

BUSINESS CLASS ARMREST

Re-design of a Business Class Armrest

MASTER THESIS INTEGRATED PRODUCT DESIGN

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SUMMARY

Airline profit margins are very small. In a highly competitive market, the challenge is to differentiate from other airlines. Differentiation within an airplane is difficult, because of the rigidity of an airplane and the strict regulations. The economy is in a lift, businesses allow their employees to fly business class more often. First class and business class only represent 10-15% of the total number of seats globally but is responsible for 50% of the revenue. This makes business class travel very relevant to major airlines

Seat comfort is a tool used by the airlines to differentiate themselves. Within a review of three business class seats, the participants were asked if there was something comfortable or uncomfortable about their sitting position. 30% of their answers mentioned shoulder, arm and hand comfort of which 65% was negative and 35% positive. 46% of this 30% explicitly mentioned the armrests.

The assignment was to improve the comfort of a business class armrest in order to improve the comfort of the entire seat. This project was done together with RECARO Aircraft Seating. The focus was on improving their current armrest (of their long-haul business class seat) in physical comfort and privacy. Furthermore, facilitating the activities reading and watching IFE (In Flight Entertainment) were selected to focus on.

During the analysis phase, general aspects that could be improved about the armrest and aspects of specific activities were identified. Some of these general aspects were, the asymmetric position of the armrests leading

to skewed sitting positions, hard and slippery materials, the lack of space to place the arms and the lack of adjustability options. A specific opportunity for improvement for the activity reading was the conflict between getting tired arms from holding the reading device on eye level or feeling the tension in neck and shoulder when looking down to the reading device. Another area for improvement was observed specifically for the RECARO business class seat. When the seat moves forward to a more relaxed position, the armrests stay at the same place reducing the length available for the arms to rest on and reducing the width.

The final proposed design is an armrest which can be integrated into the current RECARO long-haul business class seat. The top part of the armrest can automatically move forward together with the seat so the space available for arm support while watching IFE is optimized. Both armrests have the same adjustability options to improve the symmetry of the sitting position. The up/down movement of the armrest can also be adjusted automatically with the same control panel as the seat adjustments.

The reading position is improved by the added function of upwards rotation and inwards rotation. When the armrests are placed under an angle the reading device is brought closer to eye height while supporting the arms. Participants experienced the new design as more comfortable for reading than the current armrest positioning during a user test.

An option for a privacy screen was designed to be added to the armrest. This involved a

screen that rotates down originating from the current privacy panel. Although the panel improves the privacy significantly for sleeping, the effect only works if the armrests are moved fully up, which takes away moving space and does not improve the privacy for other sitting positions. Therefore a different solution for this needs to be sought.

Further improvement to the armrests can be made by searching for a way to make the inner armrest longer for reading. And the usability of the armrest design should be evaluated to check if the use is understood by the passengers.





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The background of the entire page is a photograph of an airplane cabin interior, showing rows of seats with beige upholstery and dark brown accents. The lighting is soft and even. On the left side, there is a vertical dashed line with an airplane icon at the top and bottom. On the right side, there is a vertical dashed line with an airplane icon at the bottom.

Scope

INTRODUCTION

According to IATA airline profits margins are only 4.1% (IATA, 2016) which makes it a challenge to survive in this industry. Last 40 years 1.300 new airlines were introduced and due to globalization the competition is only increasing (Cederholm, 2014). Airlines can't make a lot of changes to the planes due to strict regulations and the rigidity of an airplane. To be ahead of competition they try to win on quality of the seats. Because of growing economics, businesses allow their employees more often to fly business class (Vrijzen, 2014). First and business class represents 10-15 % of the amount of long-haul seats globally and bring up 50% of the revenue (Rosenbaum et al., 2015). This makes business travel very relevant to major airliners. In order to bind customers to the airlines, they invest a great amount in new seats (Vrijzen, 2014). And they use comfort as a tool to differentiate themselves from other airlines (Gregghi et al., 2012).

The people using Business Class are mostly business people (40.28%)(Gregghi et al., 2012). Arriving rested and relaxed to your destination is considered as most important to customers. This will prevent them from having stress, reduce time and possibly jetlag's. From earlier studies it can be concluded that possible areas of improvements to airplane seats may be the headrest, backrest, armrest, posture, seat pan and table. In which the highest percentage of participants commented on improving the backrest (25,2%), headrest (24,9%) and the armrest (17,3%) (Hiemstravan Maastricht, 2015).



PROBLEM DEFINITION

In the Business class seat industry comfort is very important. During a recent study for an airline where three Business class seats were evaluated by 12 participants for more than an hour, it came to attention that for all three of the seats the armrests were not sufficient adjustable in height and width (I was involved in this study, however the results are confidential). Also the positioning of the armrests was unfortunate and the armrests were made of uncomfortable materials. This prevented that the participants could sit, lie and relax comfortably. Insufficient support to the arms and hands demands muscle tension in shoulders and spine and is less comfortable for a longer period of time (Snijders et al., as cited in Rosmalen et al., 2009).

The current business class seats only facilitate a few sitting positions, in general these are: TTOL (Taxi Take-off and Landing), relaxing (watching In Flight Entertainment (IFE)) and lying flat. These positions only facilitate the frontal position with exception of lying flat on the side or on the back (frontal position = whole posture facing to the front). Rosmalen et al. (2009) shows the importance of a seat that gives possibilities for shifting positions in order to improve comfort.

Most of the travel time of passengers is consumed by: sleeping, watching IFE, eating, reading and working (Ting Yu Chen, 2016). In the current Business class seats the activities reading and working are not yet sufficiently facilitated. The Business class seats only facilitate a sitting position for watching IFE and eating. Adding features facilitating working and reading might give the airlines a business advantage.

In close consultation with the airplane seat manufacturer RECARO, it was brought to attention that within this environment of an airplane the combination of limited space, creating personal space for passengers and giving them physical comfort is a field of conflict. Since there is only limited space available often the choice has to be made to which aim this space is going to be used. According to RECARO the psychological comfort (in this case entailing factors as privacy and personal space) is as important or maybe even more important to them than the physical comfort mentioned in the previous paragraphs.

ASSIGNMENT

Assignment as approved by the board:
The assignment will be to develop a Business Class armrest that differentiates from the existing seats by improving the comfort of the armrest and with that the comfort of the entire seat. The design should preferably facilitate multiple sitting positions and multiple activities.

Final assignment:
The assignment will be to develop a Business Class armrest within the existing RECARO CL6710 seat, that differentiates from the existing seats by improving the comfort of the armrest and with that the comfort of the entire seat. Comfort for the armrest will be looked at in two ways, the physical comfort and comfort given by providing personal space (privacy) to the passenger. These two aspects should be combined in the facilitation of reading and watching IFE in the relax position of the RECARO CL6710 seat.



Figure 1: RECARO CL6710 long-haul business class seat

Relax Position

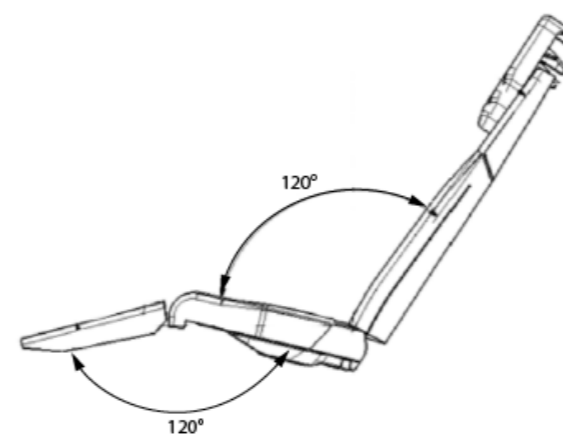


Figure 2: CL6710 relax position





RECARO

RECARO is a German company that was founded in 1906. What started as an automotive company grew to be a company having a Child Safety division, an Aircraft Seating (RECARO AS) division and an automotive seat division. The latter is recently sold but still operates under the name RECARO. The common vision of the RECARO group is to improve the performance of people in motion like no other (“RECARO Group - RECARO”, 2017). RECARO thrives to give their customers the support they need to transcend boundaries and arrive at their destinations safely and confidently (“RECARO Group - RECARO”, 2017).

The Aircraft Seating division is part of the largest three aircraft seat manufacturers in the world (“Organization - RECARO Aircraft Seating”, 2017) and is market leader in economy class seats (“Aircraft Seating - RECARO”, 2017). RECARO has 2.200 employees of which 1.000 in Germany. RECARO operates plants in Germany, Poland, South-Africa, the United States and China. With their headquarters based in Schwäbisch Hall in Germany RECARO AS generated sales of 452 million euros in 2016 (“Organization - RECARO Aircraft Seating”, 2017). Within this project we will work together with RECARO AS (Aircraft Seating) on an armrest design for business class.

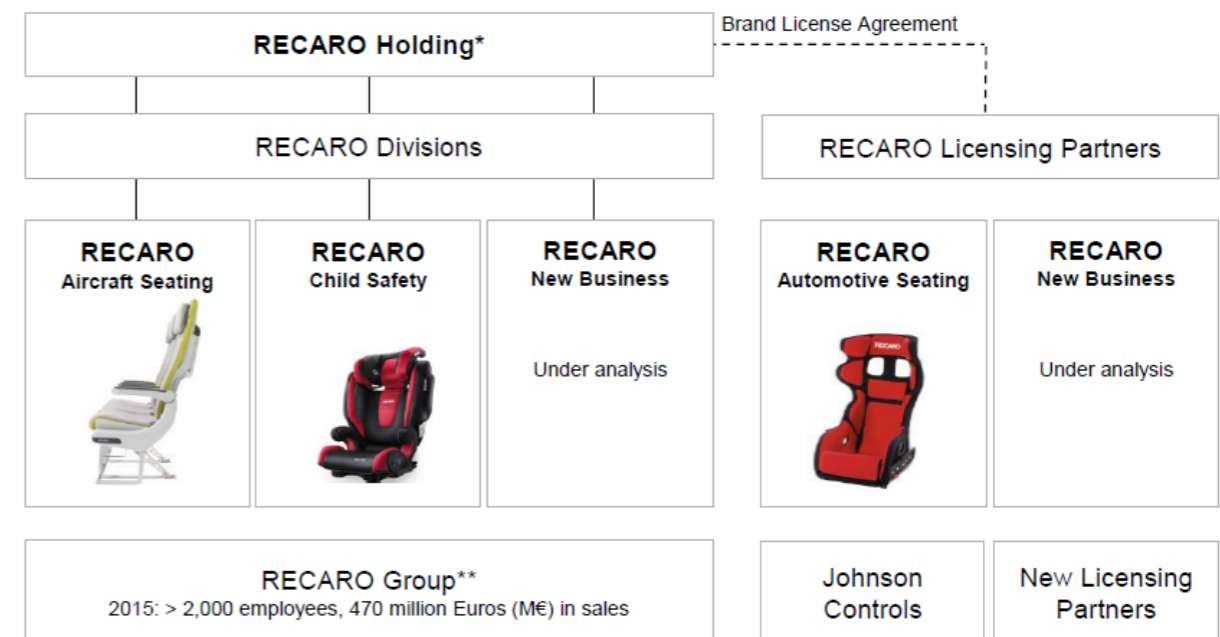
The strength of the brand lies in their brand identity consisting of the brand core, core benefits and personal traits. The brand core captures the essence of the brand: feel performance. The core benefits are promises that they offer to customers. Being: Safety, Quality and Ingenious Design. Safety and quality speak for themselves

but with ingenious design they mean the successful fusion of functionality, ergonomics and aesthetics (“Design & Ergonomics - RECARO Aircraft Seating”, 2017). The personal traits of RECARO gives them their own characteristics: distinctive, premium, consistent, reliable, open-minded and creative.

One of their three core competencies is innovative strength. And part of that is making innovative solutions in complex environments. An aircraft is a complex environment. Making sure the seats are as lightweight as possible, with constant high quality for reducing fuel consumption and this in an limited space. Combining this with passenger safety and ergonomics is what makes RECARO AS the perfect company for this project.



Figure 3: Brand Identity RECARO



* Integrating brand holding, owner of the RECARO brand.

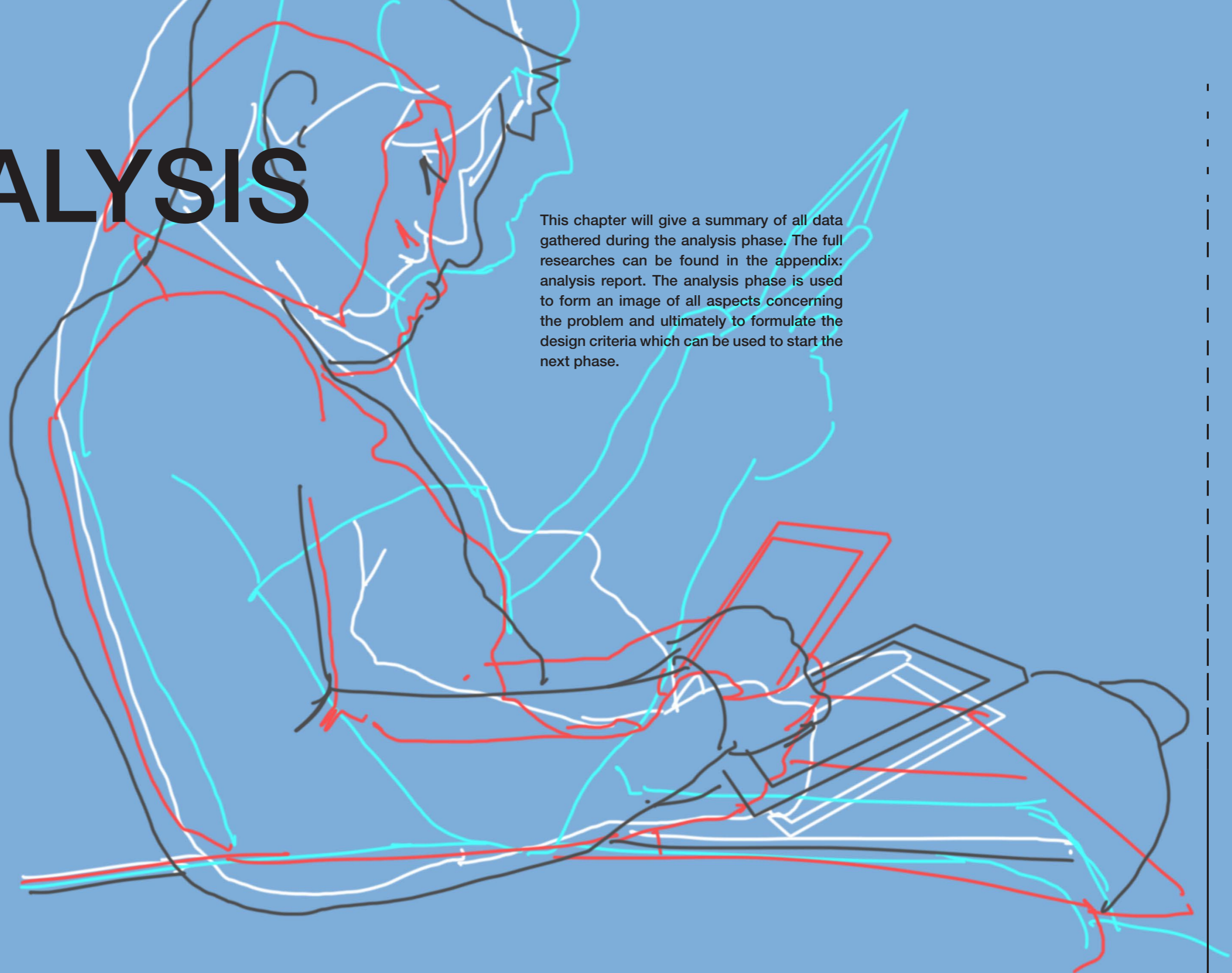
**The RECARO Group comprises RECARO Aircraft Seating, RECARO Child Safety, and the RECARO Holding.

Figure 4: Company structure



ANALYSIS

This chapter will give a summary of all data gathered during the analysis phase. The full researches can be found in the appendix: analysis report. The analysis phase is used to form an image of all aspects concerning the problem and ultimately to formulate the design criteria which can be used to start the next phase.



AIRPLANE SEAT INDUSTRY

In general there are a few classes within the airplane seat industry: economy class, premium economy class, business class and first class. Within these classes the seats will differ according to the length of the flight.

The following categories can be defined:

Short-haul: <3hours

Medium-haul: 3-6 hours

Long-haul 6-12 hours

Ultra long-haul: >12 hours

A few examples of the seats can be seen in figure 5. A few differences between economy class seats and business class seats – long haul (Which is the focus of this study) are: the seats can become fully flat beds, electric seat controls to adjust recline positions, lumbar support, a larger personal tv, laptop power ports, premium food, bigger seat pitch and wider seats.

Airlines will make five to ten times more profit flying a business class passenger compared to an economy class passenger on a long-haul route (Poladian, 2015). A single business class seat can cost between 30 to 80.000 dollar (Davies, 2013). A single economy class seat costs around 2.300 dollar (Flynn, 2013). Besides the extra comfort that a business class seat requires, the higher profit margin of the seats make it possible to invest more into comfort and therefore more in comfortable armrests. Compared to economy class more parts and material can be used.



Economy Class



Premium Economy



Short-haul Business Class



Long-haul Business Class



First Class

Figure 5: different seat segments in the airline industry.



Figure 6: A comparison between business class long-haul seats of different brands.

If different long-haul business class seats of multiple companies are compared according to armrest comfort a few areas stand out that are open for improvement (figure 6 shows some of these seats with the armrests circled). Some improvements can be:

- Match the right and left armrest. This means the shape, size, orientation and adjustability can be made the same for both armrests so the passenger can sit in a symmetric position. Now often these aspects are not the same for both sides armrests which forces occupants to take an uncomfortable asymmetric posture.
- Regarding adjustability possibilities there is also room for improvement (vertically and horizontally). If you compare the seat with the armrest the seat has far less adjustability options.
- The coating of the armrests and padding usually only consists of a thin padding coated with leather and sometimes they don't have padding at all. An improvement can be to add soft padding and different coating structures.

Within other markets, for instance the car seats or lounge seat, the absence of elaborate armrests is noticed. Looking at these markets you even might think what is the added value of more elaborate armrests. In literature most is written on the subject of armrests in working environments. In these environments you often sit in one position for a longer period of time doing repetitive movements. Perhaps it is better to compare the airplane seats to this industry, since you have to sit for a long time in a fixed position during a flight. The following ergonomic research gives more insights about this literature.





ERGONOMICS AND COMFORT

Ergonomics

Literature describes that armrests improve posture, promote freedom of movement while stabilizing the users position and reducing the muscle loads on the neck, shoulders, arms and reduce pressure on the spine and distribute pressure on the seat (Lueder & Allie, 1999). When the arms are not supported, the load is carried by the shoulders, demanding muscle tension in the shoulders and neck which is uncomfortable over a long-time period (Snijders et al., 1995). Some design recommendations that are given in literature are:

- Support the elbows to minimize muscle loads.
- Armrests should be broad and padded and support the fleshy portion of the arm to prevent pressure on nerves. Hard and sharp surfaces should be minimized.
- Armrests should include a 4 inch gap between the armrest and seat back to avoid impacting the elbows.
- Armrests that are adjustable in height, width and pivot support the weight of the arms better.
- Postures that are symmetrical and supported are generally considered superior. Therefore the armrest should promote sitting symmetrically.

Comfort

In the context of this project we are focusing on two fields influencing comfort. The functional and psychological comfort according to Vischer. The functional (physical) comfort is mainly focussed on ergonomics and providing the option to personalize the seat to preferred configurations. Within the psychological comfort the focus will be on territoriality/privacy. Factors influencing this are sound, visual openness, amount of storage, options to shut oneself of from the surrounding. Basically it is giving passengers the freedom of action to create a personal space in which you feel safe and relaxed. Thus in order to improve the passengers psychological comfort, giving them the opportunity to separate themselves from other passengers and the surroundings is very relevant and should be included in the design.

USER RESEARCH

During the analysis phase three main studies were conducted in order to gather all necessary information: the airline comfort research, the business class passenger preference survey and the arm positions research. The main findings of these studies are described in this chapter, the full studies can be found in the appendix: analysis report.

The Airline comfort research (a reinterpretation of the outcomes from a Delft university of Technology research conducted on three business class seats) proved that there is room for improvements considering the comfort of the arms. The comments that were given by the participants when answering the questions: Is there something that is very comfortable in this position and is there something that is very uncomfortable

in this position, were analysed. 30% of the total amount of answers (283) mentioned shoulder, arm and hand comfort. Of all these comments that mentioned the shoulder, arm and hand comfort 65% were negative and 35% was positive. 46% of the comments explicitly mentioned the armrests.

