST

INTRODUCTION

As a design for the interior to see how the passengers experience the new model of the chaise longue, it is compared with two other models with normal seats, namely one with an A350 and one with the Flying-V. The test persons answer the same questions in each model, which are comparable with each other (see appendix 2 for the questionnaire). The main question is if the users would like to sit in a double decker seat during a flight, and what their seat preference is. The concerns and ideas of users are also interesting for the final design.

METHOD

The test subjects receive a short explanation about the 3 different VR models, in which they are asked for their opinion with regard to what they see at that moment. First they answer some general questions, after which they will enter the first VR model.

In the first model, the interior of the A350 can be seen with the so-called Rebel Aero aircraft seats (Liu et al., 2021). The questions they have to answer can be found in Appendix 2. They are given time to explore the model and can observe the model by walking and moving from different angles. The controllers are not used in any of the VR models. The test subjects can still hold the controllers so they can see their hands digitally.

After the test subjects have answered the questions in model 1, they return the headset so that the second model can be started. This gives the test subjects some time to orientate themselves in the room without glasses, and to recover for the next VR model. Then they answer the questions while they are in the second model; The Flying-V with normal seats. After this they return the headset and everything repeats itself in the third model; The Flying-V with a double-decker seat. After the third model, the test person takes off the glasses and answers the last questions as an evaluation of the three tests.

STIMULI

- Oculus Quest 2 (VR Hardware for specifications)
- VR model of A350 (normal chairs) (1)
 - VR model of Flying-V (normal Chairs) (2)
 - VR model of Flying-V with double decker seat (3)



Figure 65 - The first model; The 350 with regular seats.

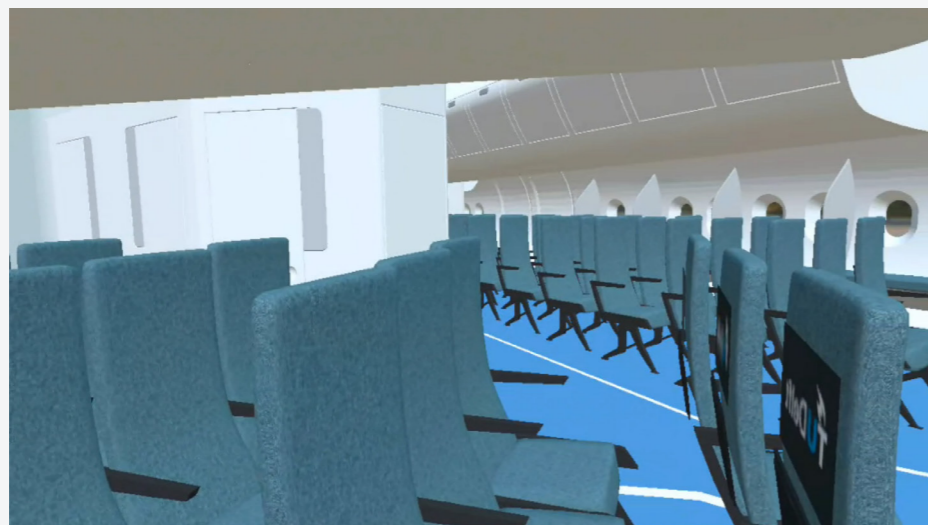


Figure 66 - The second model; The Flying-V with staggered seats

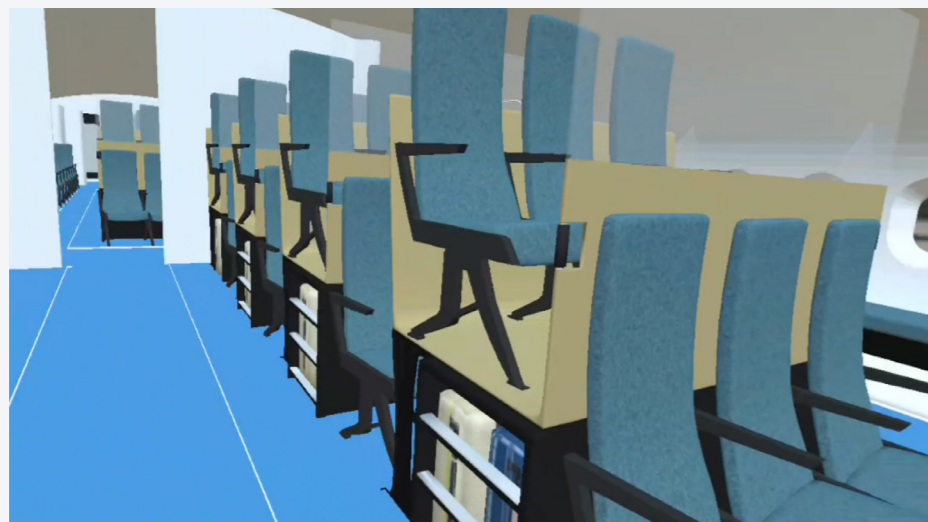


Figure 67 - The Flying-V with double decker seats.



Figure 68 - Different people who tried the three models in VR and filled in the questionnaire.

RESULTS

The test was carried out by 15 test persons, the male/female ratio is respectively 3/4 and the average age of the group is 42 years.

The majority likes taking a seat in either the bottom row of seats or the top row of the double decker seat, and are generally speaking positively about the new concept (See Figure 69). When it comes to seat preference, the rows score differently; Although the general comfort of the top row of seats is slightly higher than the bottom row of seats, the bottom row of seats scores significantly better on privacy and legroom (see Figure 69).

Looking at the other results from the questionnaire, the estimated comfort in the various aircrafts is comparable, the normal staggered seats in the Flying-V score the best (scene 2). When it comes to legroom, the lower seats of the double-decker seat score the best, as does the feeling of the most privacy. The current setup in the A350 scores lowest here, less than half the privacy score of the lower double-decker seat (see Figure 69).

The observations showed that the appearance of the chair has a major influence on the intended comfort, while this has less to do with whether the chair is staggered or whether the chair is part of a double-decker seat. The results can be found in Appendix 3.

When it comes to hand luggage, according to the test persons, it is easiest to store the hand luggage in the Flying-V with a double-decker seat. The A350 scores the worst here (see Figure 69), many test persons could not reach it. The Flying-V with a double-decker seat was experienced as the least realistic by the test persons, the A350 as the most realistic (see Figure 69).

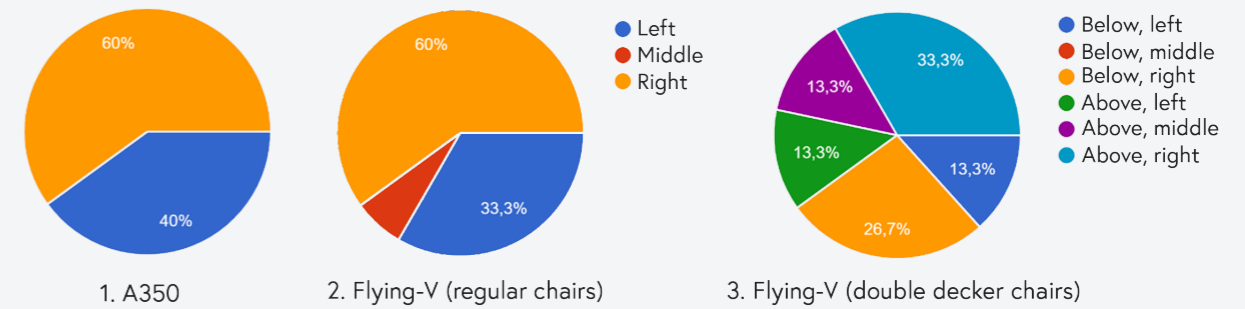


Figure 70 - Pie charts of the percentage of participants that prefer the seat for each of the three VR models.