Another outcome of the airline comfort research was that a few categories were identified in which improvement would be beneficial. These same categories were confirmed and completed by the 'Arm positions research' in which the comfort of the arms was connected to the activities reading, watching IFE and working. Things like asymmetry between the armrests and hard padding can divided under material and position. The full categories are described in table 1.

Table 1: Categories of improvement possibilities.

Support	While reading the tablet becomes heavy, support for the tablet is needed. Tension and discomfort in the shoulders and neck suggests that the support of the arms is not sufficient.
Space	There is a lack of space to place arms/shoulders. arms may fall from the armrests as a result of a narrow armrest. And limited space for the arms result in a cramped living/moving space.
Material	Hardness of cushions is a factor that influences the comfort. Especially with reading, increased pressure on the elbow will give discomfort when the cushioning is hard. Also the structure of the surfaces will influence the comfort. Smooth surfaces will increase the lack of space. Arms will slide from the armrests more easily.
Position	Bad positioning of armrests can lead to skewed sitting positions, or can lead to arms falling off the armrests. The position of the armrest can be too high or low, asymmetrically in height or rotation. The armrest can also be in the way during activities such as sleeping.
Shape	The comfort of the passenger cannot be negatively influenced by sharp corners or edges. The shape is also connected to the space. Sharp edges or protruding parts of the armrest may result in the passenger bump into them or feel uncomfortable pressure.
Aesthetics	The armrest should look comfortable. Several participants mentioned that they could not perceive the design as comfortable when it didn't gave a comfortable impression.





Besides confirming the above named categories the arm positions research resulted in a few other outcomes. For the activities working and reading, a solution needs to be sought for the support of the device (laptop/tablet) and the support of the arms. While reading the hands are near the screen holding the device and operating it. The screen needs to be on eye height to avoid discomfort in the neck. The same goes for working, where the screen preferably should be at eye height and the hands should be horizontally on the keyboard for typing. Figure 7 shows the different positions in which

the tablet was held during reading. During reading and watching IFE a few different leg positions were observed which are shown in figure 8. Including these into the comfort of the armrest could be an opportunity for design. Furthermore the locations where the arm is resting on the armrest and where the leg touches the armrest are gathered. This can give an indication where extra support is needed. One of the pictures showing this data is shown in figure 9. The full data can be found in the appendix. The data in figure 9 show that only a limited area of the armrest is actually in use during the activity.

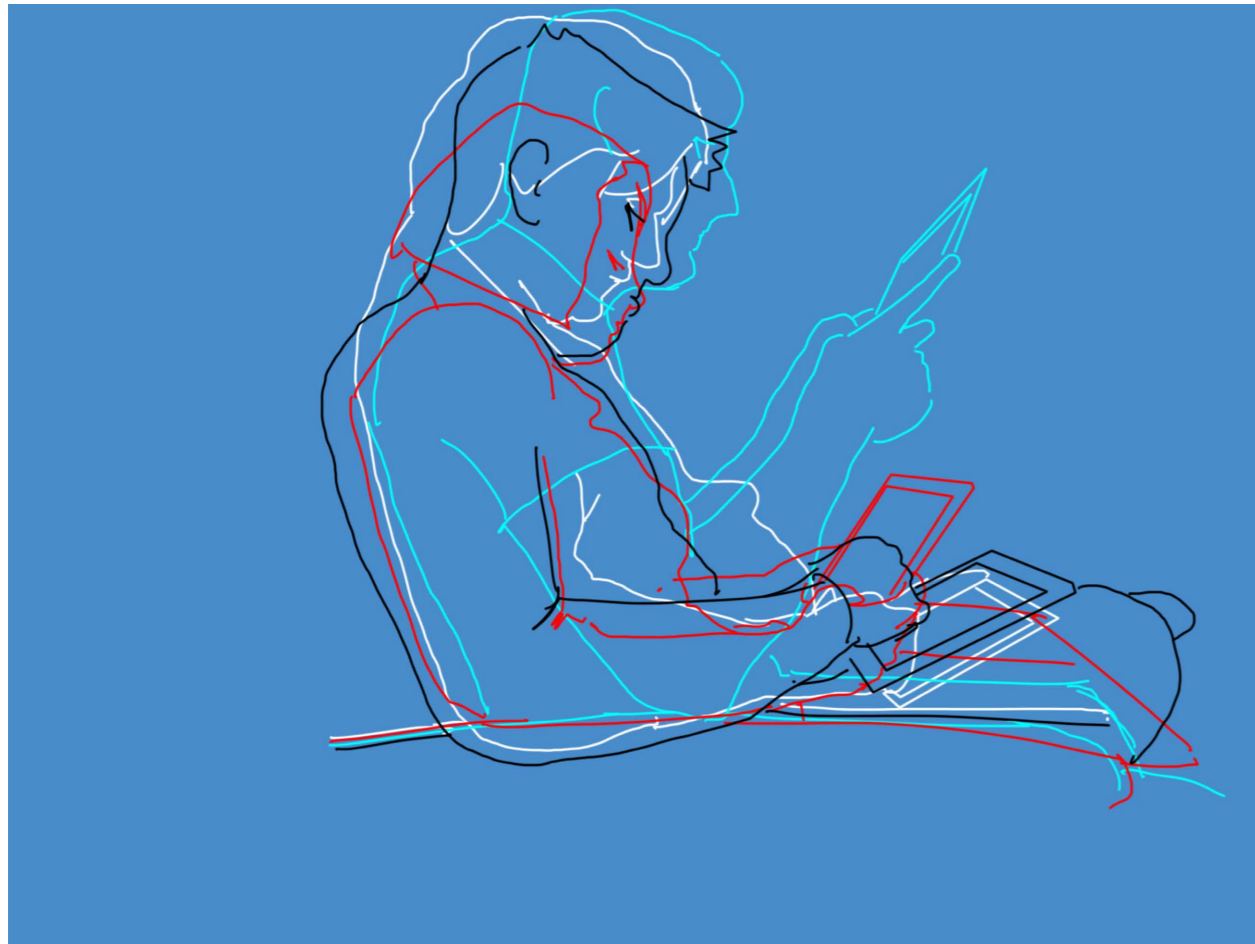


Figure 7: Different arm positions for reading.

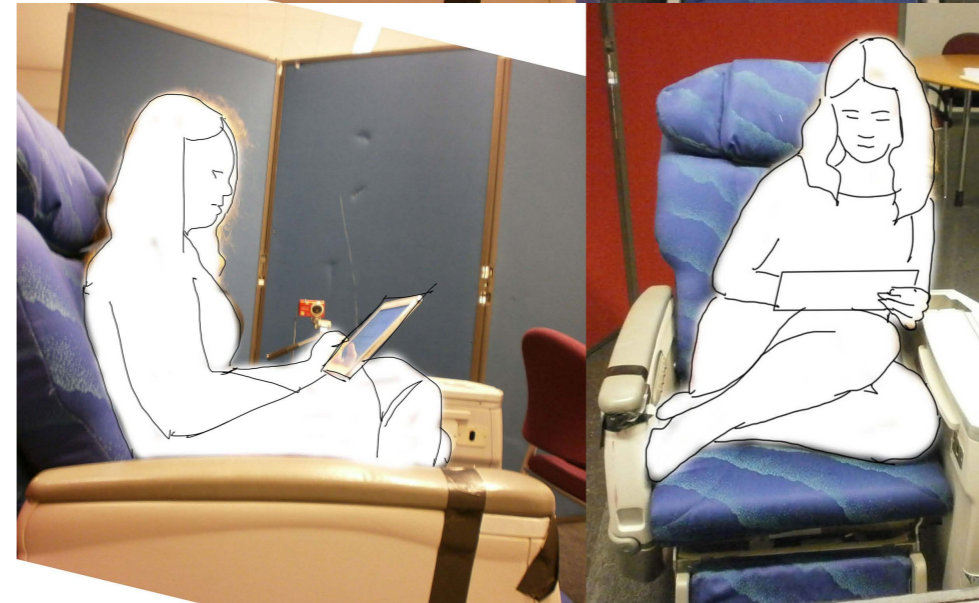
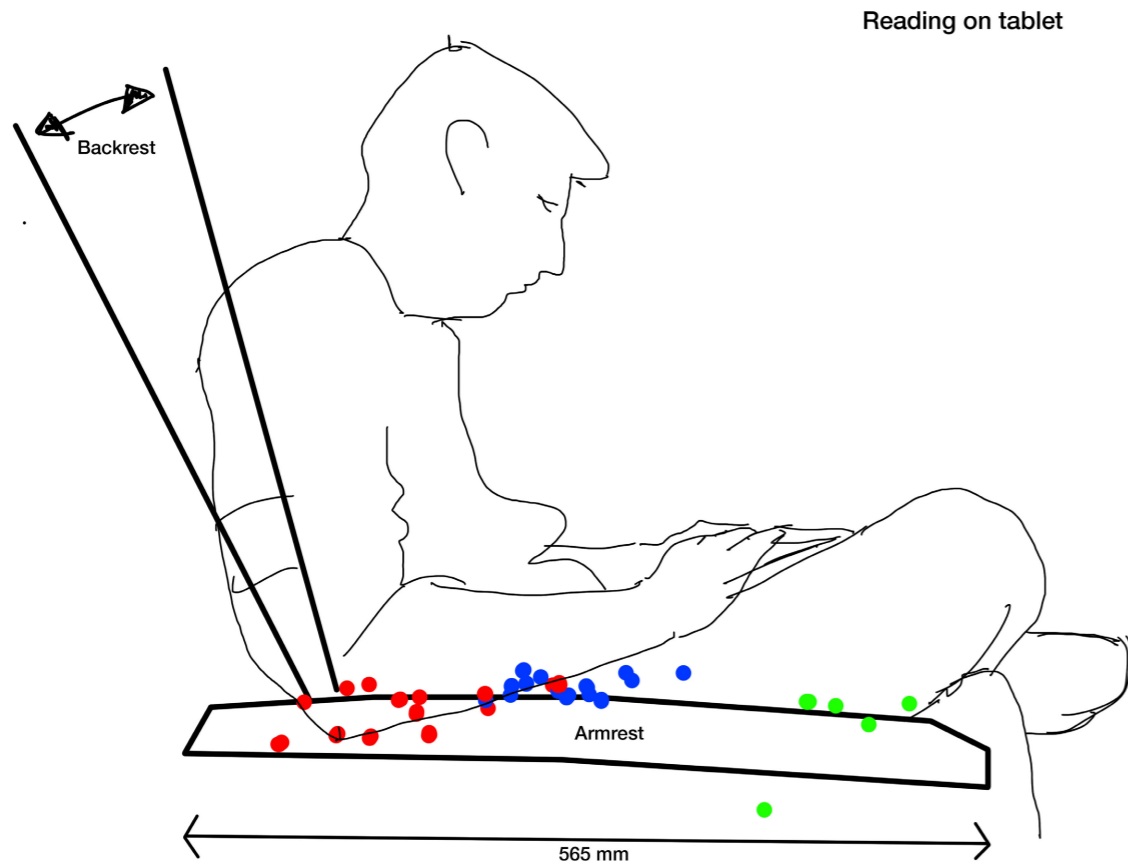


Figure 8: Different leg positions observed during the activities reading and watching IFE.





Reading on tablet

Figure 9: An example of the data gathered on the location of the arm on the armrest. The red and blue dots show the contact area of the underarms, the green dots show the area of contact of the legs.

In order to get a better view of activities and sitting positions during a flight a survey was conducted (Business class passengers preference survey). Figure 10 shows the sitting positions that were used during the research. The conclusion was that sitting position 1 and 2 during watching IFE were rated most comfortable but need better facilitation. Position 5 was seen as very uncomfortable but still 20% of the participants sit in this position. outcomes from the arm positions research suggest that this may be related to difference in human measurements and cultural differences. This was also connected to sitting position 4. Although position 4 was rated medium comfortable, it was mentioned that sitting in this position does not meet the social norm of a semi-public space.

Other outcomes of the survey include which medium passengers use during the activity reading: book 27%, tablet 27%, other 20%, e-reader 13%, laptop 7% and smart phone 7%. And which activities are spend most time on during a flight. The five most executed activities are: sleeping, watching IFE, eating/drinking, reading and working.

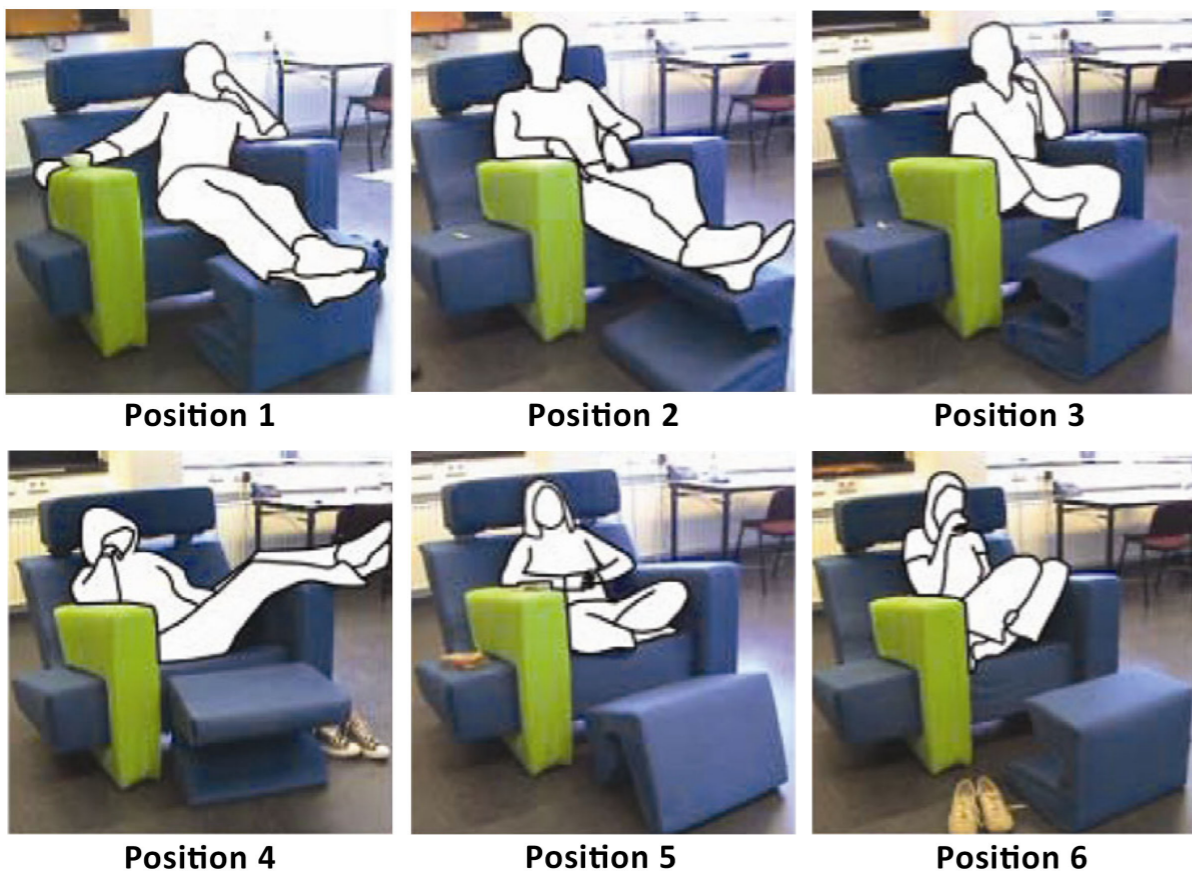


Figure 10: the different sitting positions as presented to the participants in the survey.





LIST OF CRITERIA

All data gathered from the analysis phase is combined in a list of criteria the final design should meet. The full list of criteria can be found in the appendix: analysis report. The most important criteria are listed here. Also a design goal was formulated.

Design Goal

The goal is to create a design that supports the arms of passengers on a long-haul flight during watching IFE and reading in the relax position while giving them a personal space and privacy. And in this way improve the comfort of the long-haul business class seat.

Most important Criteria:

- The design of the armrest must take into account the factors support, space, material, position, aesthetics and shape.
- The design must give the passengers the opportunity to separate themselves from the other passengers and the surroundings. (And this must be better than the current seat)
- The armrest must not limit the passengers movements in any way during their activities.
- The arm supports must be symmetrical for the left and right arm.
- The design should try to integrate as many functions as possible to save and create space. (combination of light weight, comfortable, fitting in the space, giving privacy).
- The design should be adjustable in as many directions as possible. (inwards/ outwards, rotating inwards/outwards, height etc.) And this must be at least one more direction than in the current seat.



IDEATION

Starting the ideation phase the translation had to be made from the problem, and transferred into ideas and solutions. The ideation was combined with searching for inspiration in upscale car seat interiors, talking to experts in innovative manufacturing fields, organizing external brainstorms and further defining the assignment. The following subchapters will give a more detailed description of this phase.

arm

laptop

rolling screen





CAR SEAT INTERIORS

To get some inspiration for the armrest design a number of car dealers were visited to compare the car seat interiors with those of business class airplane seats (among the cars looked at were the Mercedes-Benz S-Class and the BMW 7 series). Figure 11 gives an impression on the interiors and some of the details. Some of the features noticed during the visit are:

- One of the seats moves together with every bend to avoid falling over of the passenger.
- Integrated air conditioning in the seat and neck.
- Adjustment options to the seat (airco or positioning) integrated into the front touch screen of the car.
- Heating and air conditioning integrated into the steering wheel.
- Changeable mood lighting.
- Massage function integrated into the seats.
- Multiple USB and other power options.
- LED lighting detail.

Other details that were noticed are the great amount of detail that the interiors have and the use of valuable materials (leather, wood, brushed metals, etc.).

These visits also helped answering another question. What does luxury look and feels like? A small list was made:

- High contrasts
- Great detail vs. smooth surfaces
- Seamless finishing
- Soundless moving parts
- Smooth moving parts
- Luxurious materials
- Shiny vs. matt finish
- Shape integration

- double curved lines
- adding non functional shape and material faces

These upscale car interiors look very comfortable. Integrating some of these functions and details into the design of the armrest will be beneficial to the psychological comfort. Luxurious materials, finishing of the materials and great detail in the design should be integrated in the design during the materialization of this project. Other functionalities as integrating heating and/or air-conditioning into the armrest or adding a massage function for the arms are opportunities which RECARO could explore to further improve the design of the armrest in the future to generate the same luxurious feeling as in these cars. Within the scope of this project these options will not be further explored.

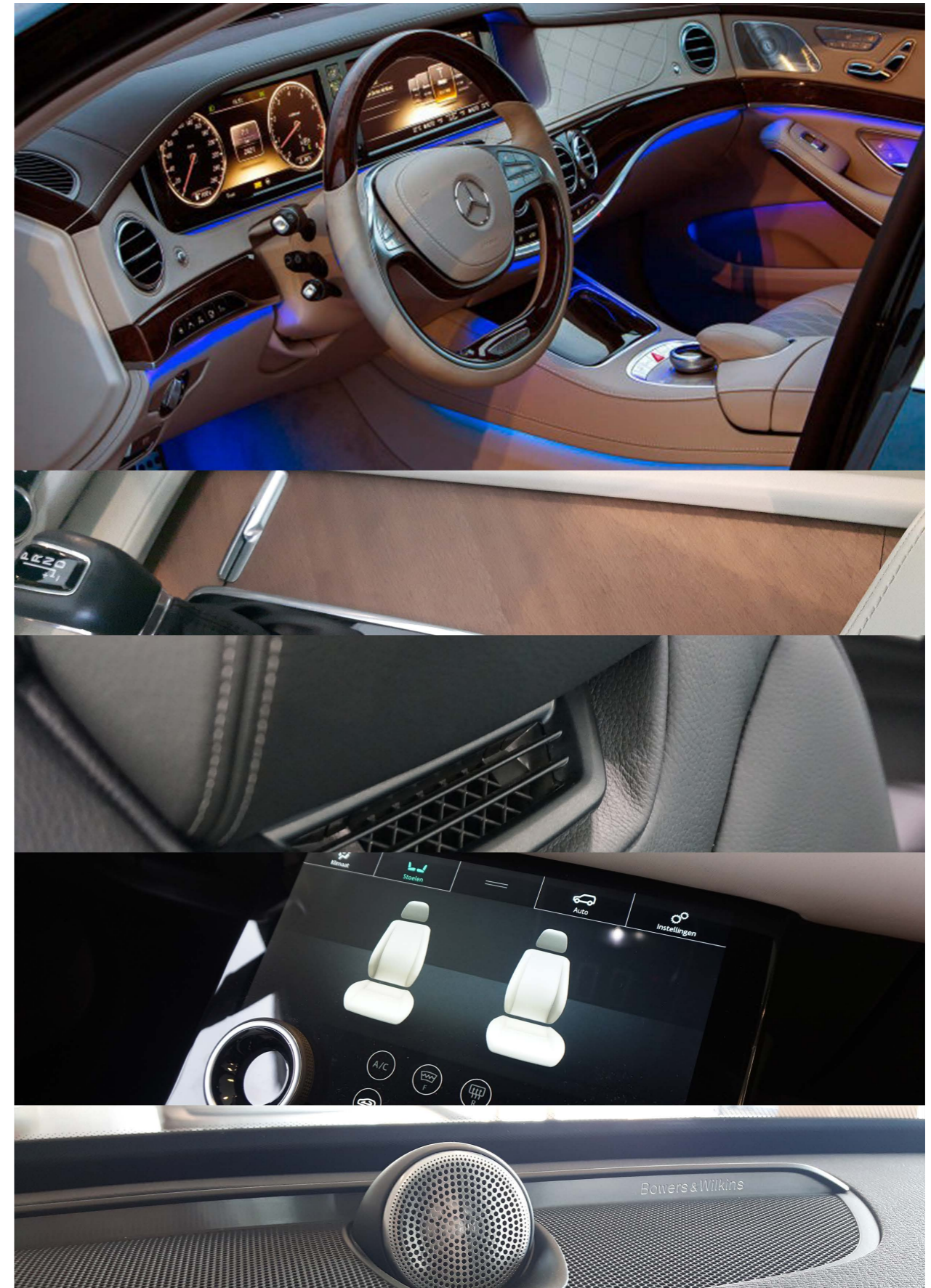


Figure 11: a collage showing an impression of the car interiors looked at for this short study.





SOLVING THE PROBLEM

The most important criteria shown in the chapter 'list of criteria' were used in the first round of ideation. The complete process can be found in appendix 1: first ideation wave. Five first idea directions covering the aspects adjustability, space divider/partitioning, forming to arm shape, table integration and saving space are shown in figure 13 and 14. During further detailing it became clear that the criteria set up for this assignment were too broad. Therefore the scope and criteria were further defined during a visit to RECARO (the full report of this visit can be found in appendix 2: RECARO visit).

The result of this visit was that the assignment was defined into focusing on their current seat. The armrest should be designed to fit their current CL6710 long-haul business class seat. Also the lack of space to place your arms in the relax position of their seat

was noticed. Therefore the focus will be on improving the comfort of the armrest in the relax position during the activities reading and watching IFE. This resulted in the newly described assignment:

The assignment will be to develop a Business Class armrest within the existing RECARO CL6710 seat, that differentiates from the existing seats by improving the comfort of the armrest and with that the comfort of the entire seat. Comfort for the armrest will be looked at in two ways, the physical comfort and comfort given by providing personal space (privacy) to the passenger. These two aspects should be combined in the facilitation of reading and watching IFE in the relax position of the RECARO CL6710 seat.

In addition the two different armrest were defined as non-console side and console side armrests (figure 12).



Figure 12: console side armrest and non-console side armrest

Idea direction 1

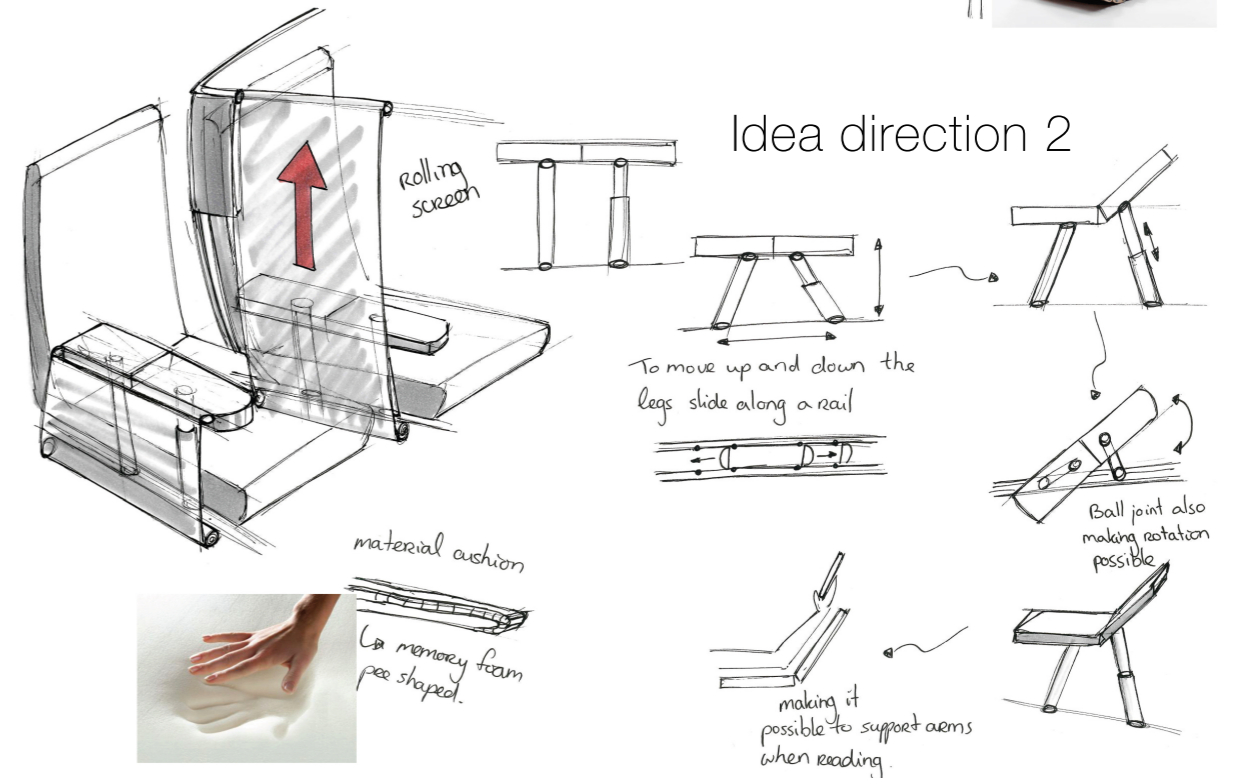
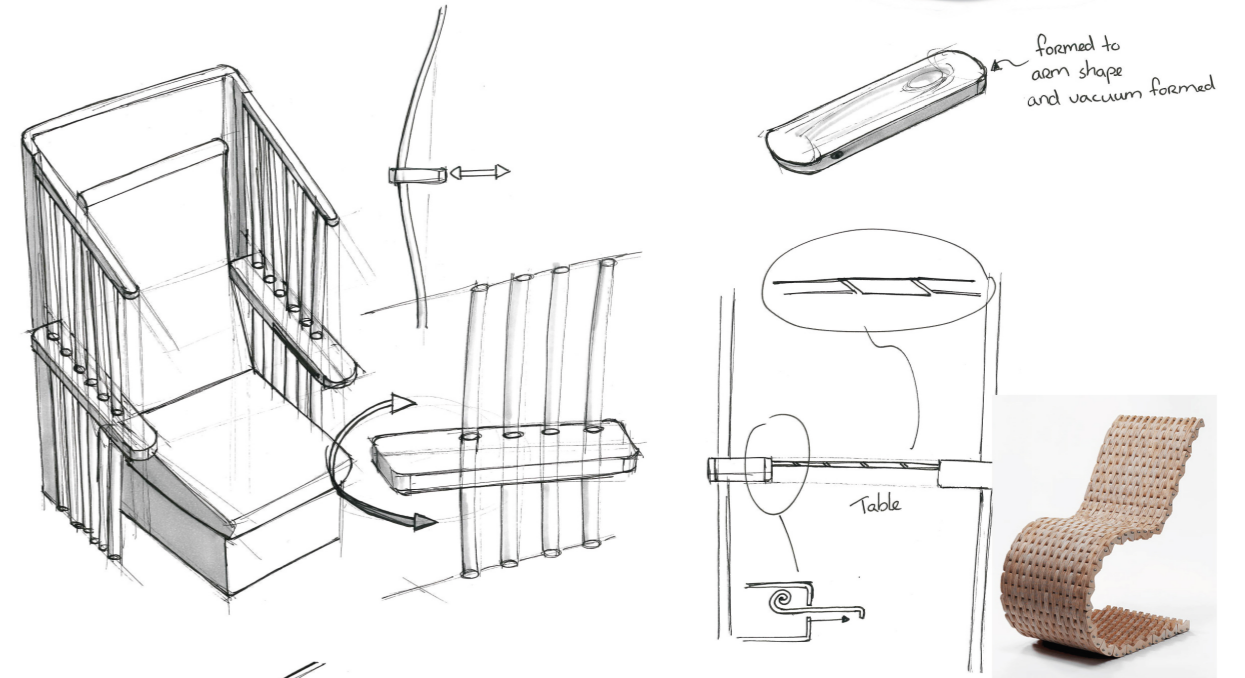
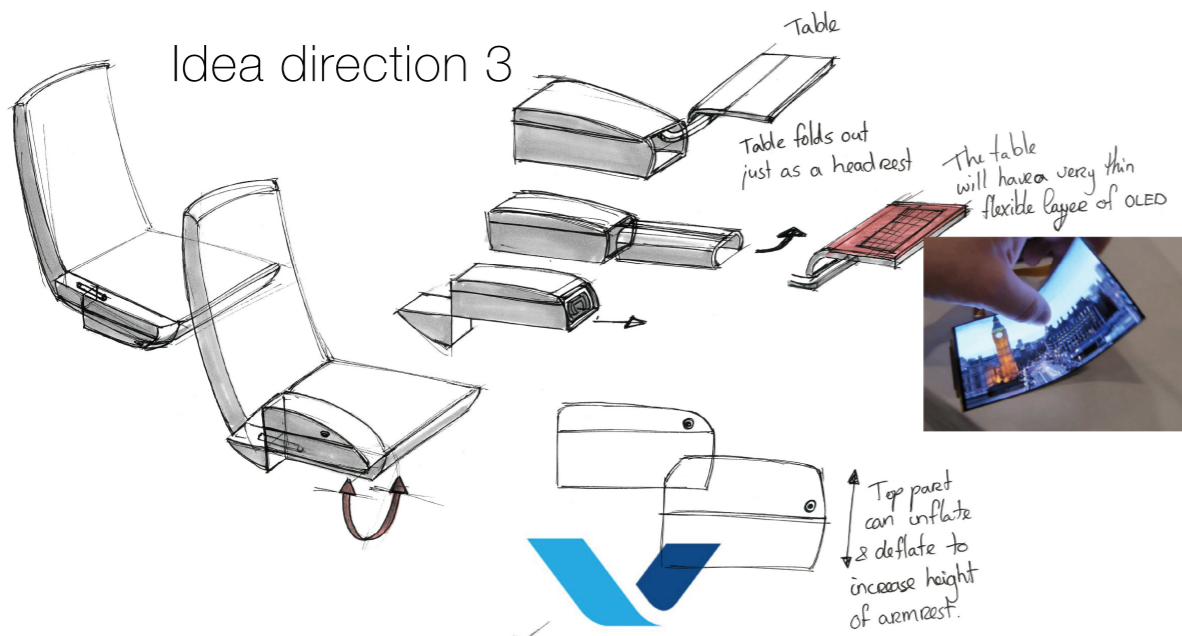
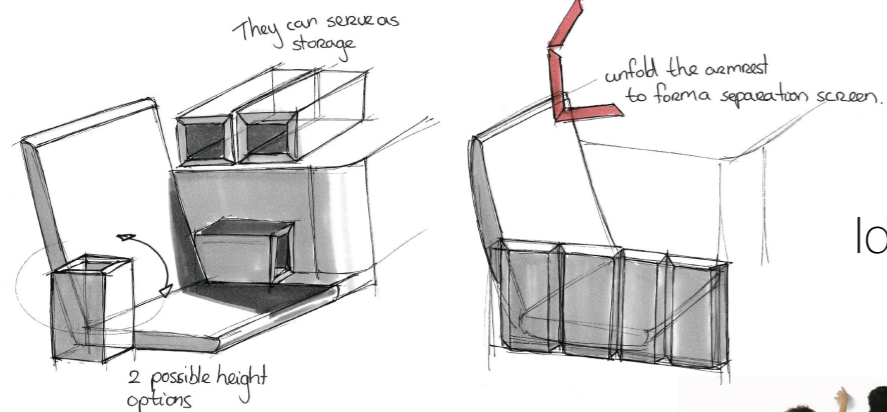
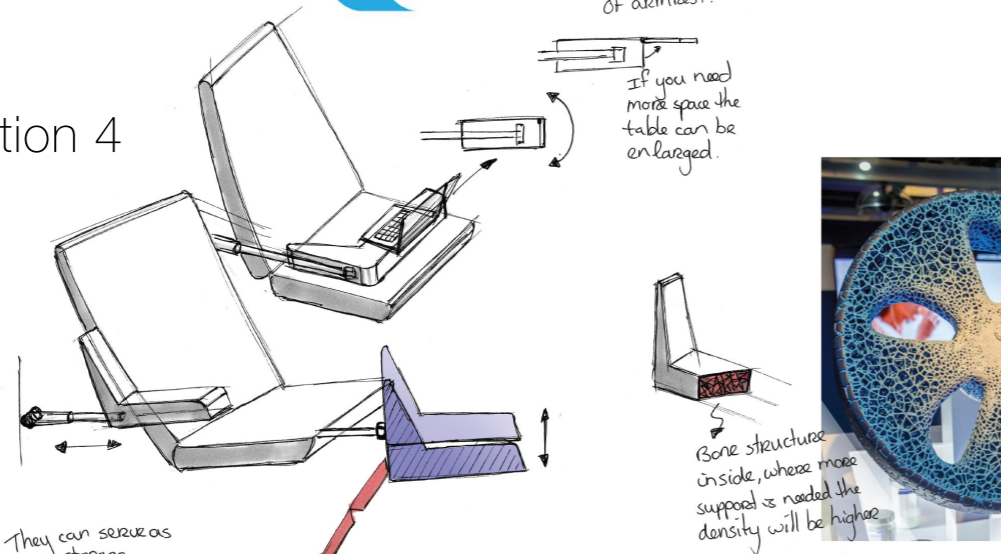


Figure 13: First idea directions.





Idea direction 4



Idea direction 5



The reformulated main criteria are:

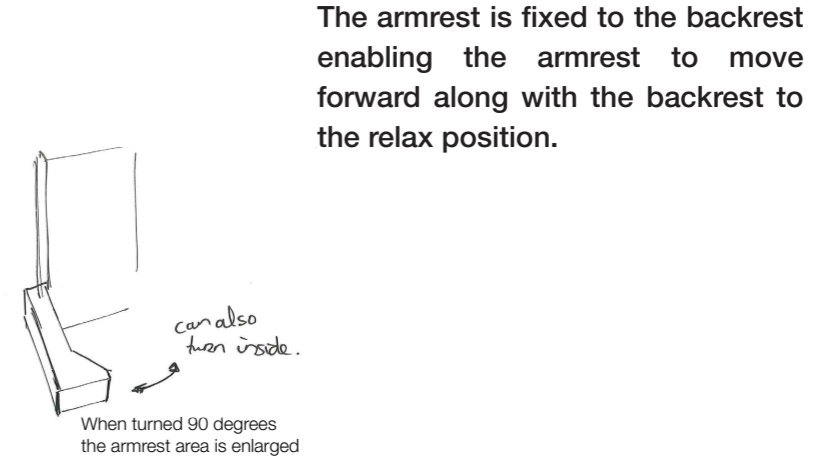
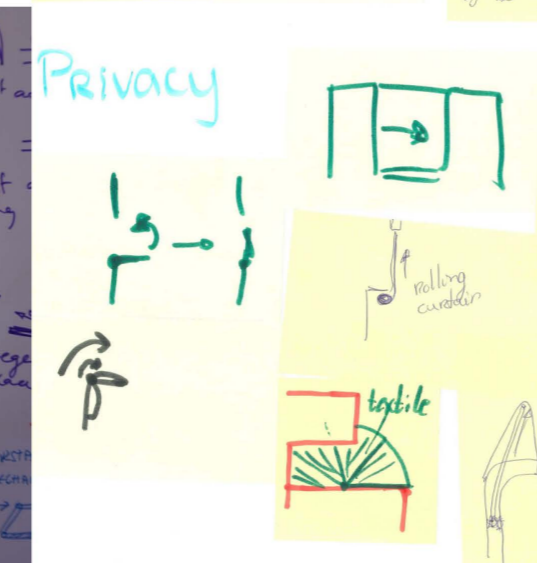
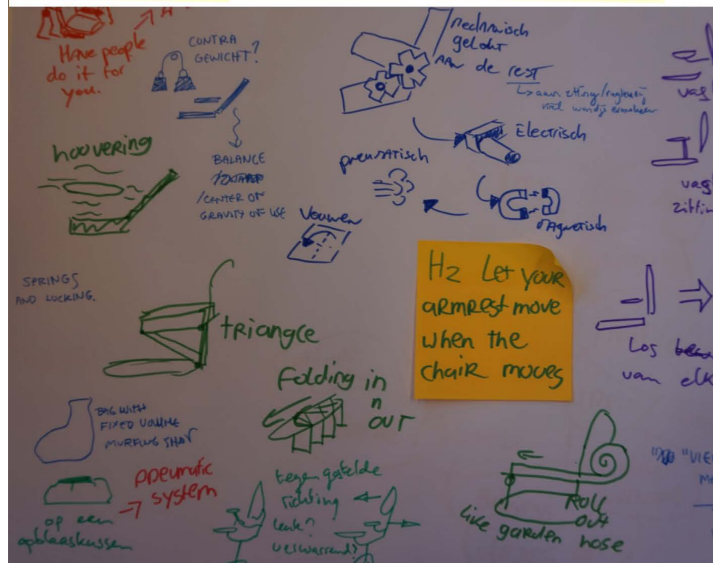
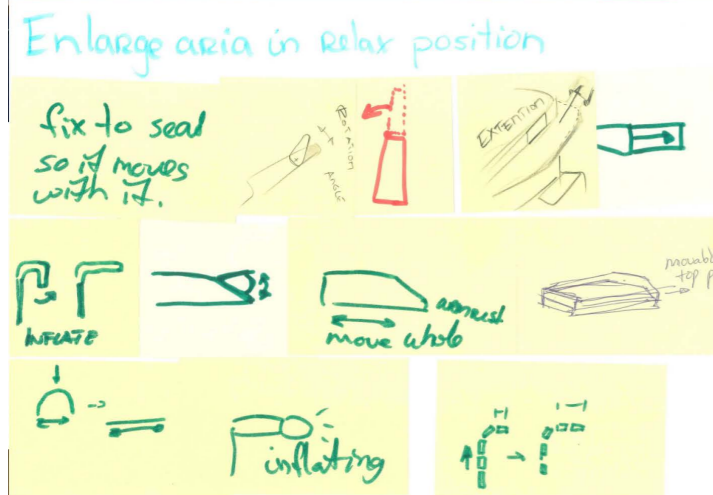
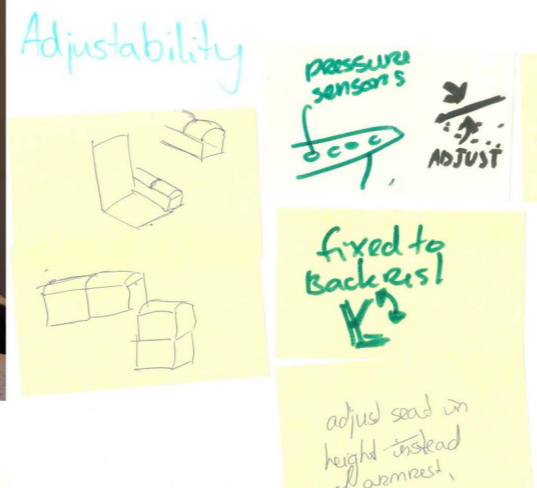
- The design must give the passengers the opportunity to separate themselves from the other passengers and the surroundings.
- The armrest must not limit the passengers movements in any way during their activities.
- The arm supports must be functionally symmetrical for the left and right arm. (in placing arms parallel, in space provided to the arms and in the same adjustability options to both sides)
- The design should be adjustable in as many directions as possible. (inwards/ outwards, rotating inwards/outwards, height etc.)
- The design of the armrest should fit within the boundaries of the current RECARO seat CL6710.
- The design must find a solution for the tension between the tablet on eye height and supporting the arms.
- The design should give enough space to the arms to rest on.
- The functioning and use of the design must be clear to the passengers. (usability)

Figure 14: First idea directions.





The following second ideation wave (also to be seen in appendix 3: Second ideation wave) was started by two brainstorm sessions one during the RECARO visit and one at the university. Figure 15 gives an impression. Combining the ideas from these sessions gave two idea directions. Both covering the aspects: adjustability, privacy and increasing the surface area.



The second idea has more similarities with the current armrest. It is fixed to the shell, the same as in the current seat. And it moves up and down the same way as the current armrest. The top layer of the armrest moves forward automatically when the seat moves towards the relax position.