The ideal seat on the plane looks different for everyone. Where one person likes to sit by the window, the other prefers to sit by the aisle and keeps a close eye on the escape routes (See appendix 3). One prefers to sit in the back, and the other, for example, in the middle of the plane (See appendix 3). There is a shared opinion that it should be comfortable, and everyone wants enough space. It is striking that right-handers often go for the right seat and left-handed for the left seat. Test subjects indicated that they then had more room to perform actions with their good hand, such as writing. In another case, a bad leg was leading. With the staggered chairs, the free space in front of one's own chair was important where the bad leg can be stretched (see appendix 3).

Few people were pleased with the chairs. They are considered fragile and very thin. They also look hard and uncomfortable. Although the same chairs are used in every VR model, this has a major influence on the perceived comfort. Also, the hand luggage in models 1 & 2 was placed too high for many, it has to be lowered, or the handle has to be moved downwards according to the test persons. The models of the aircraft are found to be quite bare, by incorporating more details into the model, such as fire extinguishers, stickers, the sense of realism can be increased (see appendix 3).

Looking at the doubledecker, it differs per person whether above or below is preferred. The advantages of the top row that are mentioned are the overview, and that you can look out the windows and see the ground better. The disadvantages that are mentioned are the climbing and descending of the thin bars. There is also apparently less legroom than the seat below. As for the bottom row, the advantages are more legroom, and a great sense of privacy, because one is slightly hidden. Disadvantages that are mentioned is that people can look at you from above through the transparent screen. Also, the space is found to be claustrophobic. In general for the double-decker, the hand luggage downstairs is experienced as very pleasant, but people do ask their questions about the luggage in the middle, which is difficult to reach. It was also mentioned that it is difficult to get up because one cannot grab the chair in front of oneself as support (see appendix 3).

What was striking is that the test subjects could move much more easily in the VR environment. The range was limited to the physical space, but the test subjects became less nauseous and gave much more feedback on the different VR environments and designs (See appendix 3). Also by interviewing the test subjects during the VR experience, she did not have to remember what it looked like afterwards. The adjustments to the VR and the test set-up had a positive impact on the feedback that the test subjects gave about the concept

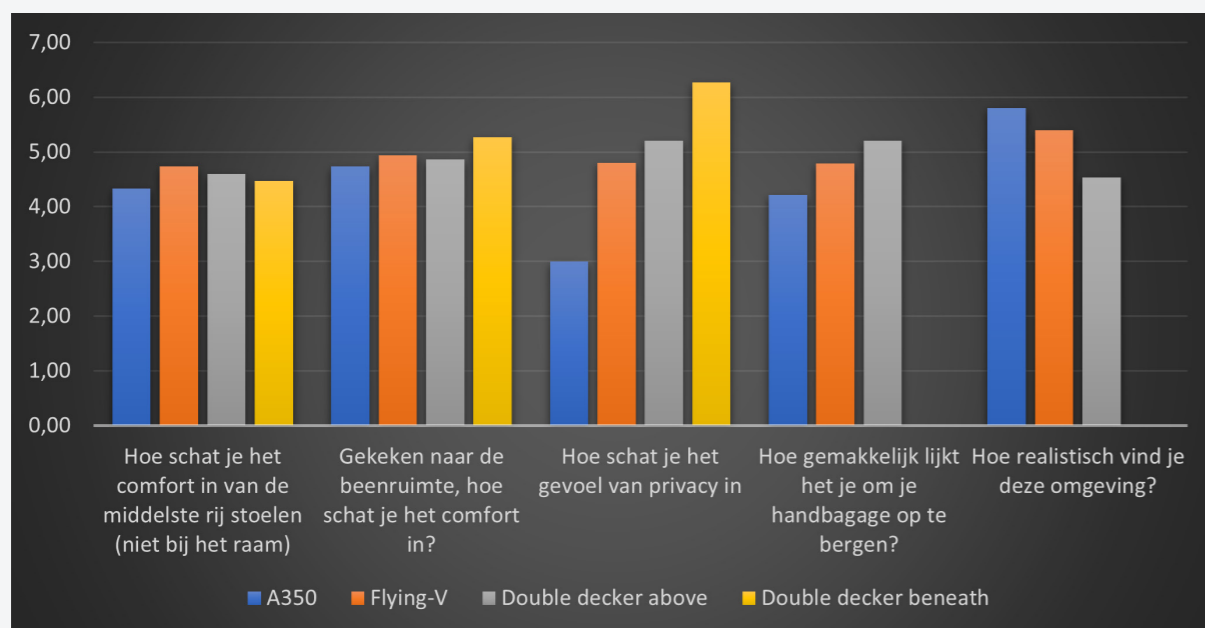


Figure 69 - Graph with the results of five questions; Perceived comfort, perceived legspace, perceived privacy, easiness of storing luggage, realism of the experience.

DISCUSSION

Double Decker seat

The test subjects had different opinions about the doubledecker seat. One thought 'this is the future' and the other never sees this happening in real life. Anyway, several adjustments were suggested by the test subjects. For example, the stairs must be easier to climb, and the luggage compartment must be completely closed. Also, the top row can now look down, which compromises the privacy of the bottom row. Finally, the shape of the double-decker can still be optimized, there is still unused space, for example behind the seats (see appendix 3).

Test subjects are positive about the hand luggage downstairs, but it does take away the opportunity to lie down and stretch your legs. In the final design, it can be checked whether it is possible to store six pieces of hand luggage, without losing the possibility to stretch your legs.

VR

The VR worked well during the test to show a conceptual design to test subjects, and people also manage to form an opinion about it. However, it is necessary to pay close attention to how the VR is constructed. Because VR is so immersive, people can see details that have a direct influence on the experience within VR. These details can distract from what you want to investigate, or offer an addition. For example, the texture of the seats was perceived as uncomfortable, although this was initially not seen as important, so not much attention was paid to it. People also indicated that they found the plane bald. Adding stickers and icons to the aircraft can help increase the sense of realism and make people feel even more included in the model.

As a result of the previous research with people in VR, the movements with the controllers were removed from the model, which had a major positive effect. All test subjects indicated that they experienced the use of VR as pleasant. No one suffered from motion sickness either. The movement in the VR was synchronized with the physical movement of the test subject, so no game or VR experience was needed to use the model. It is important that the starting position is chosen correctly, because the person can only walk as far as the available physical space.

Another positive change from last time was the use of the Oculus Quest 2, stand alone. This means that no computer is needed to run the VR model, everything is on the headset. In this way, the distance you can walk is not limited by the cable, and it is only necessary to turn on the VR glasses and the test can begin. However, there were problems with taking off the guardian, this is a safe area that you sign off before using the glasses, so that people know when you threaten to run into something.

The test subjects were very enthusiastic about the use of VR, which was reflected in the level of detail in criticism of the model. Because the subjects could view the model in 3D at their own pace, they could find something about every aspect, and test its dimensions. Several tried to open the luggage bins, only to find that they could not reach them.



05. FINAL CONCEPT REDESIGN



THE FINAL DESIGN



Figure 72 - Front view of the final concept



Figure 73 - Rear view of the final concept

INTRODUCTION

The final concept is based on the results obtained in the previous tests. For each part, the changes are discussed and why they were made. The different Chaises Longues are also next to each other to compare.