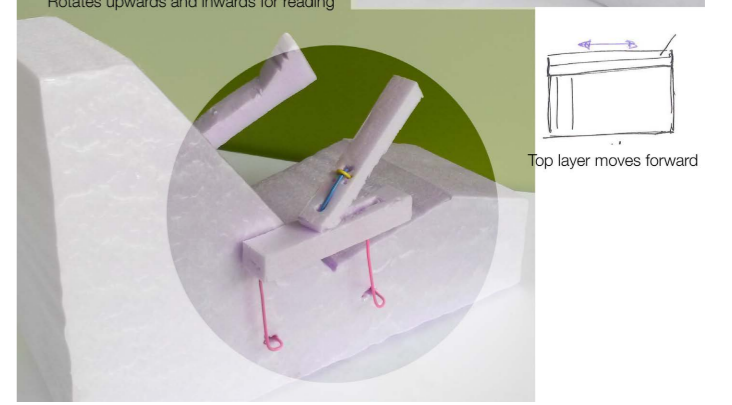
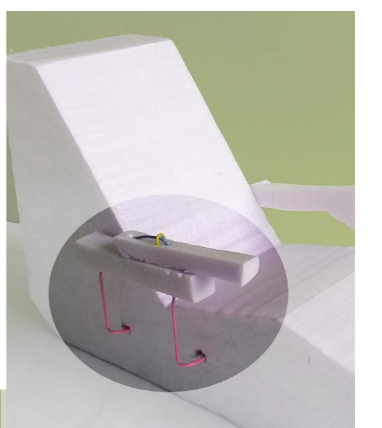
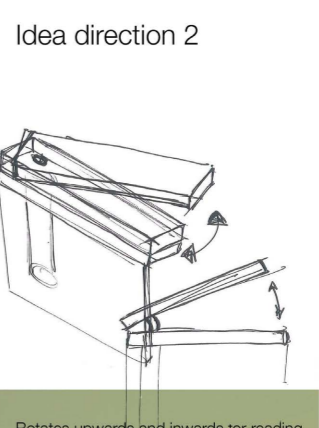


Figure 15: an impression of RECARO brain storm and the brainstorm at the university.





Initially it also was the goal to improve the top layer and cushioning of the armrest in order to improve the pressure distribution along the arm during watching IFE and reading. Figure 16 and 17 show a few ideas and the criteria the top layer should full fill. But because optimizing the top layer would ask for elaborate studies concerning the load distribution and were support is needed this part was discarded within this project. Still further development of the top layer can be seen as an opportunity for design to RECARO.

Top layer/ cushioning design ideas

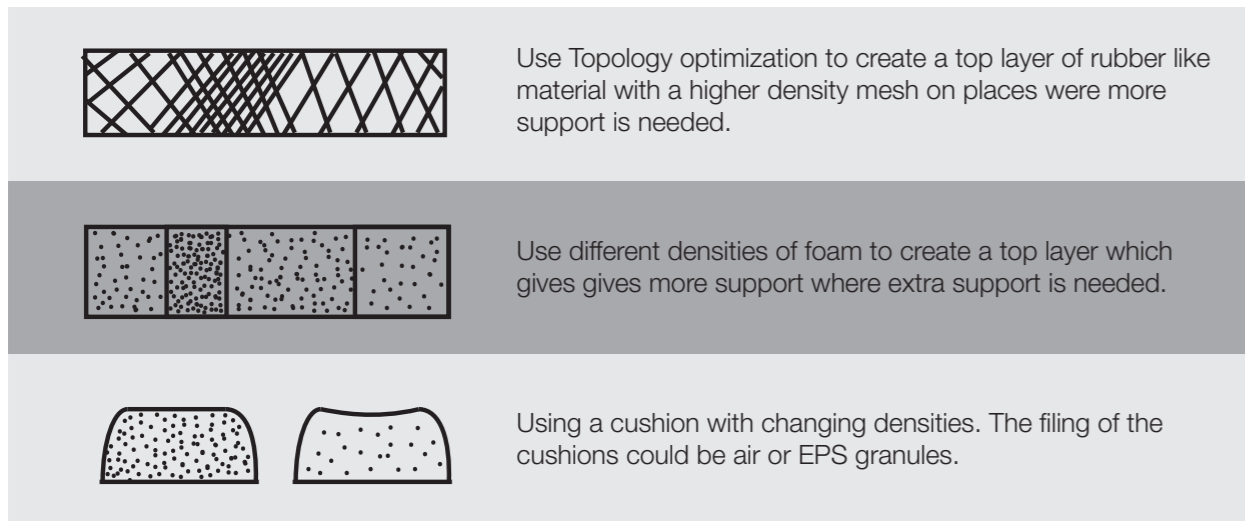


Figure 16: Ideas for optimizing the top layer of the armrest.

The armrest should take into consideration the areas where the elbos and underarms are placed based on the arm positions research.
The surface of the armrest must be more ergonomic than the current armrest (referring to softness and the surface and shape).
The armrest should fit the human contour of the arms.
The material of the armrest should feel soft and comfortable and give sufficient support at the same time.
The material of the armrest must give sufficient grip and therefore support the passengers arms. The material must avoid slipping away.

Figure 17: Criteria the top layer would have to full fill.





CONCEPTUALIZATION

During the conceptualization phase the first idea of the two concepts is worked out into full concepts. Models of the concepts are used to further define the shape and to test if the concepts will work. Finally a choice between the concepts is made at the end of this chapter by comparing them with the use of the criteria.





CONCEPT PRESENTATION

Concept 1 – the rotating armrest

This concept shown in the following figures is fixed to the backrest. This enables the armrest to move forward when the seat is moving to the relax position. This way the area where the arms can be positioned is increased in relax position. The rotation of the armrest allows the bottom of the armrest to become the top of the armrest (see figure 19). The shape of the lower side of the armrest is meant for reading (see figure 20). The shape allows the upper arms to rest on the angled surface. And the slope at the end of the armrest gives support to the hands carrying the reading device.

All adjustability options should be automated. A first sketch of the working mechanism can be found in appendix 4.

Besides the armrest itself and the adjustability options, the armrest gives extra privacy to the passenger by means of a strung elastic fabric between the armrest and the bottom shell (figure 21) and a rolling curtain pulled down from the fixed privacy panel (figure 21).

When the armrests should be out of the way during sleeping, the armrest can be moved fully down. In order to fit the armrest next to the seat, it first needs to move fully up along the backrest and then rotate downwards (figure 23).

Another important aspect that needs to be noticed, is the extra space needed next to the console side armrest. This space, shown in figure 22, is used to fit the rotating mechanism of the armrest. The downside is that this will take away some leg space.



Figure 18: Concept 1 in TTL position.

Rotation of the armrest

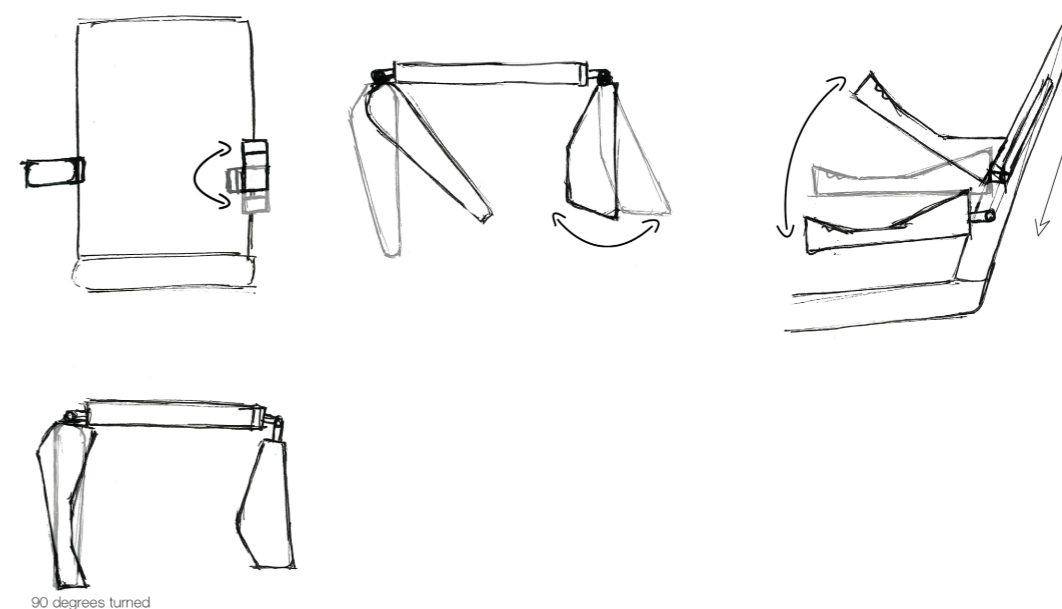


Figure 19: Adjustability options concept 1.





Figure 20: Relax reading position concept 1.

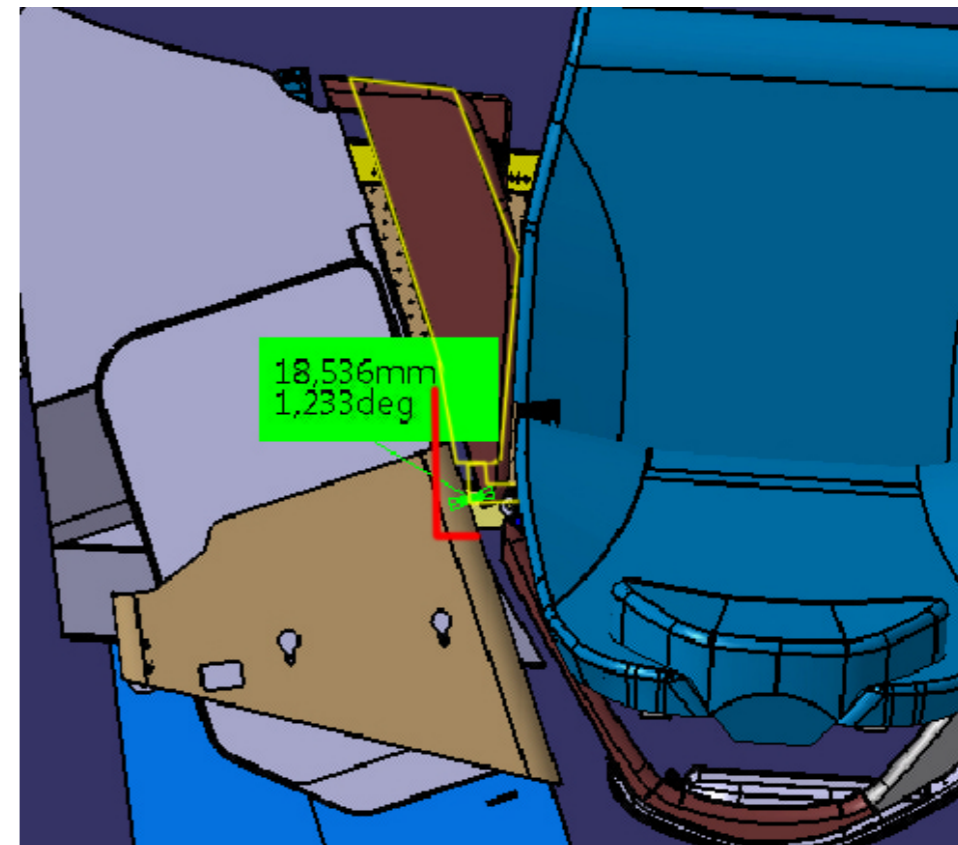


Figure 22: top view concept 1, showing space that will be taken from the leg space.



Figure 21: Privacy options concept 1.

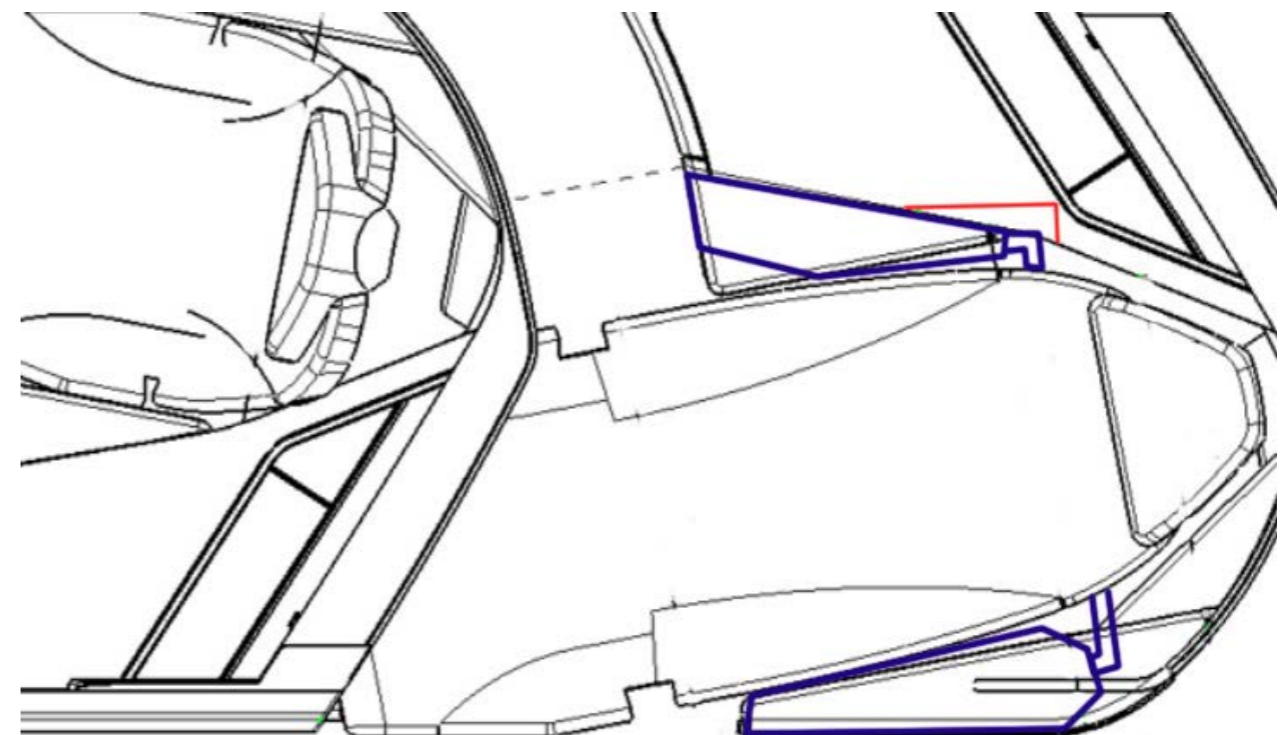
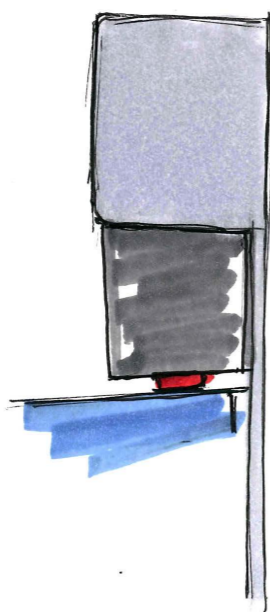


Figure 23: Top view concept 1, showing the armrests stowed away. First moved fully up along the backrest and then turned down.





Concept 2 – the sliding armrest.

Concept 2 slides forward along the base of the armrest (figure 25). This base is attached to the seat through the shell. The moving up and down mechanism will be the same as for the current armrest, but then it will be applied for both sides and it will be automated. Next to the option of moving up and down, all other adjustability options should also be automated (a few first sketches of the working mechanism can be found in appendix 4). To improve usability the automated options should be integrated into the panel used for the seat controls. The shape of the armrest will be flat, only containing indents at the end of the armrest as a support for the reading device.

The extra privacy option of this concept consists of a pivoting panel (figure 29). The panel rotates up and down into the fixed privacy panel, giving it the possibility of rotating together with the armrest when the armrest is rotated upwards for reading.



Figure 24: concept 2 in TTL position.

Movement of the armrest

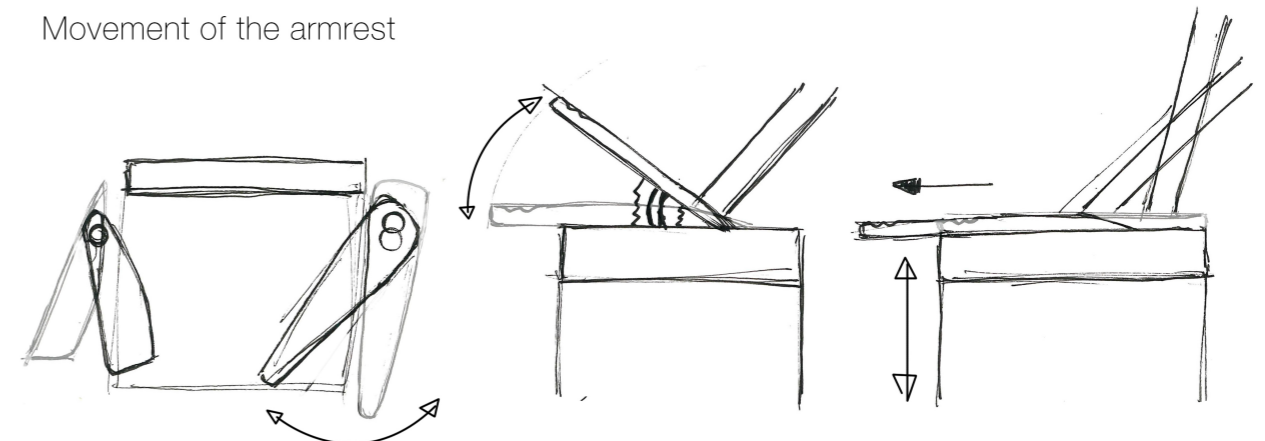


Figure 25: Adjustability options concept 2.



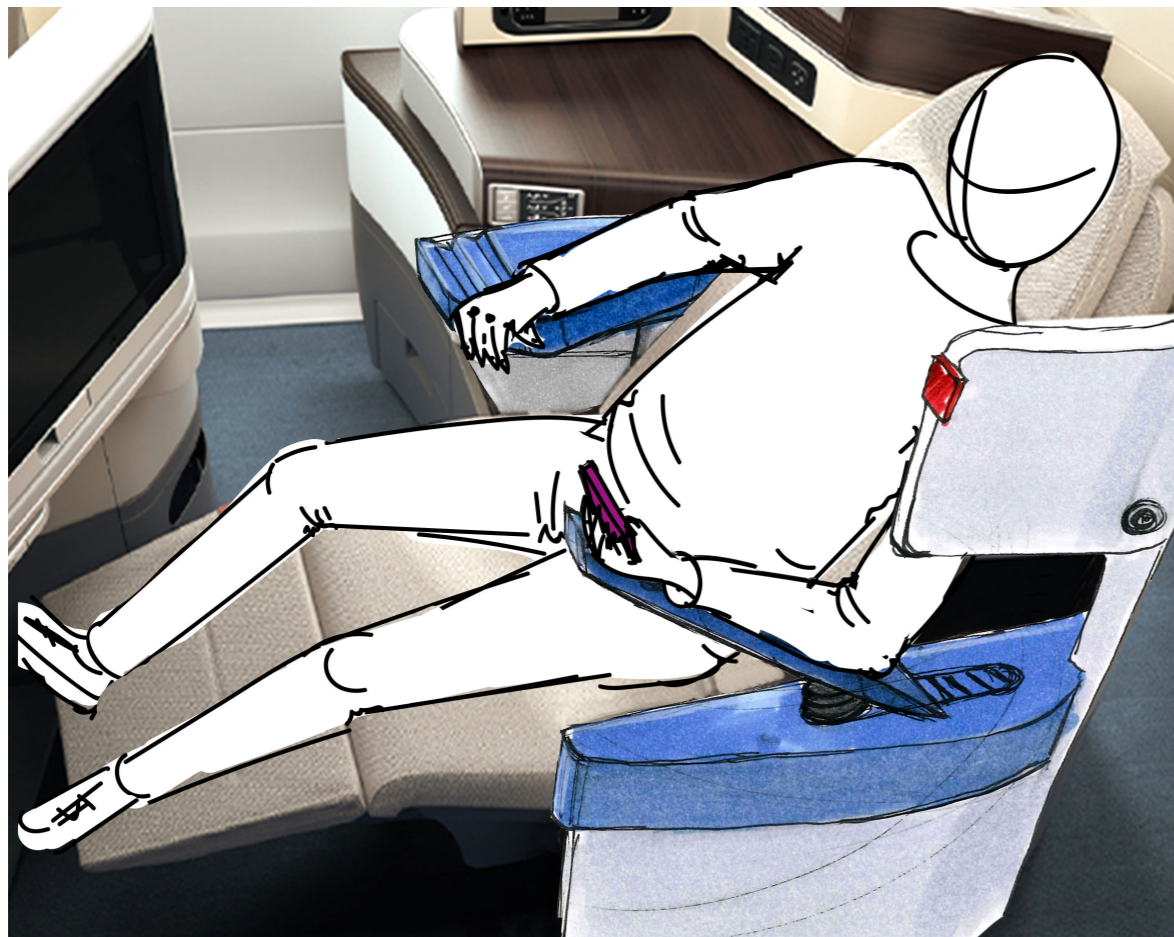


Figure 26: Concept 2 in relax reading position plus human.