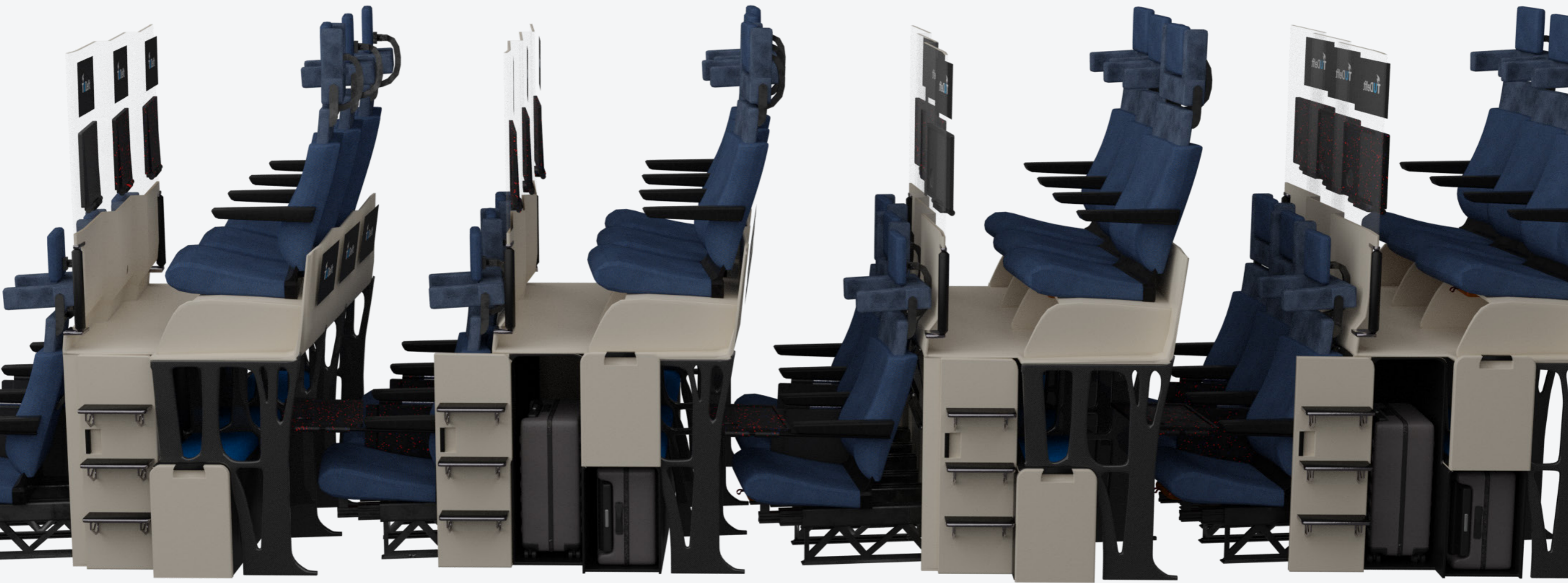


Figure 74 - Side view of the final concept

COMPARISON

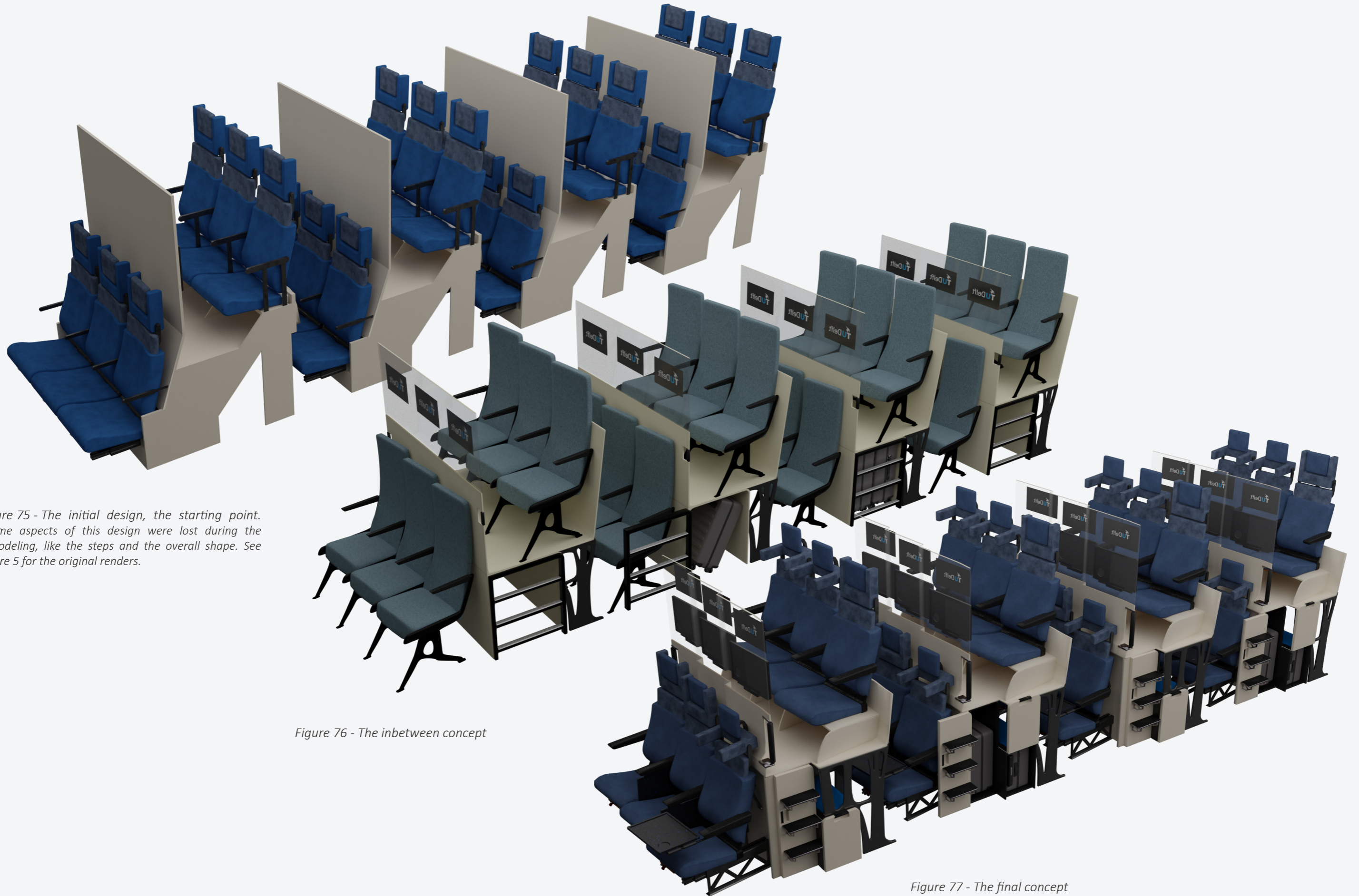


Figure 75 - The initial design, the starting point.
*Some aspects of this design were lost during the remodeling, like the steps and the overall shape. See Figure 5 for the original renders.