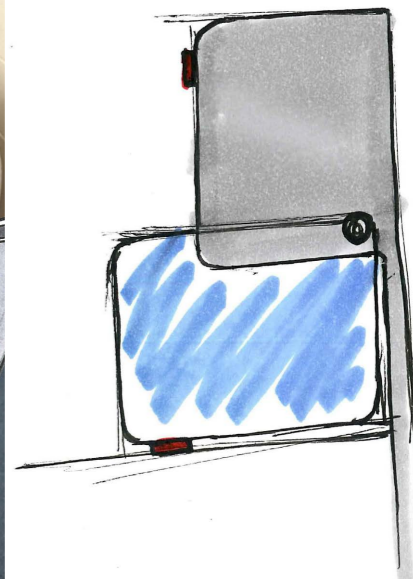
Figure 27: Concept 2 in relax reading position.



Figure 28: Armrests moved forward in relax position.



Figure 29: Privacy option concept 2.





CONCEPT MODELLING

In order to work out the concepts and to evaluate and improve them, two real size models were made. The aim of the models were to further define the shape, size and functioning of the concepts. For both concepts a collage of the models made is shown in figure 30 and 31.

Concept 1: The shape of both sides armrest does not work. The aimed effect of supporting the upper arms with this specific shape is not reached because the armrests are too short. The length of the armrests also cause that the hands are not supported. Besides the length of the armrest the shape also makes a rotation around the axes of the armrest not possible. When the flat side of the armrest is used for reading the angle for reading can be adjusted sufficiently. Also in this case the reading has an increased comfort compared to the current armrest, the arms are supported better.

Concept 2: The flat surface rotated to the inside and vertically rotated up works good for reading. The best height of the armrest still needs to be determined in a user test together with how the space between the armrests is experienced and the difference in length of the armrests. The space between the armrests is larger than the usual smartphone or tablet which means that it would have to be held with one hand if the space between the armrests is too big.

Conclusions from model making: A flat surface in an angle up and inwards can work as an improvement for the reading position. An additional user research is needed to backup this theory. With changing the shape of concept one to also flat for reading brings

both concepts closer to each other regarding ergonomics. Also as mentioned above the relation between the distance between both armrest and the difference in lengths of the armrests and what this means for the comfort needs to be tested.



Figure 30: Different positions tested with the model of concept 1.

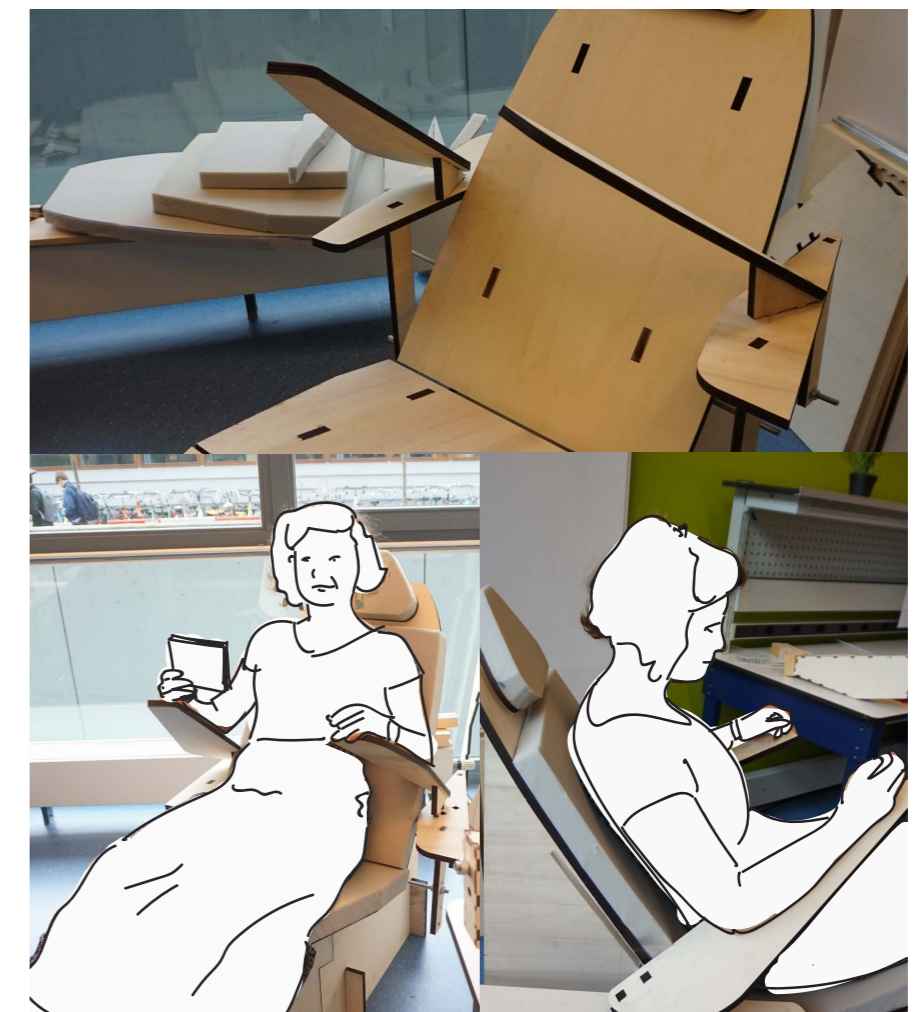


Figure 31 Different positions tested with the model of concept 2.





Based on the conclusions made for concept 1 an opportunity for improvement of the concept was seen. As shown in figure 32 when changing the shape of the concept to making it wider towards the end of the armrest on the non-console side armrest will give the possibility to enlarge the area for the arm when the armrest is turned only 90degrees. This change would eliminate the need for rotating around the horizontal axe of the armrest on the console side and would limit the movement for the non-console side to only turning 90degrees. Another benefit of this change is that if the armrest is turned 90 degrees, the inwards rotated angle is met by the increased area of the armrest. This may also eliminate the need for the whole armrest to turn inwards on the non-console side. The console side armrest would still need to turn inside.

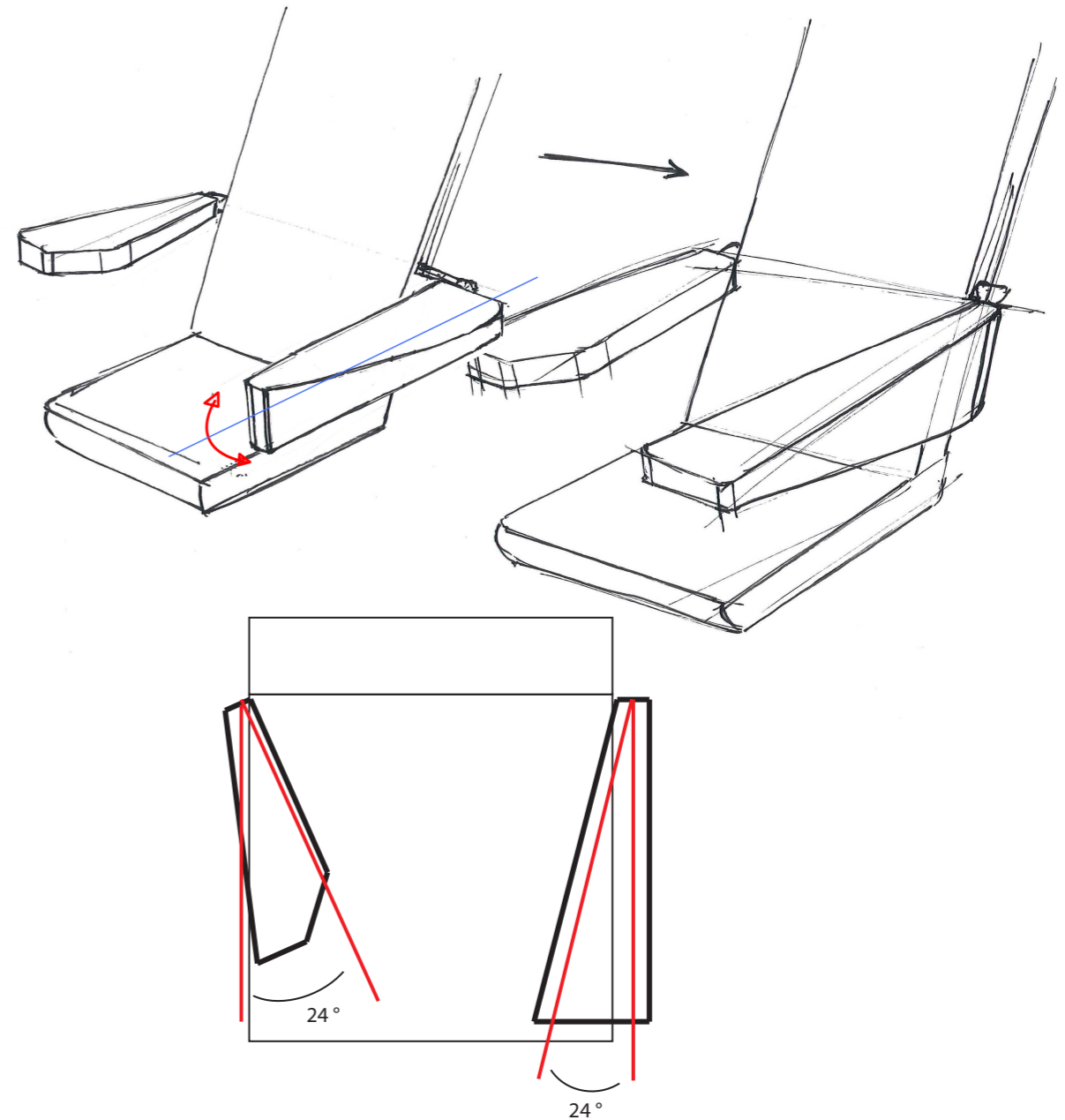


Figure 32: Picture showing the redesign of concept 1. The turning of the non-console armrest with 90 degrees used to enlarge the contact area and meeting the 24 degrees angle inwards.





CONCEPT CHOICE

In order to make a good comparison between the two concepts, the weighted objectives method was used (Boeijen et al., 2013).

Explanation of the chosen Criteria and their weight

Eight criteria were chosen as the base for the concept choice. Each criterion was given a weight according to their importance. The sum of all weights is 100. The criteria chosen for the weighted objectives method are only partially the same as the most important criteria defined earlier during the ideation phase. The most important criteria are focused more on privacy and ergonomics. During the model making of the concepts, the conclusion was drawn that the concepts have a lot in common on many ergonomic aspects. Because of this similarity, the ergonomic criteria were still included but were given a lower weight. Instead of the ergonomics criteria, the criteria concerning technical reachability and aesthetics were seen as most important in this case. This criteria selection will help to reach the goal of integratin the armrest into the current RECARO seats.

Explanation of the score appointed to the concepts:

For every criterion a score between 1 and 10 was given to the concepts, this score is then multiplied by the weight of the criteria, the sum of all these scores are the total score of the concept.

Technical reachability: concept 1 was given less points. Within the space behind the backrest, there is not enough space to place a mechanism for the armrest. This was confirmed by one of the RECARO engineers

working on the CL6710. This engineer noted that there is no possibility for implementing a sliding mechanism and a rotation axis with an integrated actuator in the current backrest. This insight combined with the fact that the first concept would have more difficulties in meeting the requirements regarding forces and loading on top of the armrest (not impossible but more difficult to reach) and making the armrest full flat is a bigger technical challenge, this concept was given a lower score. The second concept also has some disadvantages concerning the technology. For instance, the mechanics for making the concept work still need to be thought out and the question is if there is enough space to let the armrest sink into the casing for the full flat mode. But with the current knowledge, these concerns are not insurmountable.

Aesthetic/appearance: RECARO currently uses straight lines and big contrasts in their style. These lines are made by a difference in colour, material, and shape. Concept two scores higher on this requirement because of the more static base of the armrest and the fixed shape of the privacy screen. This fits the style of RECARO. Concept 1 is scored lower since the privacy screen is a diaphragm with less fixed shapes and lines. However, when the joints between the diaphragm and armrest/rest of the seat, the material, and colour are chosen right, this will have a positive effect on the score. Still this will be harder than with concept 2. It will be more difficult to cover the cavities showing the working and moving parts of the armrest and seat.

Privacy: The first concept uses a diaphragm

Weighted objectives method					
Criteria	Weight	Concept 1 - Rotating		Concept 2 - Flip	
		Score	Total	Score	Total
Technical reachability of the concept of placing the armrest in the current seat	23	2	46	7	161
Aesthetic, appearance: The design should take the visual integrity of the seat into account. (Currently the seat has clear visual lines in the design, these lines are made by a change in colour, material and shape)	20	5	100	8	160
The design should provide as much privacy as possible.	15	6	90	7	105
The design should take away as less as possible living space from the current seat (e.g. space for legs and feet).	12	4	48	4	48
The width of the armrest should be as broad as possible.	10	8	80	4	40
Reading on a tablet should be as comfortable as possible.	10	7	70	7	70
The design must be adjustable in as many directions as possible. (inwards/outwards, rotating inwards/outwards, height etc.)	5	8	40	8	40
Costs (changes in outside shell of the current businessclass seat)	5	4	20	3	15
Sum	100	Total score	494		639

to create more privacy. This diaphragm mainly covers the bottom part beneath the armrest. The benefit of the diaphragm is that it will move forward together with the armrest if the seat moves to the relax position. The downside of this option is that it does not give extra privacy above the armrest (between the armrest and the to panel). The second concept uses a more fixed privacy option. A board that moves out from the top panel gives extra privacy added to the privacy given by the closed part beneath the armrest. Because this concept has the option for more privacy between the armrest and the top panel, this concept scores higher than concept 1.

Not restricting living space: concept 1 takes away space from the legs and table, concept 2 takes away open space beneath the armrest. This may generate discomfort in the TTL position for concept 2. For concept 1 this may create discomfort in the relax position and in the full flat position. Because for both concepts this discomfort has not been

measured, the assumption is made that it will give equal discomfort to the passenger. The space taken away from the legs for concept 1 could be less intrusive than the space taken away in the TTL position for concept 2, but it is estimated that more time is spent in the relax position and full flat position than in the TTL position.

Width of armrests: Concept 1 gives the user the possibility to enlarge the area for the arm by rotating the armrest. Both concepts give the possibility of enlarging the area for the arm by moving forward together with the seat. This is why concept 1 was given a higher score than concept 2.

Reading comfort: This comfort is scored the same for every concept. The shape of the armrests will be the same on the top side of the armrests and the movements required for the reading position are met by both concepts.





Adjustability options: Both concepts can move up and down vertically, move forward together with the seat and rotate upwards, and inwards for reading.

Costs: This criterion is focused on extra costs that are generated when the outer shell of the current seat needs to be adapted. The fact that changing this part gives a big rise in cost for production was brought to the attention by one of the RECARO engineers. The exact score for this criterion was not easy to determine since a lot of knowledge about the current seat and its parts is unknown to me. This is why this criteria was only given a small weight. Because it is still important it was integrated into the weighing of the concepts. Most likely both concepts will need changes in the outer shell. The first concept won't be attached to the outer shell and therefore will require the least changes. Still, joints for the privacy diaphragm will be necessary and the current armrest joints need to be taken out. Concept 2 might require more changes. Although the vertical moving option will stay the same as the current armrest, the fact that the armrest needs to go further down due to the technology integrated into the armrest this may mean that on the aisle side the shell needs to change to make this happen. For instance, the step on that side which is used to reach the overhead lockers may have to be relocated.

Conclusion

If the scores of the two concepts are compared, the second concept has the highest score. Based on the above-made argumentation and the score that came with that, concept 2 is the most logical choice to continue with.





DETAILED DESIGN

Is the new design really better for reading than the current seat? How is the armrest used? What does the new design look like and how does it work? These are all questions that will be answered in the following chapter.



USER TEST OF THE CHOSEN DESIGN

After the choice was made to continue with the second concept, a short user test was set up in order to define a few variables and to see if the concept was perceived more comfortable for reading than the current design.

To make this test possible the model made earlier was modified. The modified model is able to change to three different angles in the vertical direction (figure 33, 100/90/80°). The current situation was simulated by changing the height of the armrest and by taking away the upper part (figure 36). The distance between the armrests was changed with the use of another model (figure 37, 10/20/24°).

The participants were asked to sit in the seat with the current situation for 10 minutes while they were reading. In the new model with angled armrests the participants were asked to read for three minutes for every angle. The same was done for the angles inwards. After experiencing the different sitting position the participants were asked if they could score their comfort on a scale of 1 to 7 where 1 was very uncomfortable and 7 very comfortable. Figure 34 and 35 shows the mean comfort score for the different positions. Furthermore the participants were asked if there was something they found very uncomfortable or comfortable about the sitting position and they were asked if they could rank all positions in comparison to each other. The complete question list can be found in appendix 5.

The test consisted of 5 participants all between the age of 20 and 25. With two male participants and three female participants. Their length varied between 172mm and

194mm. When two of the five participants finished the test, a negative comfort score was observed for the 90 degrees angle. Based on comments of these participants a quick solution was added for the 90 and 80 degrees angled position. The wedge that was added shown in figure 40, was added to give more support



Figure 33: Adjustable angles.

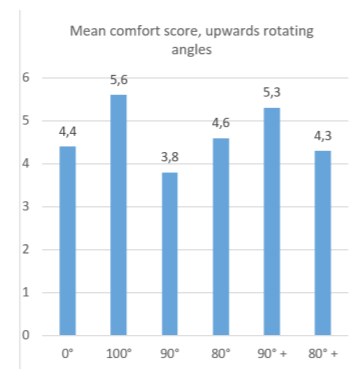


Figure 34

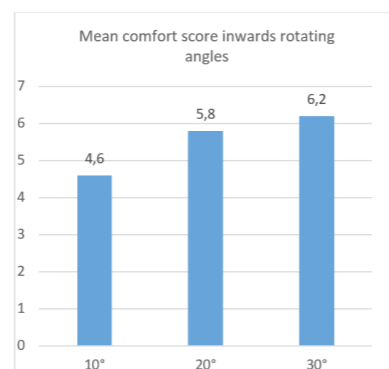


Figure 35



Figure 36: simulation of the current situation.

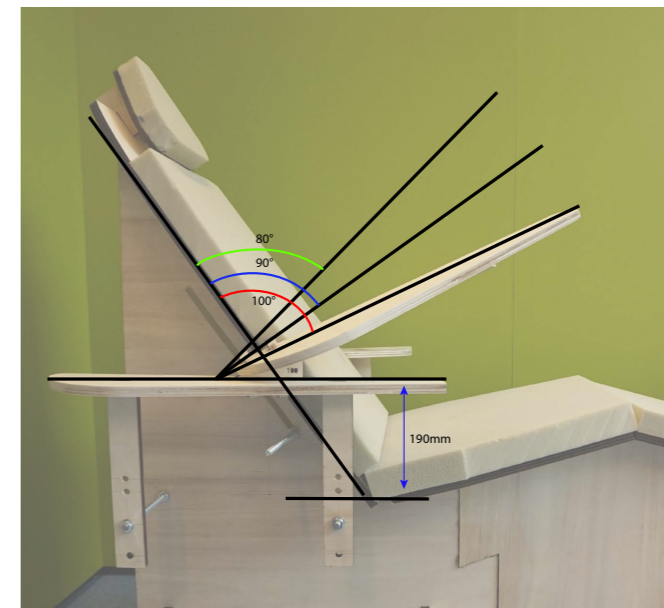


Figure 37: New design with adjustable angles.

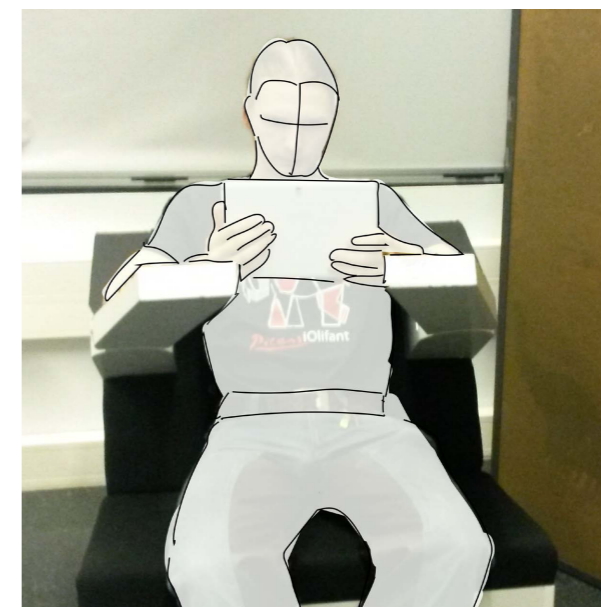


Figure 38: Seat used for inwards rotating armrests.