Figure 76 - The inbetween concept

Figure 77 - The final concept

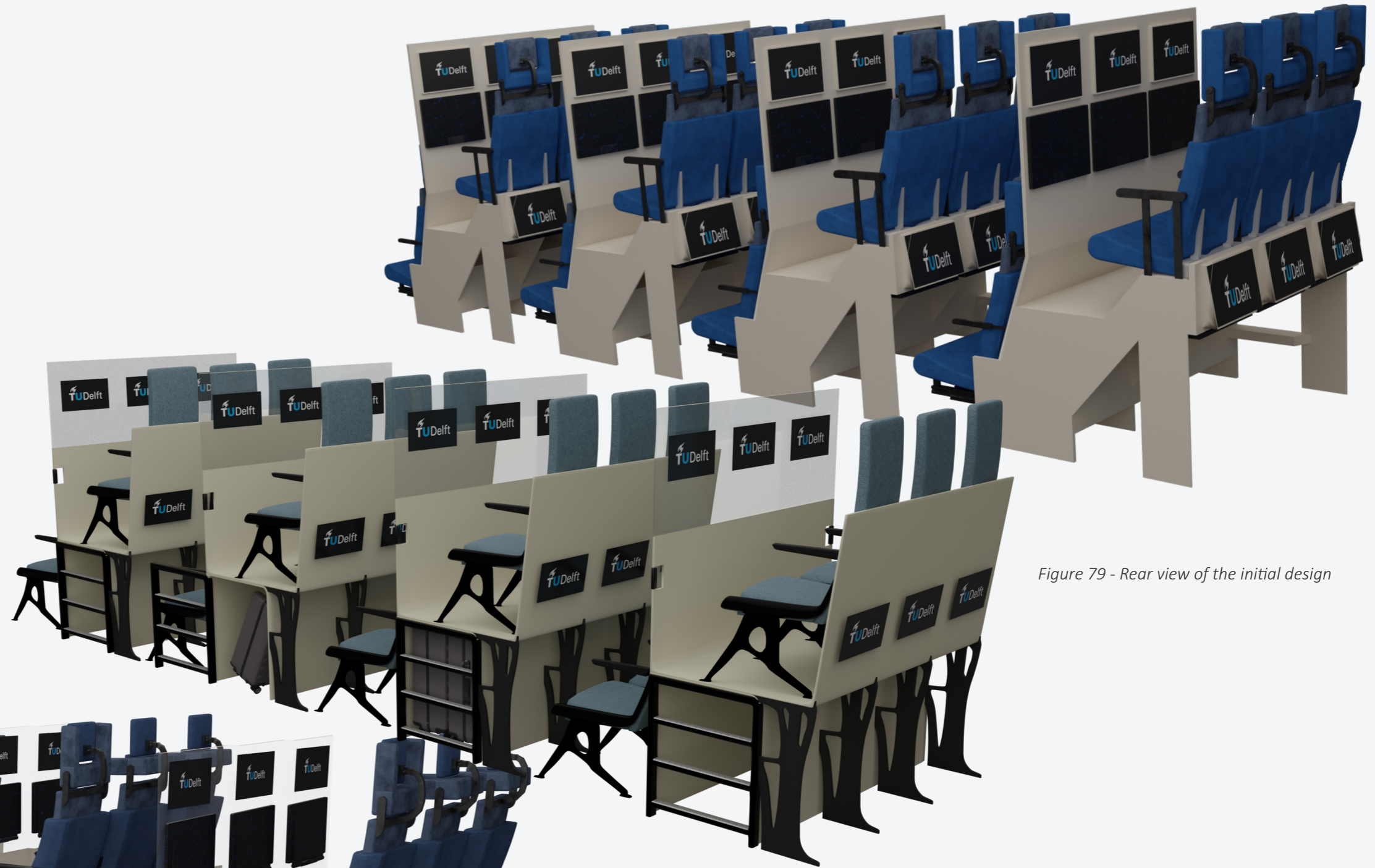


Figure 79 - Rear view of the initial design



Figure 78 - Rear view of the final concept

Figure 80 - Rear view of the in between concept

FRAME & SEATS

The frame supports the seats and also creates space to store the hand luggage, attach screens and trays above, as well as the steps to get up. Compared to the previous concept (Figure 75), the frame flows through in places where there was still unused space, giving a few centimetres extra space for the feet near the seats above (Figure 81). It was mentioned a number of times that the upper legroom looked narrow (see appendix 3). This has been met by spacing the Chaises further apart and making the recesses.

The transparent board provides an overview for the staff (FAA, 2021), but also makes the construction more open, with a view to people with claustrophobia. This also applies to the topologically optimized structural part (Figure 84). In the test, some people indicated that the passengers upstairs could look down on the passengers below, which creates privacy issues. In this design, large transparent boards have been chosen to give priority to openness. For a future design, only the top part could be made transparent (Street, 2022) so that it is less easy to look down at the top.

The distance between the Chaises Longues has been increased to 64 inches compared to 62 inches of the previous design. The latter design is also wider to give more space for luggage, the staggered seats and the stairs. In addition, the footstool is back, and the row below can recline again and stretch his or her legs. The frame had to be higher so that people with large feet can also put their feet on the footstool. The total height is now around 1.90m, this is very high for the Flying-V as the cabin of the Flying-V is 2.10m high in the current designs (Vos, Geuskens & Hoogreef, 2012). One option is to reduce the foot height (Figure 79) of the footstool to create more headroom.

The Aero seats have been replaced by the seats that are in the initial design, so the end result can be better compared with the beginning, since the seats are not included in the redesign, and are therefore unchanged. This also applies to the reclining system. In addition, several test subjects found the Aero seats to look uncomfortable (see appendix 3). In a final design, a structure will be incorporated into the frame that holds the chairs, rather than a chair with legs and all being placed on the frame. The renders (Figure 72) also show the life jackets and there is a compartment under the seat for a small bag.

HANDLUCCAGE

To make room for the footstool, the space for hand luggage had to be redistributed. The design now has two separate compartments (Figure 83), where in one the hand luggage can stand and in the other it can lie down. Because the frame is higher, this means that there is even more space in the large hand luggage compartment than necessary (Figure 83). This can be used to store items purchased from Tax-free or small bags. In the two compartments there is enough space to store 6 pieces of hand luggage measuring 56cm x 45cm x 25cm (IATA, n.d.).

For those who have their hand luggage stored in the middle, it can be difficult to get it. Additional doors or a roller shutter for the middle passenger's seat could help with this. Chaises Longues of two people instead of 3 can also be looked at.

The hand luggage compartments are closed by a door in the latter concept. For small items that are stored, the compartment must be able to be closed so that they remain in the compartment. The door of the large compartment opens to the side, the door of the small compartment opens upwards. In this way, as little physical space as possible is required to open the doors and they do not block escape routes if they are open during an evacuation.



Figure 81 - Detail of the frame and the recesses



Figure 82 - The footrest. The foot height is the space between the rest and the seat deck for the upper row.



Figure 83 - Hand luggage compartments. Left closed, right opened.

STEPS

In the test, the stairs were found to be thin and fragile, and test subjects also wondered whether you can put your feet on the gate if it is full of suitcases behind it (see appendix 3). That is why a larger step has been made (see Figure 72), and you can hold on to a handle in the frame. Ideally, the handle would be higher than now shown (Figure 72) for easier access.

SCREEN & TRAYS

The screen and trays of the row above are attached to the transparent board (see Figure 73). The people downstairs have nothing in front of them to which a tray can be attached (Figure 74), partly because the Chaise has become higher. In the initial design, the tray slid out from under the top row of seats. As a result, it has now been decided to attach the tray to the chair (see Figure 85). This way the passenger can still reach it, whatever position the seat is in. The screen is attached to the Chaise Longue. This can optionally be attached with, for example, a telescope arm to be able to put it in the desired position.

STRUCTURAL COMPONENT

The structural components had to be extended by creating the footstool. A new topological optimization has been performed for this, which is combined with the old model (Figure 84). Also, the two centre structural components are now rotated with the seats, as they were in the passenger's legroom due to the seats being staggered. These are now straight relative to the seats. This allows for legroom differences in width within a row (see Figure 84). It has been decided that every passenger can sit with their legs straight ahead, without hitting a component. That produces this configuration.