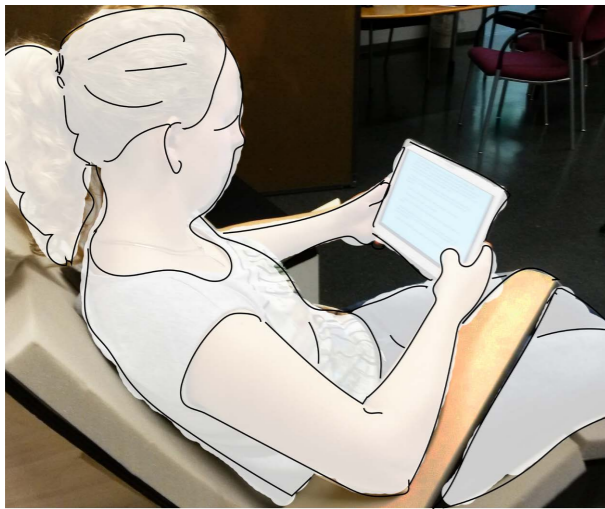


Figure 39: Reading, 100 degree angle.

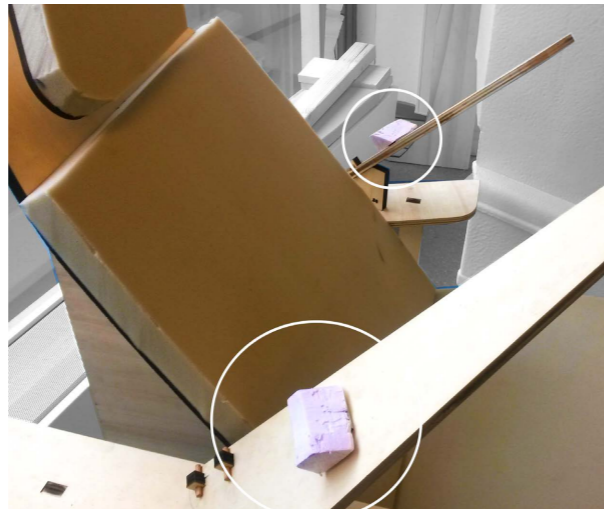


Figure 40: Added supports for the elbows.



Figure 41: Reading in the current situation.



Figure 42: Reading, 80 degrees angle plus elbow support.

to the arms by avoiding slipping away. The opportunities for the design that followed from the results are listed below: (The full results can be found in appendix 6.)

- If the arms of the passenger leave the armrest to the middle over the edge. The edges should not cut into their arms. Thus the sides of the armrest should also have soft edges.
- An elbow support is needed to alleviate the stresses in the neck, shoulders and upper arms, since the friction between the armrest and arms is not high enough without support the arms slip down. The comfort score for the angles 90/80 went up when the wedge was added.
- Armrests need to get closer to each other, especially with smaller angles (90-80 degrees). The weight of holding the tablet after a while becomes quite heavy. When the armrests are too far apart from each other the tablet cannot be supported by the armrests.
- In addition to the previous point, integrating a ridge into the armrest to support the tablet could also help to give support to the tablet (or another way of additionally supporting the tablet could be sought).
- When adding the elbow supports, the optimal location of the support should be examined. If the elbow supports are too high this may lead to cramped high shoulders (figure 42). This effect can be counteracted if the armrests can move up and down on the vertical axes or forward on the horizontal axes. This also explains the low comfort score of participant 5 on the 80degrees position.
- Multiple times throughout the test, the asymmetrical length of the armrests was mentioned as a point of discomfort. When only holding the tablet in one arm, it was not possible to switch from the non-console side to the console side armrest because this armrest is too short.

Other outcomes of the test are:

- All participants preferred the new design over the current situation for reading.
 - One participant mentioned that she would find the 100 degree angle position also a comfortable relaxing position, not only for reading.
- On average the upwards angle of 100 degrees scores best on the comfort scale. But when afterwards ranked the preferred angles is not unambiguous. For neck comfort the angles 80 or 90 degrees may be better, but the tension in the arms seem to be higher. Although this can for a large part be compensated by elbow supports. The best angle is not yet determined. For further design the advice would be to integrate at least two possible angles. One angle giving more rest to the arms and which can also be used for just relaxing and one where the eye height and distance to the eyes is best suited for reading.
- The best inwards angle is the angle where the armrests are closest to each other (24degrees). Thus the goal is to place the armrests in an angle as close to each other as possible. One side note to this is that the armrests should be easily moved out of the way to avoid a cramped or locked up feeling.
 - The overall preference of the participants for reading is the third model used in the test. This can be explained by the distance between the armrests and the look and feel of this third model. Compared to the own developed model the third model felt less fragile during use and used more comfortable materials (such as leather for the armrests).
 - In order to stand up from the seat, the armrest should be easily moved aside. The participants don't want to worm around the armrest. They would also like to use the armrest to push themselves up from the seat.





FINAL DESIGN





SCENARIOS

As the design further developed, it became clear that this assignment holds a few criteria that are at conflict with each other. Earlier in the analysis phase it was concluded that more adjustability options would improve the comfort of the armrests, because the orientation of the armrest can better be personalized and thus give better support. But more adjustability options have a few downsides. For instance more adjustability may lead to problems with usability by the passenger. Solving this problem lead to difficulties in technical reachability within this project or a decrease in living space.

There are Two possibilities considered in solving the first conflict (usability vs. adjustability). Both options are also visualized in figure 43.

Option one is the optimal situation. All adjustability options are automated and can be controlled electronically. Within the seat controls a pre-set button for a reading position is integrated to make sure this is visible and understandable for the passengers. Separate adjustments to different parts of the armrest can be adjusted with separate buttons. To ensure the passenger always enjoys the benefit of extra arm space on the armrest in the relax position, the armrests will always move synchronized to the seat forward when the seat is set to the relax position.

The second option includes limited manual adjustability options. Manual in this case is described as not electronically adjustable, with the use of own force. The idea is to make the armrests adjustable in all suggested directions but instead of making it possible to adjust them in unlimited positions, it is

only possible to adjust them into certain pre-defined positions. This is done to make the choice for the best position easier for the user.

Off course this is not a black and white situation. You can include some manual adjustable parts and some electronically adjustable parts. Or you can leave out adjustability options entirely.

Figure 44 compare a few scenarios in adjustability options to the conflicting criteria and to the added value for the customer. if a cross is put into a box, this means the design in this scenario has these adjustability options and that this scenario is beneficial for the criteria. The technical reachability is looked upon from the perspective of this project. All options will be technically reachable but not all will be technically reachable within the time given for this project. Therefore I would advise RECARO to assess the scenarios again when this concept is further developed.

Scenario 1 shows the “optimal situation”. However as described earlier, optimizing the adjustability and the usability has the downside that this will take away more living space and that it will become more expensive and technically challenging to reach this goal. Developing this further would be an recommendation to RECARO.

Because scenario 1 is not reachable within this project, the rest of this project will focus on scenario 5. This scenario includes electrical adjustability options for moving forward and for the up/down movement. But the vertical and horizontal rotation is made manual with pre-set angles. This way the user

Improving usability while retaining adjustability

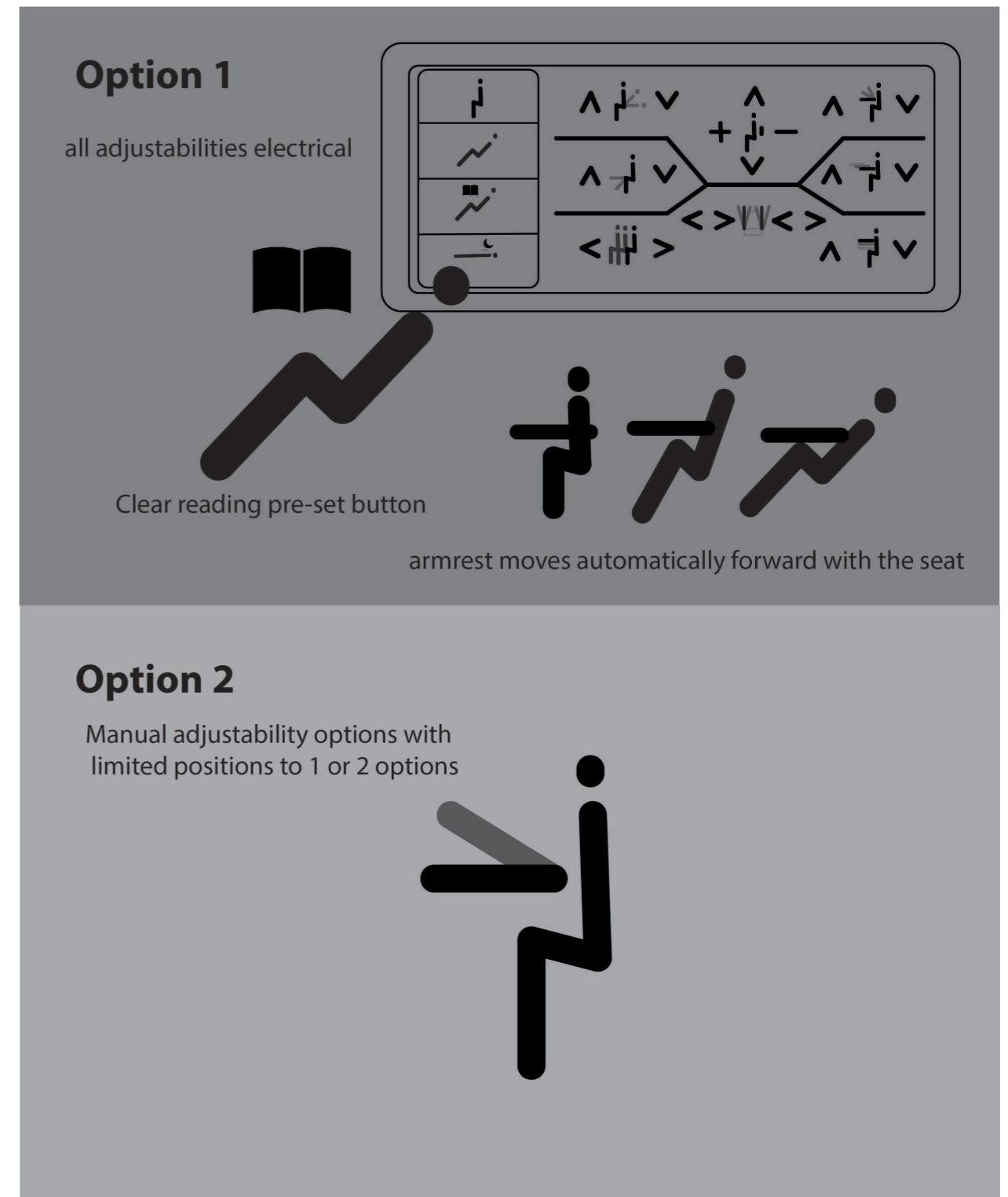


Figure 43: Adjustability options





will be aware of the movement of the armrests because it moves forward along with the seat and the improvement of the comfort in the relax position is always guaranteed. The option for manual installation of the armrests in rotation will improve the comfort of the armrests for reading but without the personal optimization. This will make it easier for the understanding of the use. Technically this solution will use less space in the rotation mechanism because no motor has to be included.

	Scenarios						
	1 Fully adjustable with electrical pre-sets	2 Fully adjustable	3 No up/down	4 Super simple	5 Compact adjustable	6 No inwards rotation	7 (3 but manual)
Moving up/down (electrically)	x	x		x			
Moving forward along with the seat (electrically)	x	x	x	x	x		
Moving up/down (manually)					x	x	
Moving forward along with the seat (manually)						x	x
Rotating vertically (electrically)	x		x				
Rotating horizontally (electrically)	x		x				
Rotating vertically (manually)		x					x
Rotating horizontally (manually)		x					x
Rotating vertically (manual in pre set angles)					x	x	
Rotating horizontally (manual in pre set angles)					x		
Adjustability	x	x			x		x
More living space			x				x
Technical reachability			x	x	x		x
Usability	x			x	x	x	
added value: better reading comfort	x	x	x		x	-	x
added value: better relax position arm support	x	x	x	x	x	x	x

Figure 44: Scenarios

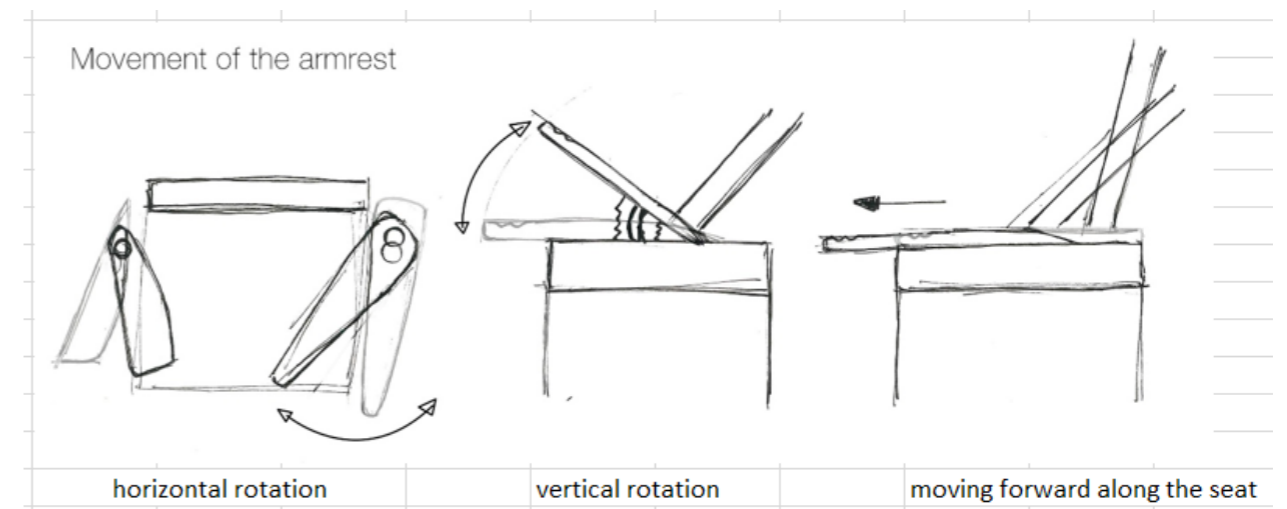


Figure 45: Movements of the armrest





FORMGIVING

To improve the form and visual aspects of the design in order to fit it into the current design and to make it look luxurious a small form study was conducted. Figure 46 shows a few details in the current design which gives the seat its identity. Next to that figure 47 shows a few aspects of the new armrest design which could be improved and were the new functionalities should be better integrated. Combining the previous study of car seat interiors into this a new design is presented (figure 48). Some sketches made in advance can be found in appendix 7.



Clear visible line through the middle of the seat, by colour and material

Repeated single rounded curves.

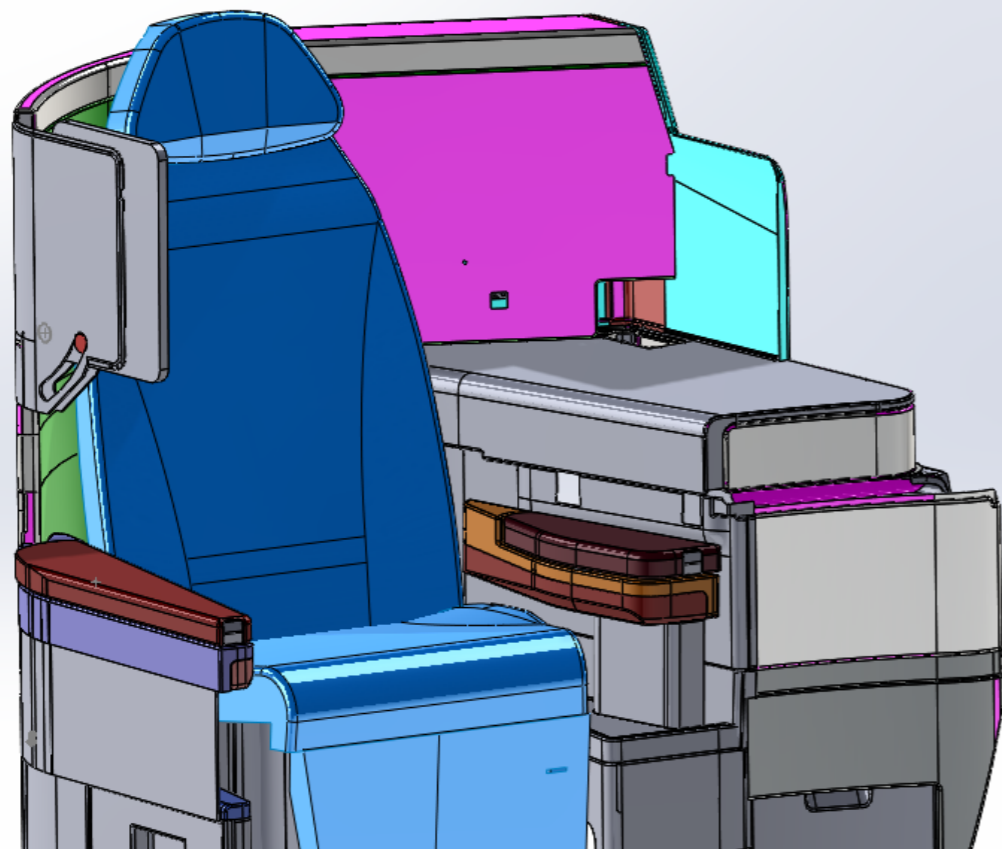


Figure 46: Visual aspects of the current RECARO business class seat





The new design contains extra contrast due to the added brushed aluminium lines. The single curved lines from the original design are seen back in the contours of the armrest from the side and the stitched lines. Furthermore the upper part of the armrest will always stick out a little bit to the front to avoid disturbance in the look when it moves forward. Furthermore the back of this same upper part is made in an angle so the shape is less disrupted.



Integrating the new lines in into the existing lines of the current seat.

Form the P-shape that it integrates the new mechanism into the whole.

Smoothly integrating the moving top part into the stationary bottom part. And how to handle the gap that will form when it moves.

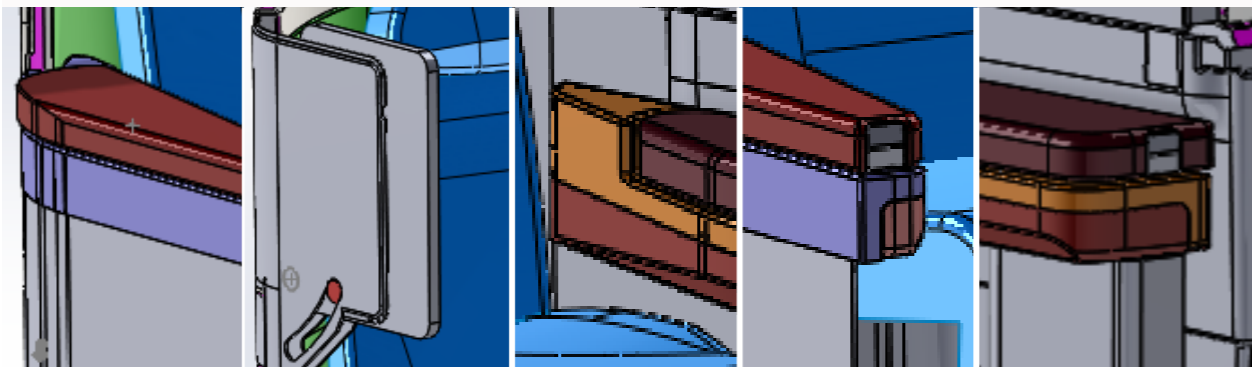


Figure 47: Areas where visual improvement is needed

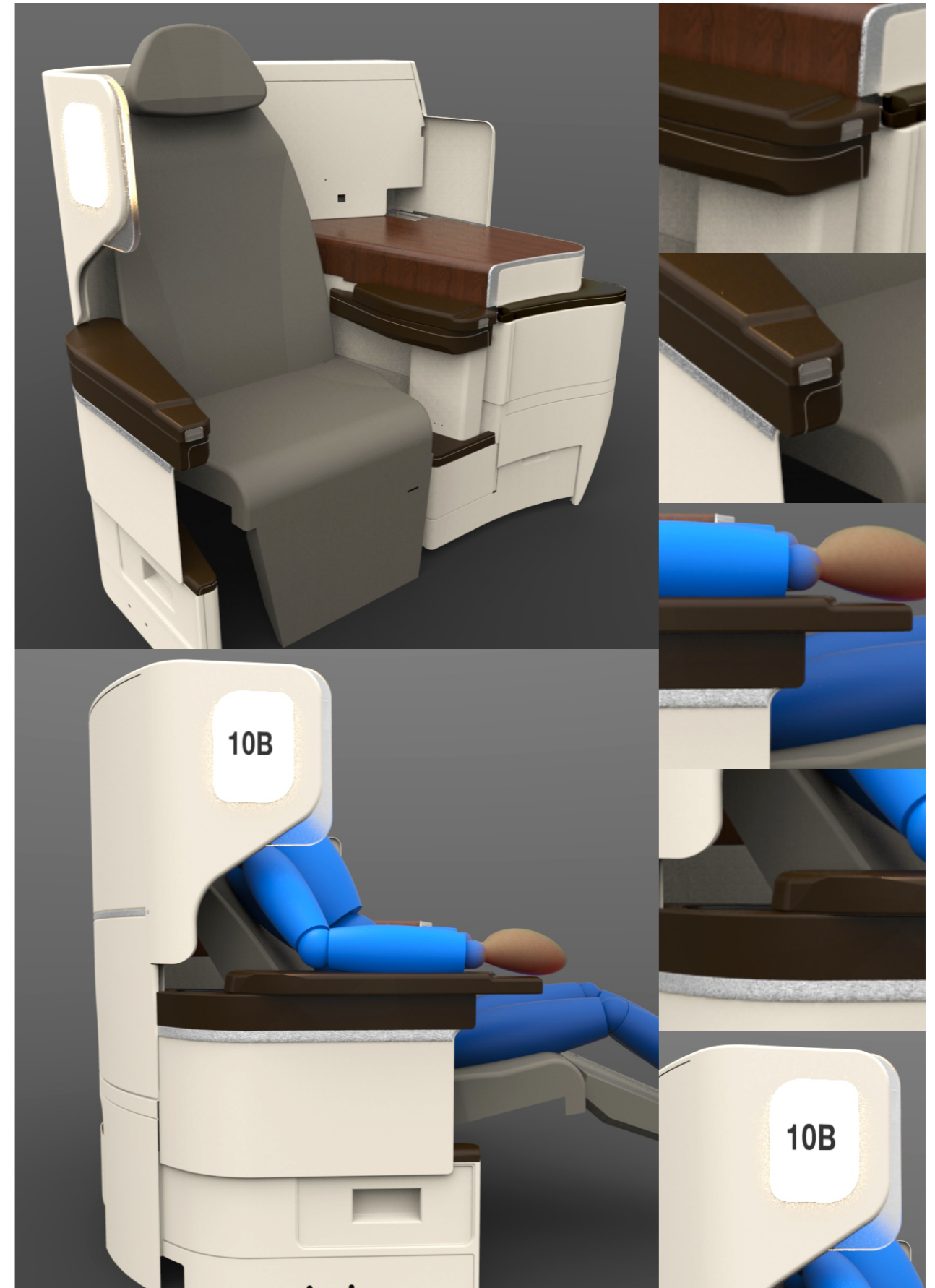


Figure 48: The new design with some form details.





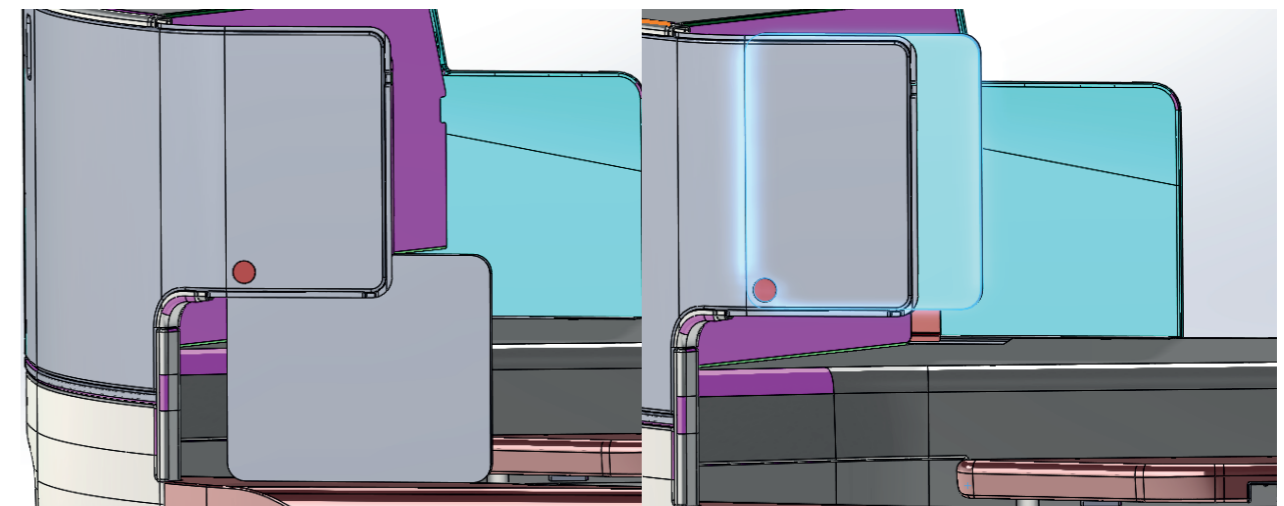
PRIVACY PANEL

During the development of the privacy panel a few different working mechanisms were modelled to explore the possibilities. These models are shown in figure 49. In the model it was tried to maximize the area that is covered when the panel is folded out, but to minimize the length of the panel when folded up. The panel with two pivoting points met both these criteria but was difficult to handle. This is why the panel with a sliding mechanism and a pivoting point was chosen to continue with.

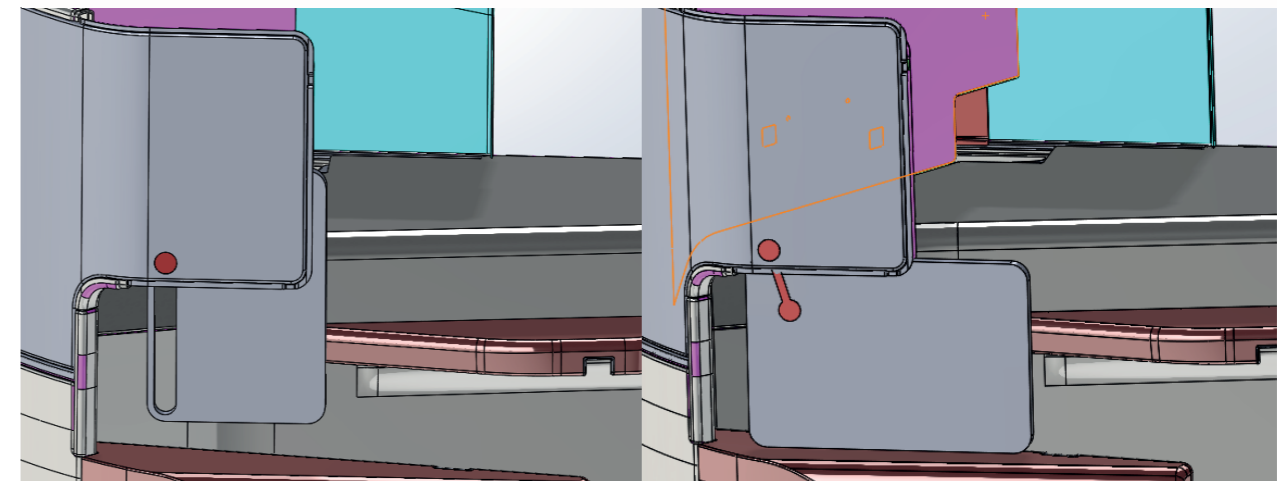
The panel was shortly tested with a simple model. Figure 50 and 51 show that the panel does not give extra privacy when the seat is placed in the relax position. The panel does give significantly extra privacy when the seat is placed in the full flat position. Thus during sleep the privacy is improved. This is shown in figure 52 and 53.

This design also requires the P-shaped current privacy panel to increase in surface down. This means the room for the elbows and upper arms may be limited. During the short test, the conclusion for this was that this would not be a problem in the full flat and relax position, but the effects in the TTL position should be researched. Figure 54 shows the increased area in the TTL position.

The final design of the privacy panel is shown in figure 55, 56 and 57. In the final design the shell is extended forward to close the gap between the privacy panel and the shell when it is folded open. Furthermore the shape is changed to fit the current design.

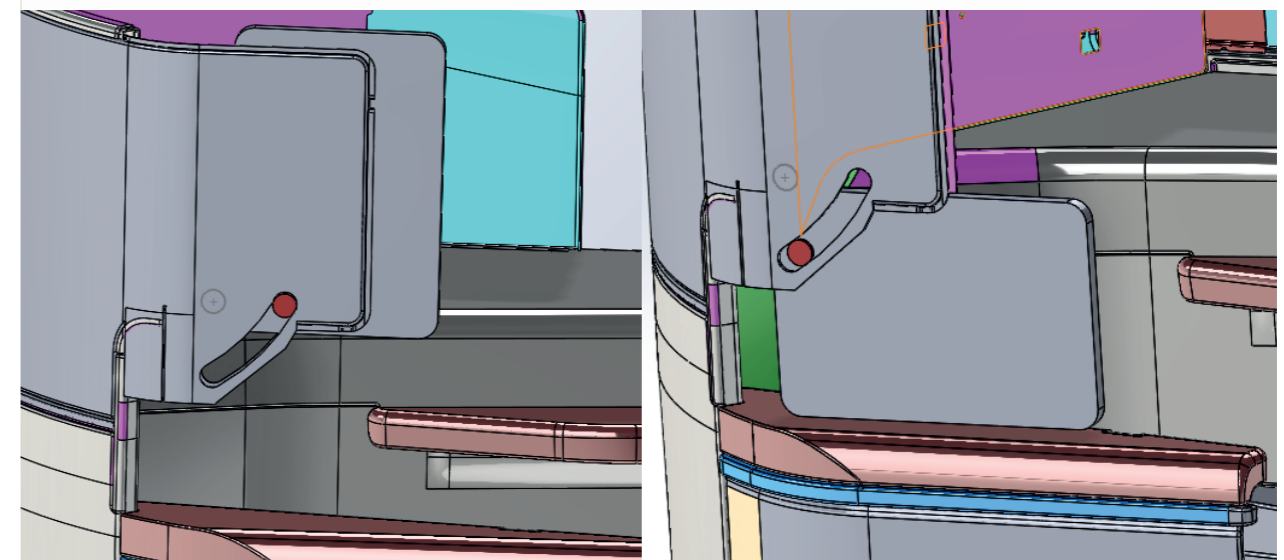


Using a bigger panel than the size of the current p-shape



A sliding panel

panel with two pivoting point



Panel with a sliding mechanism and pivoting point

Figure 49: Privacy panel models



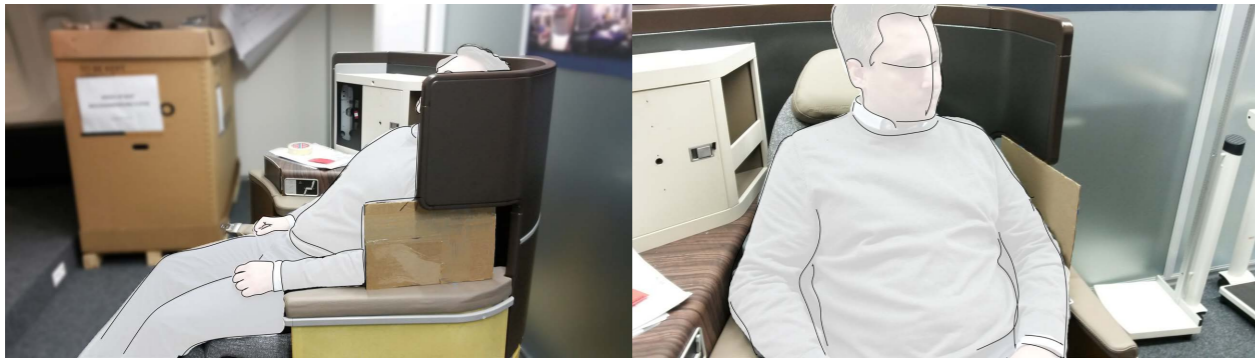


Figure 50: Privacy panel tested in the relax position Figure 51: Privacy panel tested in the relax position



Figure 52: Privacy panel in full flat position Figure 53: Privacy panel in the full flat position

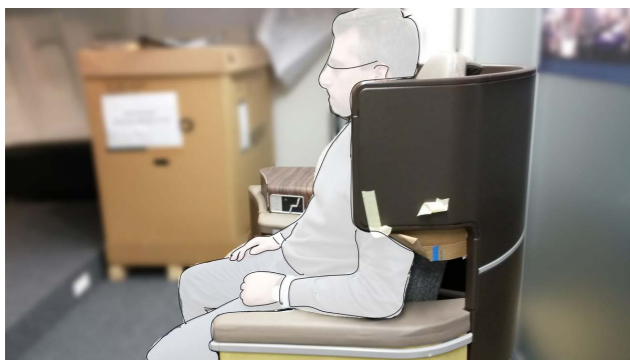


Figure 54: Extension of the current panel

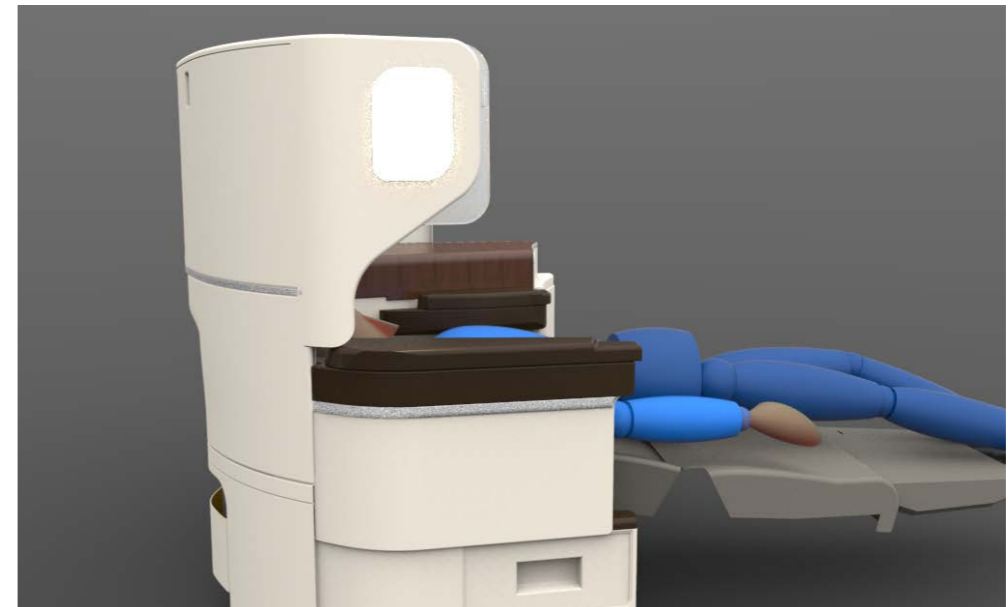


Figure 55: Privacy when only the armrest is moved fully upwards

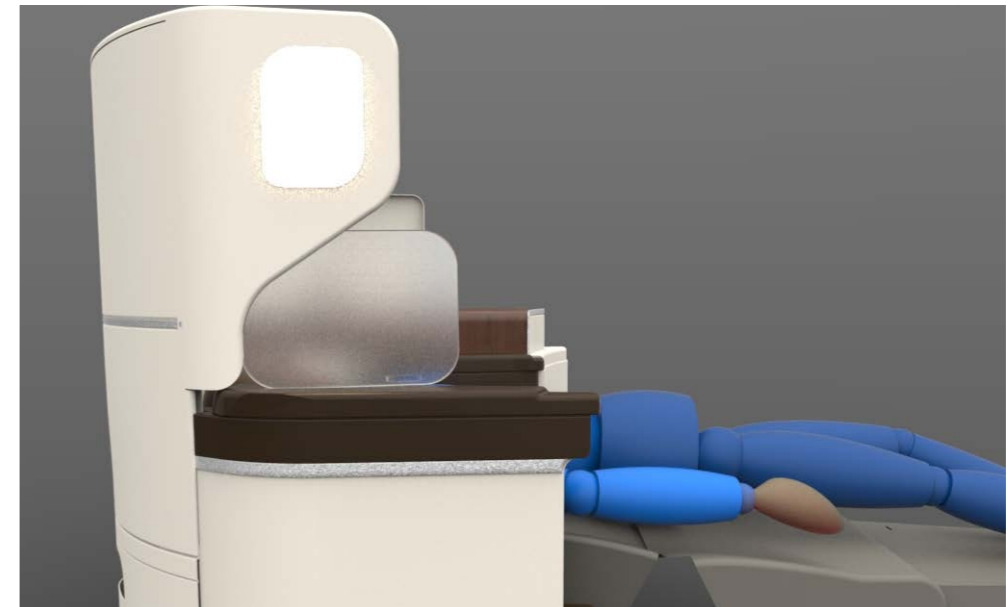


Figure 56: Privacy when the privacy panel is moved down and the armrest is moved up

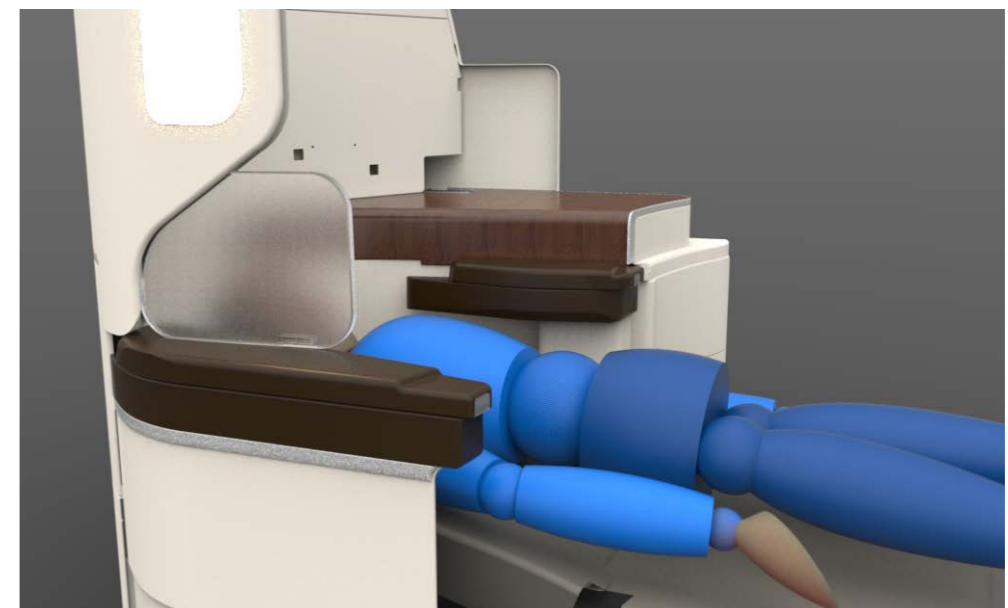


Figure 57: Privacy when the privacy panel is moved down and the armrest is moved up.





USE

The use of the product is explained with the use of the following pictures.