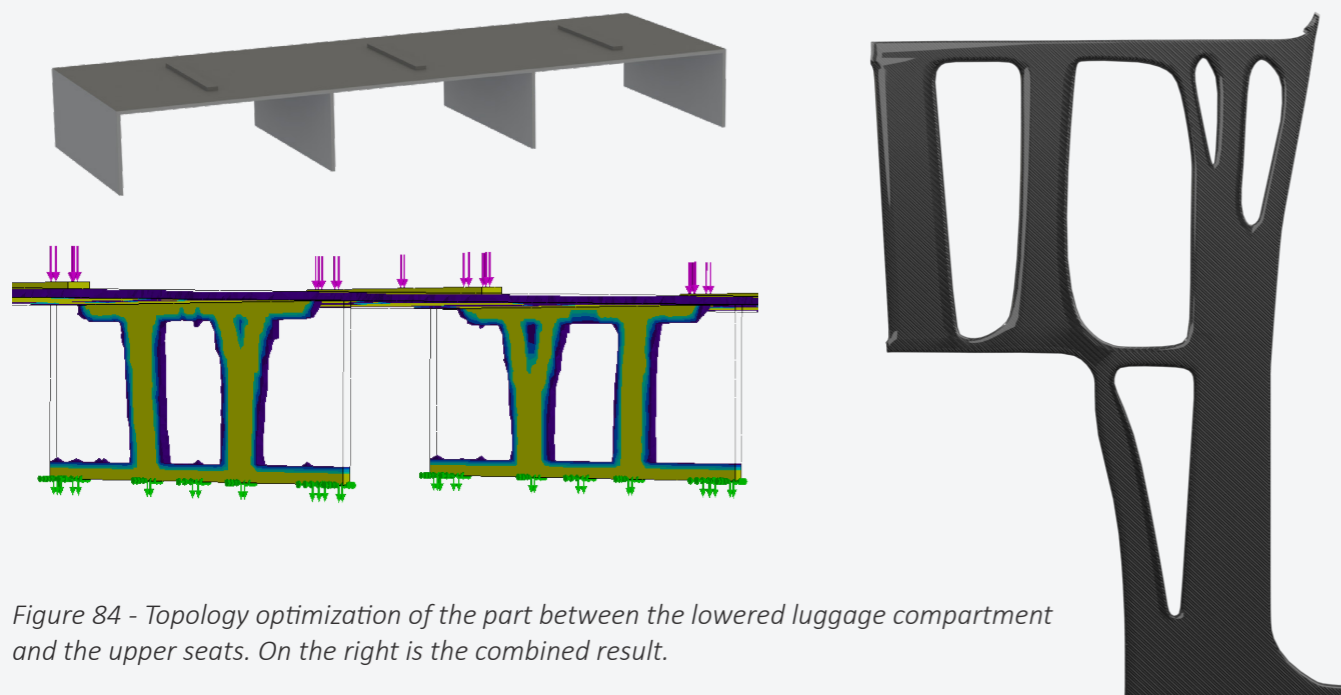


Figure 84 - Topology optimization of the part between the lowered luggage compartment and the upper seats. On the right is the combined result.

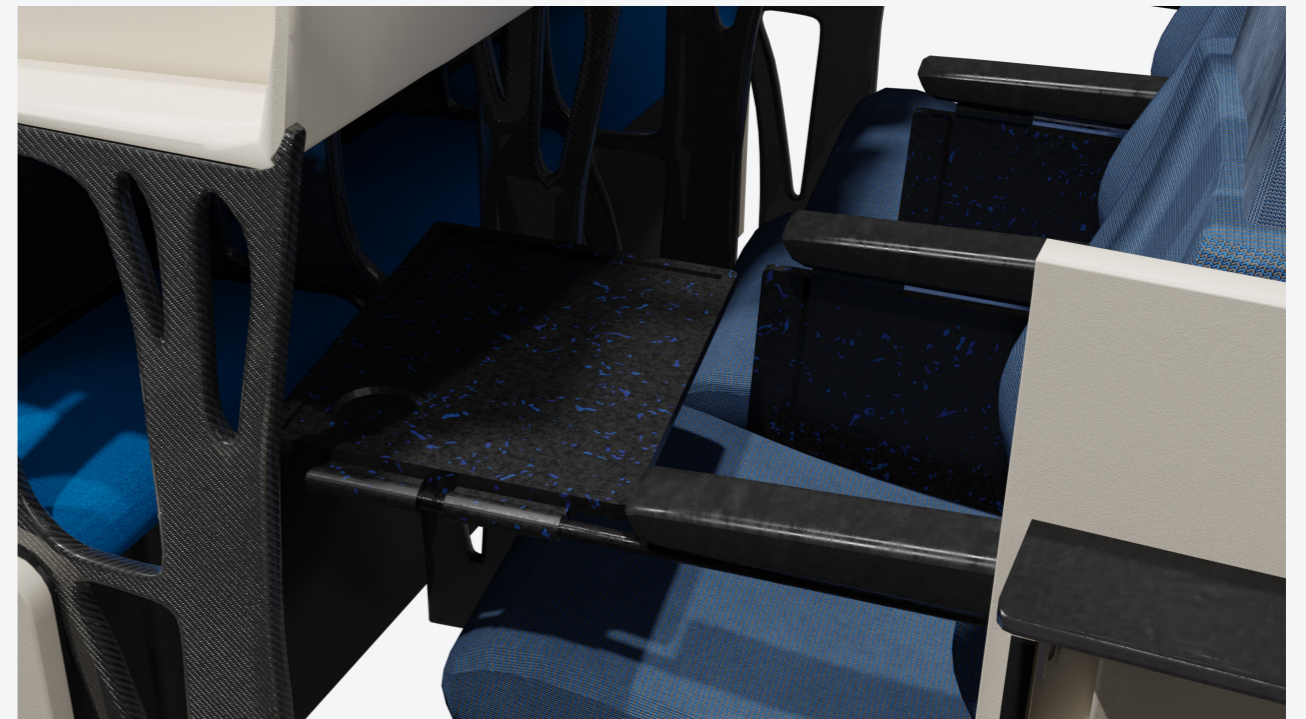


Figure 85 - Detail of the tray attached to the armrest



Figure 86 - Top view of the Chaise Longue, with the rotated structural parts

06. CONFIGURATIONS

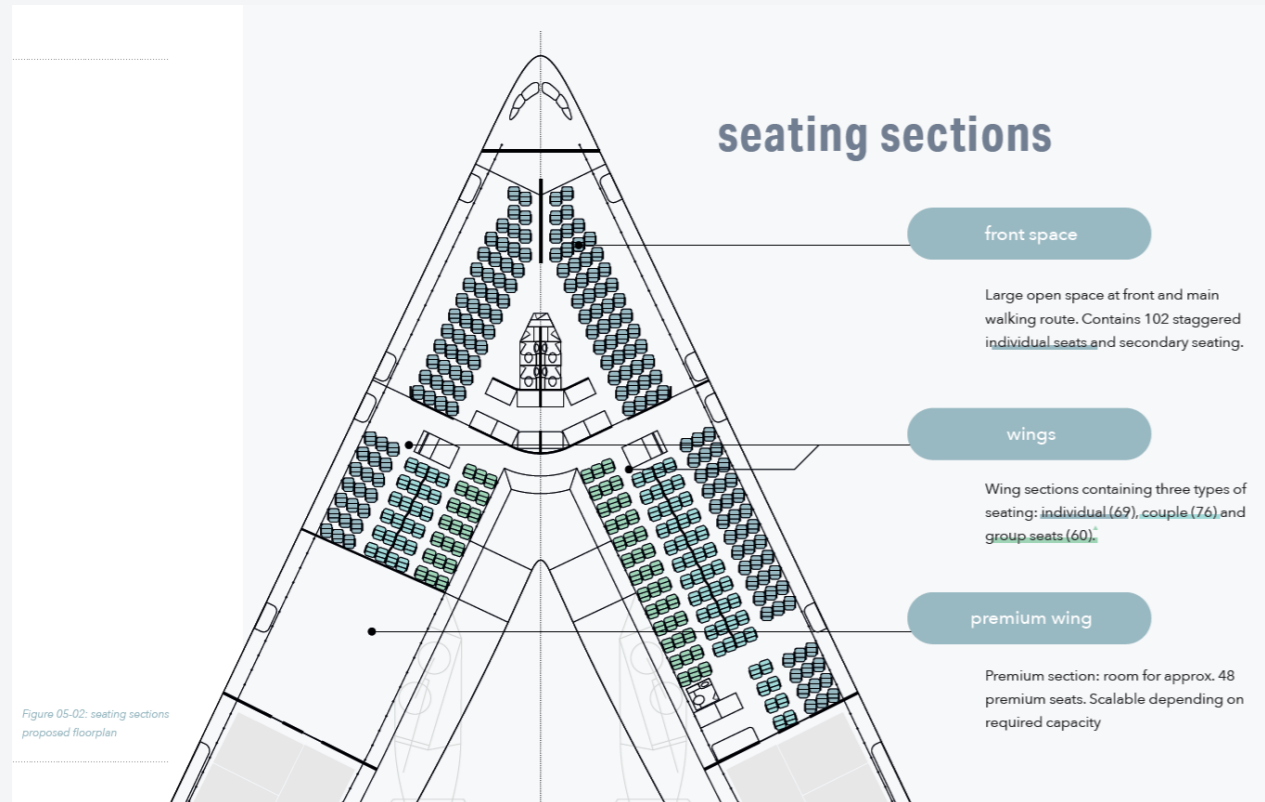


Figure 87 - Seat layout map by Lisa Wamelink (Wamelink, 2021)

The layout used in the VR setup comes from Lisa Wamelink (Wamelink, 2021). This layout is continued to see the effects on capacity with the redesign of the Chaise Longue. Different layouts are shown on the following pages with the consequences for the capacity. Since the Chaise Longue can only stand in the middle due to its height (Vos, et al., 2012), it replaces the rows of four chairs in the middle of the wings. This will reduce the capacity, as the Chaise longue contains three seats and is approximately the same width due to the luggage space and the steps that protrude. If we assume a layout without a premium wing (see Figure 86), then the Flying-V can accommodate 424 seats if the benches are replaced by rows of two seats. The following capacity cost rule of thumb can be applied to place different elements in the aircraft:

Sofas (wamelink, 2021)	48 chairs
Food corner (Lam, 2020)	8 chairs
Chaise Longue (whole middle path)	42 chairs

So when all the above is applied in the layout, the remaining capacity is 326 passengers. This is comparable with an A350 (Airbus, 2021). If the premium wing is added with 48 premium seats (Wamelink, 2021), this will cost two more seats of the 326 seats.

416 PASSENGERS

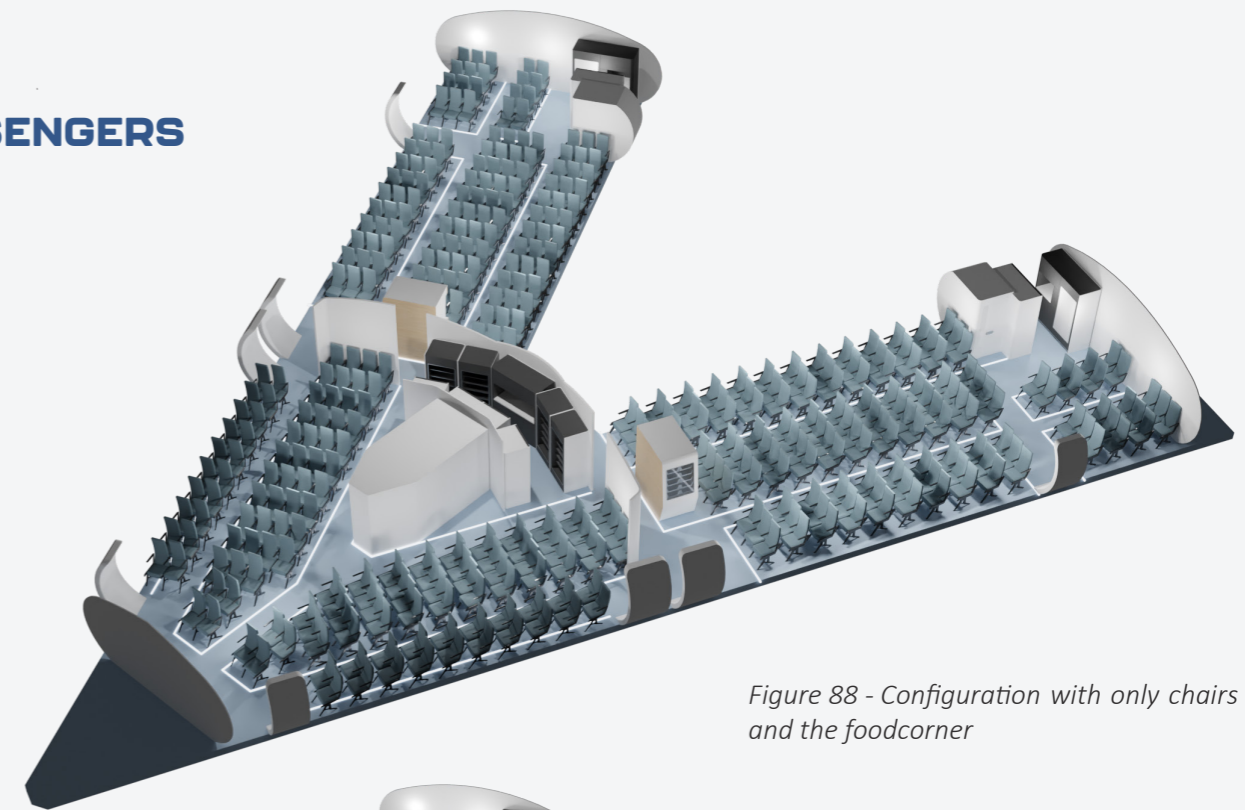


Figure 88 - Configuration with only chairs and the foodcorner

374 PASSENGERS

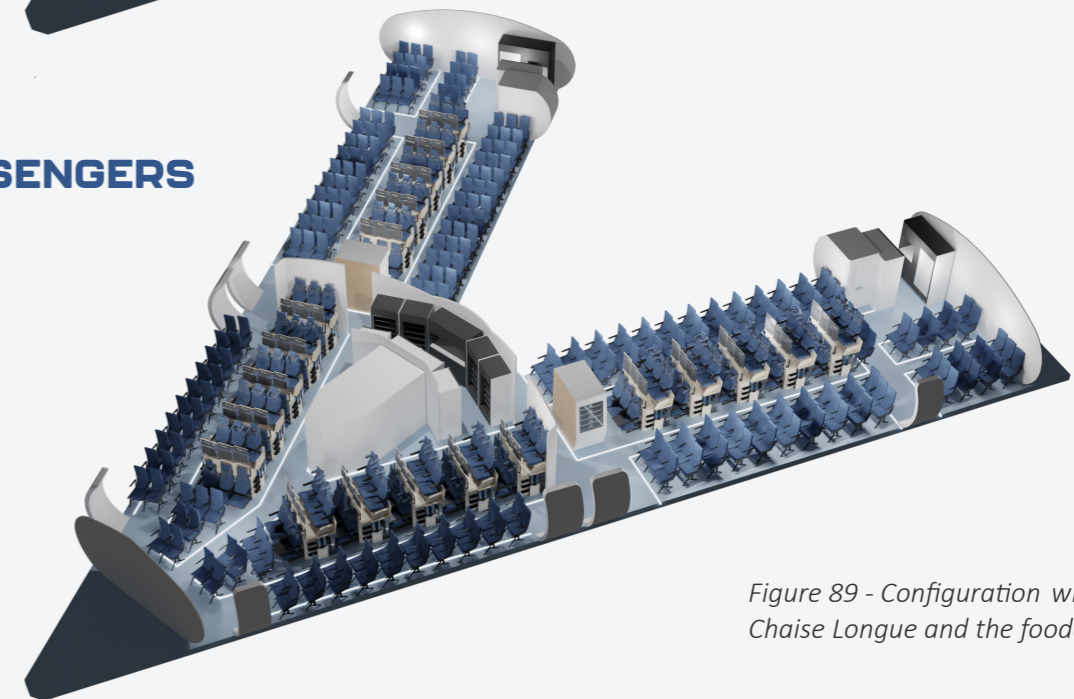


Figure 89 - Configuration with chairs, the Chaise Longue and the foodcorner

324 PASSENGERS

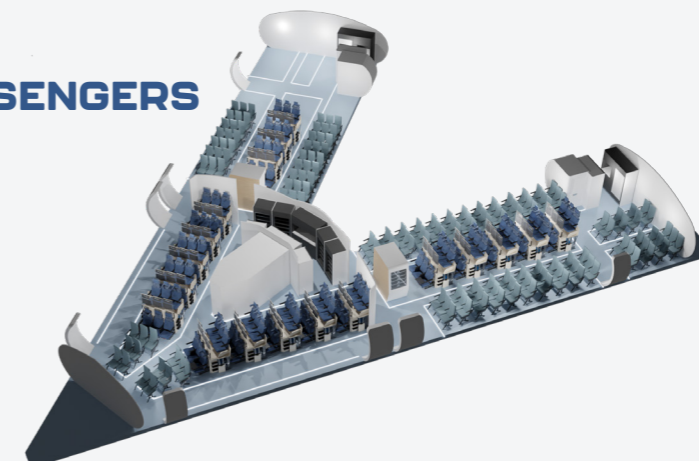


Figure 90 - Configuration with an empty premium wing in the back. The sofa is not shown, but is included in the capacity count

326 PASSENGERS

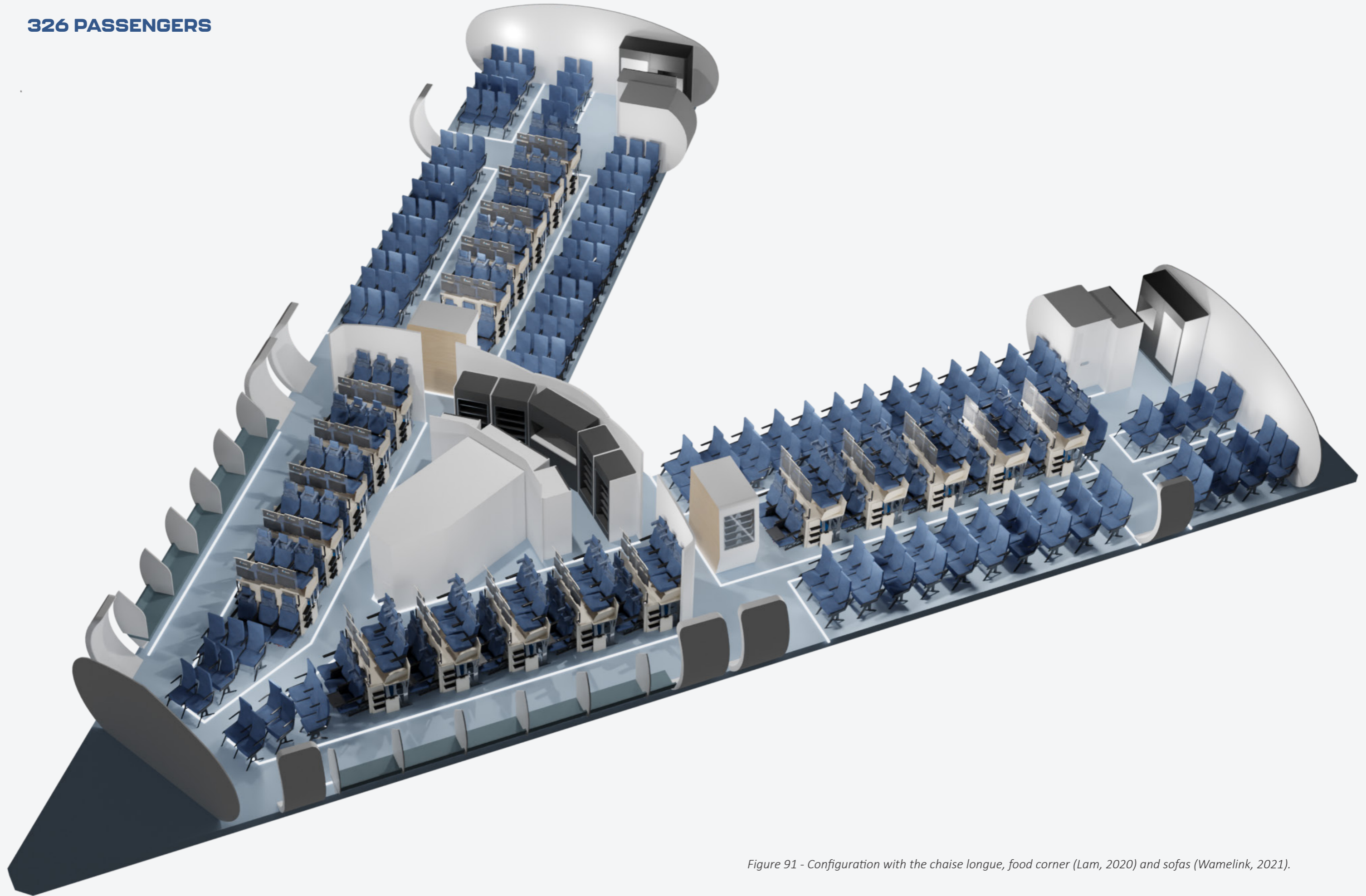


Figure 91 - Configuration with the chaise longue, food corner (Lam, 2020) and sofas (Wamelink, 2021).





07. OVERALL CONCLUSIONS

VR

Virtual Reality can be used well in user tests with conceptual models, subject to certain conditions. For example, the controls of the VR must be easy to use for all users, otherwise the VR will distract from the test. It works to leave the controllers down and let the people move physically. In this way, the test subjects gave more feedback on the model. It therefore works well to use a headset that is not attached to a cord, such as the Oculus Quest 2. The test subjects can then move without hindrance. An additional advantage is that no laptop or PC is required, so that the headset can be used anywhere (such as trade fairs, conferences or outdoors).

The interactions added in the first test added little to the test other than entertainment for the users, although it took a lot of time to create. It must be examined per test whether interaction can add something to the end result.

The models adopted from previous graduates proved to cause many problems in VR due to the large number of vertices they contain. That is why almost all models were counterfeited so that there was more control over the number of vertices. This also applies to Solidworks models. The mesh exported from solidworks turned out to be unsuitable for putting directly into VR. It contained too many vertices, or the mesh was constructed differently, creating artifacts when texturing.

What struck me is that not everyone is enthusiastic about setting up a VR headset. People indicated that it could also be seen on the screen, and therefore did not want to try the VR. It worked on the second test not to turn on the screen anymore. For example, others saw the reactions of the person with VR, but not what the person saw. For example, those who were curious also wanted to try VR.

VR can work well to take people into conceptual ideas that are hard to imagine. Building VR requires some knowledge, but it fits well with an Industrial Design background, because there is already knowledge about modeling in Solidworks, for example. VR can be as complex as you want it to be, but a simple CAD model that you can walk around can also work, even better if it's in the intended environment.

CHAISE LONGUE

The Final Concept of the Chaise Longue provides space for passengers to lie down, have ample legroom and enjoy their journey in comfort. Attention has been paid to the openness of the concept so that people feel as confined as possible and that the staff has an overview of the cabin. Passengers can feel at home in a cabin where they can walk around and sit on a sofa by the window when they need it (Wamelink, 2021), or go to the food corner when they need a snack (Lam, 2020). But they can also watch a favorite movie lying down, such as at home on the couch.



08. FUTURE RECOMMENDATIONS

Requirements	Status
Structurally correct	Partly fulfilled
Place for 6x hand luggage (50cm x 45cm x 25cm) (IATA, n.d.)	Partly fulfilled
Space for life jackets	Fulfilled
Passengers below must be protected from passengers above	Fulfilled
Space for reclining seats or for Aero seats which are in a reclined position.	Fulfilled
Overview for cabin personnel, are able to look to the back of the aisle. (FAA, 2021)	Fulfilled
Every seat has a screen & tray	Fulfilled
Legroom advantage compared to 'normal' setup at 32"	Fulfilled
Three people can sit above and three people can sit downstairs.	Fulfilled
No more than 18 degrees out of the direction of flight. (FAA, 2021)	Fulfilled
Wishes	
As few sharp corners as possible due to crash safety	Partly fulfilled
Easy to get in top	Partly fulfilled
Easy to get in downstairs.	Partly fulfilled
Meets the structural requirements of the FAA (FAA, 2021)	Partly fulfilled
Amount of material used similar to material used for stowage boxes.	Partly fulfilled
Round & Friendly design, passengers need to feel themselves at home.	Partly fulfilled

Figure 93 - List of requirements with its status

CHAISE LONGUE

Looking at the requirements set, most of them have been met (Figure 93). The ones that are partly met are explained in this section. Requirements of the FAA are difficult to achieve because there are strict test requirements, such as for the 16G test (Figure 92). Nevertheless, these requirements have been taken into account in the design. For example, the seats are now staggered, there is a transparent panel so the staff has more overview, and this structure should be able to hold the forces when optimized according to the materials used (see Topology optimization page 44).

However, there are still a number of things that can be improved on the Chaise Longue. Some of the things already mentioned in the previous chapter are the height of the Chaise Longue, the handles on the stairs, and the way to reach the middle cases, especially the small compartment. But the convenience to get in the bottom row of the Chaise Longue can also be improved. In the initial design, the seatpan slid back (Figure 6), in the current design that's where the hand luggage is. To have more space to sit in the bottom row, something could be devised for the seatpan and the reclining system.

One solution is to make a two-seater instead of a three-seater. This solves a number of problems; the staff can more easily serve the passengers because everyone is seated on an aisle. The passengers do not have



Figure 92 - Screenshot of "Aircraft seat 16 g structural test with ground deformation" - Youtube Channel: DynamicTestCenter

to climb out and down past anyone and it is also easier to get to the hand luggage, because there is no middle hand luggage. Now the stairs and the excellent hand luggage compartment take up extra space, with a two-seater that would double. An extra aisle is also created, but there are plenty of options in terms of configurations to come up with something (see page 74).

The stairs are somewhat cumbersome and are separate from the design. By optimizing the door with holes in which you can put your foot, without being bothered by the hand luggage, a cohesive whole is created, without protruding elements (Street, 2022). The handle on the steps can also be improved, it still looks very sharp and angular, making it look like you could hurt your foot.

During the test, a number of people indicated that they grabbed the chair in front of them when getting up, but that is not possible in the Chaise Longue. Handles can still be designed that can help people get up.

A few more things can be added to meet the vision. Getting your own food and being able to walk around contribute to the feeling of autonomy, and is just like being at home. It is important that the atmosphere in the cabin is also like at home. For example, more natural elements can be added, or a multimedia system and lights that can be personalized for the trip. This way you can create your own place.

VR

Looking at the VR experience, a few things can be added so that it can be used at trade fairs and conferences. To begin with, fixed places must be determined within the model between which one can teleport (Rantala et al., 2021). From that point one can physically walk and look around. This way you can see more of the plane and other elements can be shown such as the toilets and the galleys linked to investigations that have been done, without having to walk around with the controllers, which can cause motion sickness (Clifton & Palmisano, 2019). In addition, more elements can be added to the aircraft to make the experience more realistic, for example emergency exit signs or stickers.

It may also be interesting to look at the use of haptics (Senseglove, 2022). Gloves or even whole suits can make the experience more immersive for the user. For a VR experience as used in the test, haptic gloves can work well. This allows one to grasp things more intuitively without having to use the controllers (Senseglove, 2022).

An alternative to VR when, for example, a model has to be shown to several people is a powerwall. This is a large 3D wall that the audience looks at with 3D glasses. One person moves through the model and the others watch. This works well when someone does not want to wear a headset, or when several people have to look at the same model and have to discuss it (TechViz, 2021).



09. REFLECTION

The graduation trajectory felt like a great adventure in which I was able to meet many people and visit special places. From graduates on the Flying-V to people from the aircraft industry in the Middle East. From Ras-Al-Khaimah to Hamburg at Airbus. It felt good to be able to participate in a project that so many other people are also working on. There is a lot happening around Flying-V and that means there is a lot of information and new things are constantly being added, for example a new design or prototype by Alex Nuñez Vicente. That also coincides with the redesign of an aircraft interior, which sometimes also felt very large. There are so many facets within a cabin, and certainly within the cabin of the Flying-V, and certainly combined with VR. I then found it difficult to limit myself to a specific part that is possible within the IDE graduation time. Certainly at the start of the redesign after the midterm, I was looking for where to start. I may have lost a precious month there, as I would have preferred to show the first redesign at the first update meeting after the midterm. Then there could have been one more iteration of the final design, which is now presented in this report. Ultimately this had to do with the fact that I should have determined the goal more clearly before I started designing. Now I kept designing in the darkness for a while. In the end, I look back on the design with satisfaction. I think that after the greenlight meeting, quite a bit of progress has been made and the outline and benefits of my design have become clearer.

I found the VR very interesting about the project and I learned a lot from it. It surprised me that VR glasses attract very few people at a conference and most walk through, and how nauseous you can get from walking around in VR with a controller while sitting still. The second test was much more fun, because the test subjects understood the VR model much better and were much more involved in the project. People also got really excited and wanted to try it this time.

The tour at Airbus through the VR facilities was one of the many highlights. Very special to see meter size setups for a small VR booth. Understanding the software and being able to build the VR environments took a lot of time. I would rather spend my time on that than writing the report. The possibilities are endless; textures, interactions, life size models, anything is possible. I am also very happy with the things I was able to borrow from TU Delft, without it it would have been a lot more difficult. When looking for a job, I still see if there is something with VR, I would love to be able to continue working with it and learn more from it.

The collaboration with Daan van Eijk and Peter Vink also went very well. I got a lot of information and feedback from the meetings we had, and when I emailed for more information, I got a quick response. The trip to KLM with Peter Vink was also very nice, unfortunately I have not been able to process the results of this day in this report.

All together I look back with satisfaction on an educational, adventurous and unforgettable graduation project.



Photo by Peter Vink



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