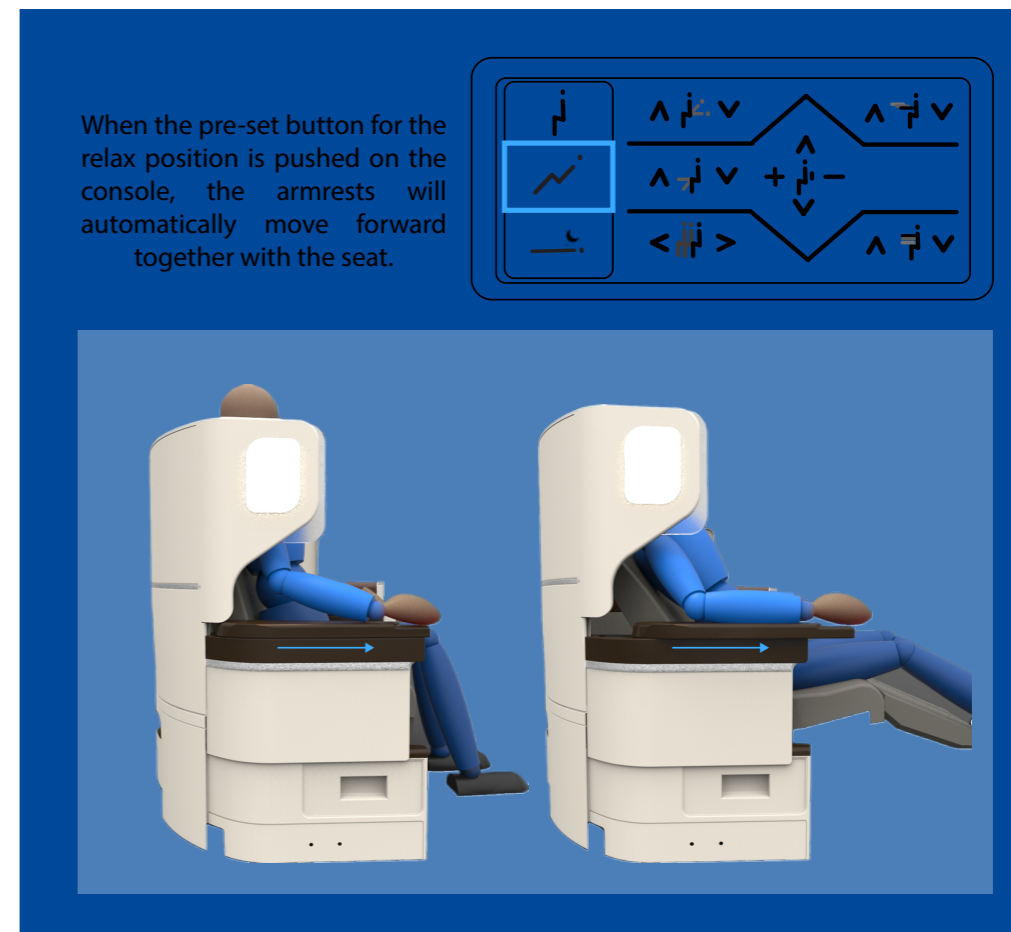


Figure 58: Use step 1

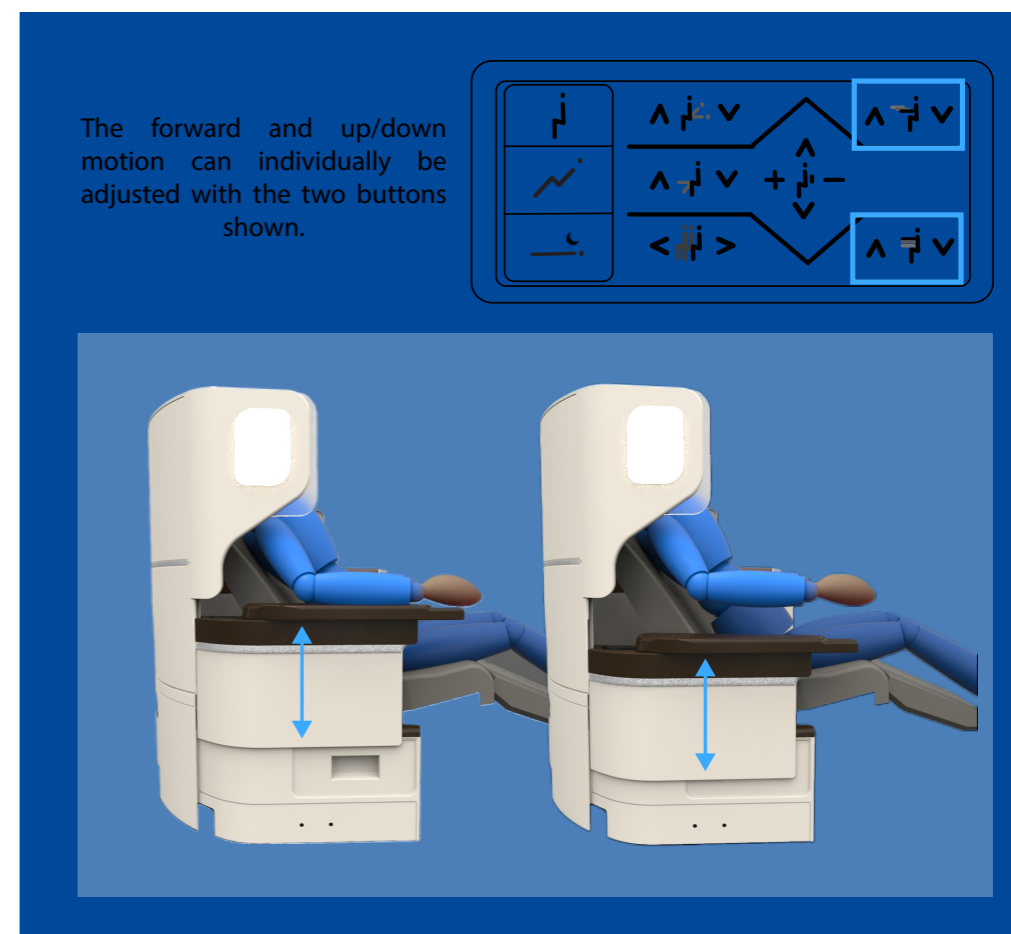


Figure 59: Use step 2





The upwards rotating angle can be adjusted by pushing the button on the front of the armrest.

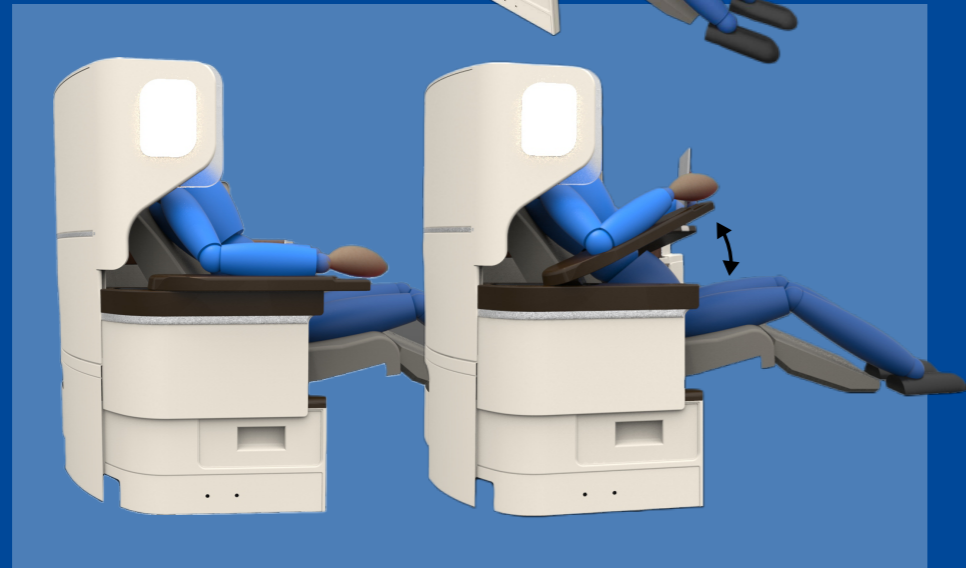


Figure 60: Use step 3

The inwards rotating angle can be adjusted by pushing to the inside or outside of the armrest, this is shown by the blue arrows. Because no button is needed, this is very easy for pushing them aside for ingress or egress.

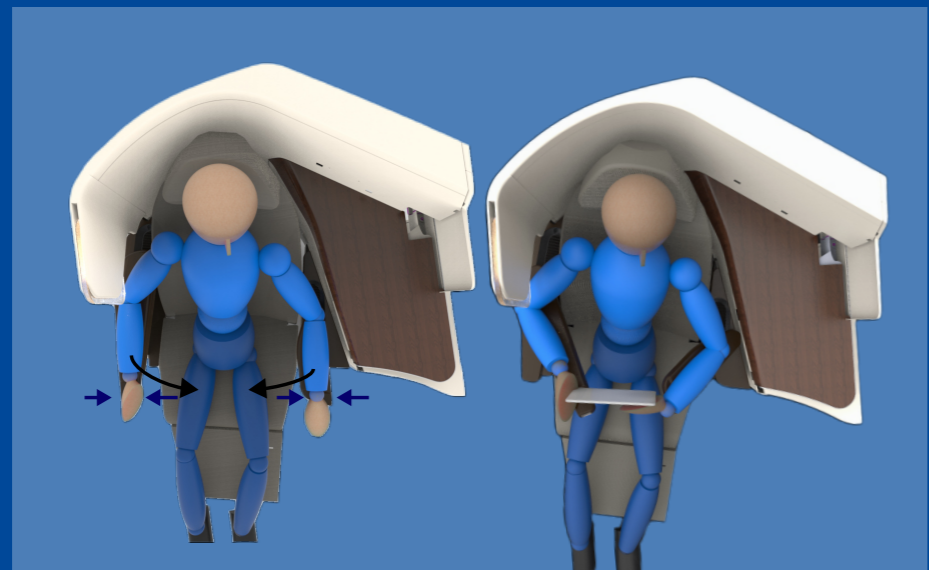


Figure 61: Use step 4

As an extra indicator that the armrests are movable an embroidered book and arrow is added to the armrest



Figure 62: Use step 5





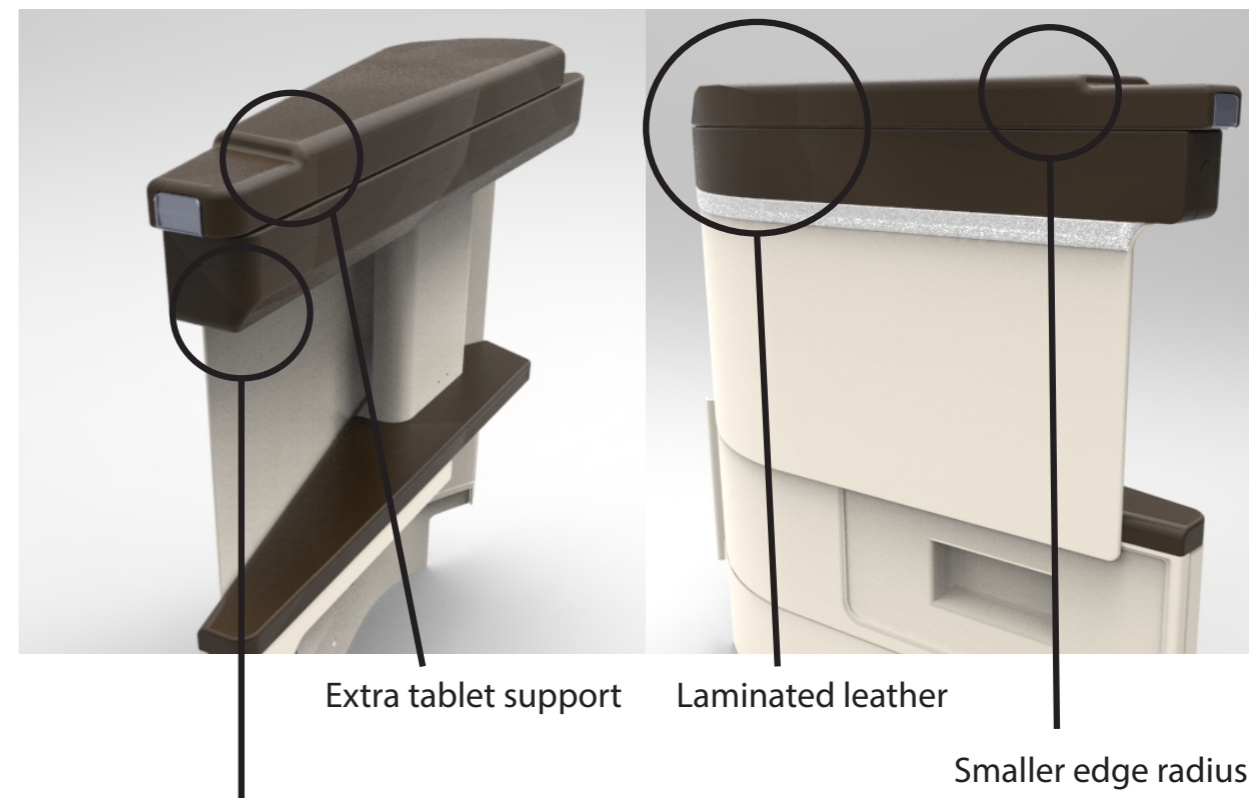
COMFORT DETAILS

In order to improve the comfort of the armrest not only the adjustability options were changed. A few other details of the armrests were optimized. These are the following details (all shown in figure 63):

- The radius of the outer corner of the non-console side armrest was made smaller. This was done to enlarge the area available for the arm to rest on and to avoid slipping of the armrest.
- A ridge was added to the armrest to give extra support to the elbows and to avoid slipping down the armrests during reading. This ridge is only added to the hard casing underneath the foam part to avoid pressure on the underarm when the leaning on the armrest in the horizontal position. adding a softer foam where the ridge is could be considered to improve the comfort of the elbow and to improve the resistance.
- An extra chamfer is added to the hard part underneath the foam. During the last user test, it was observed that the edge of the moving part would cut into the underarms when the participants were holding the tablet. This is now avoided with this extra chamfer.
- Another extra chamfer is added to the bottom of the housing of the mechanism. This is done to avoid impact with the thighs and to avoid sharp edges.
- The housing of the mechanism is also padded with laminated leather. Consisting of a layer of leather and a thin layer of foam. Since this part will also get in contact with the passenger, this material is chosen to make the housing feel less hard and cold. Another consideration for choosing this material is the fact that

more leather suggests that the armrests look softer and more comfortable.

- As a mean to give extra support to the tablet, a ridge was added to the foam part of the armrest.
- The top moving part of the consol side armrest was made 12 mm longer. This was possible because there was 12 mm space between the most sticking out part of the shell and the current armrest.



Chamfer to avoid pressure on the thighs

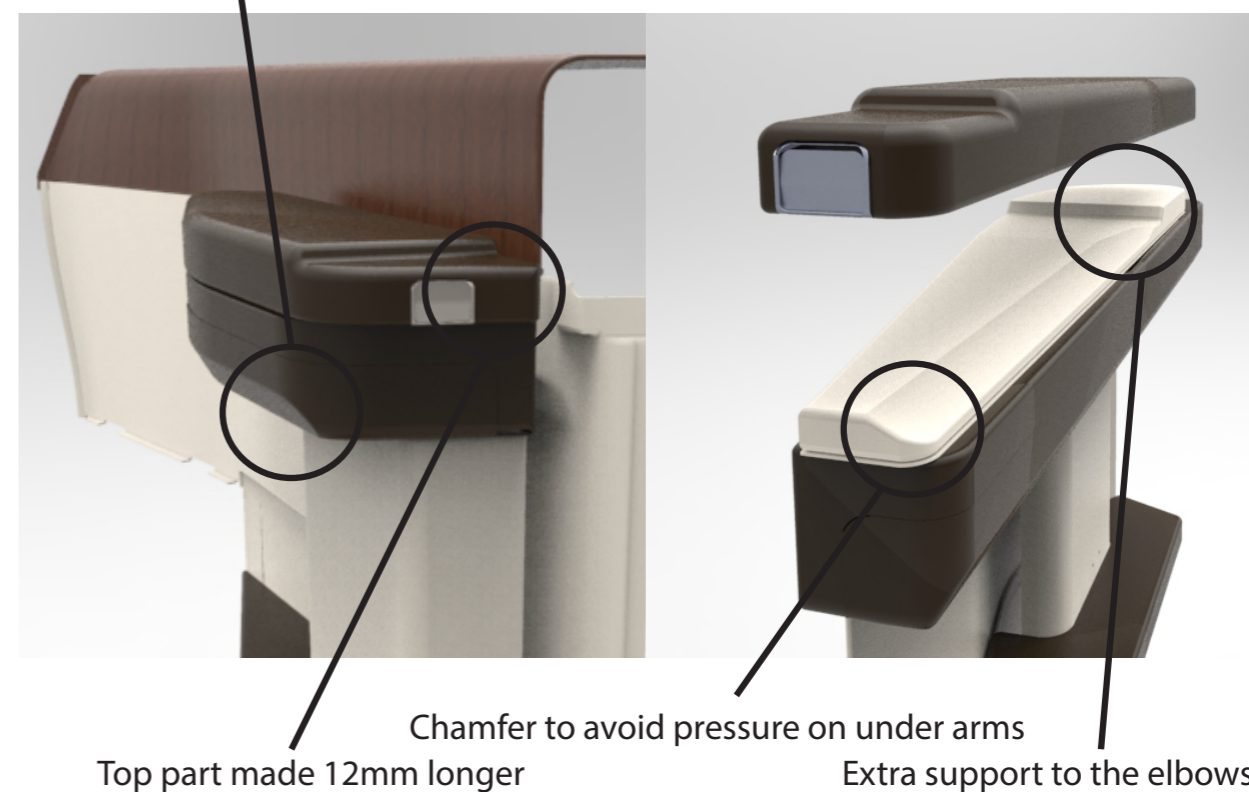


Figure 63: comfort details





WORKING MECHANISM

To explain how the armrest works, first the different outside parts are named in figure 64, 65 and 66. Appendix 8 holds a few technical drawing showing the outside measurements of both armrests. To further explain how the armrest works, the working mechanism will be explained movement by movement. Meaning the functioning is divided into: moving up/down, moving forward, rotating inwards and rotating upwards. The movement up/down will have the same working mechanism as the current armrest only electrical controls are added. Therefore this movement is

not further modelled. In modelling the new armrest design and adding the new functionalities, the space needed for the up/down mechanism was taken into account. The rest of the movements are explained in the sub chapters.

The non-console side and the console side work in the same way, but because the difference in size and shape the mechanisms are organized a little bit different. The mechanism will mostly be explained with the help of the non-console side armrest.

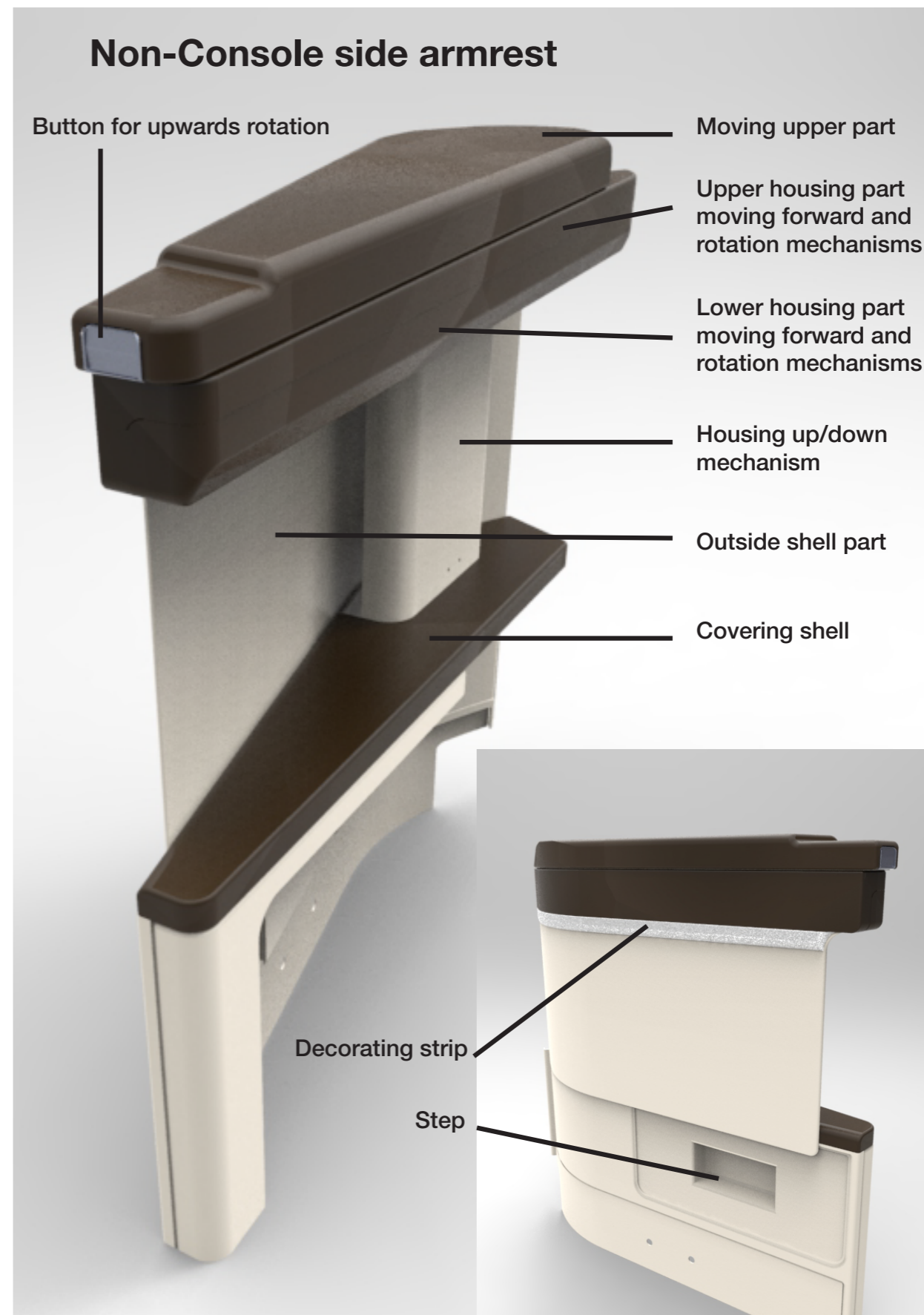


Figure 64: Non-console side armrest





Console side armrest

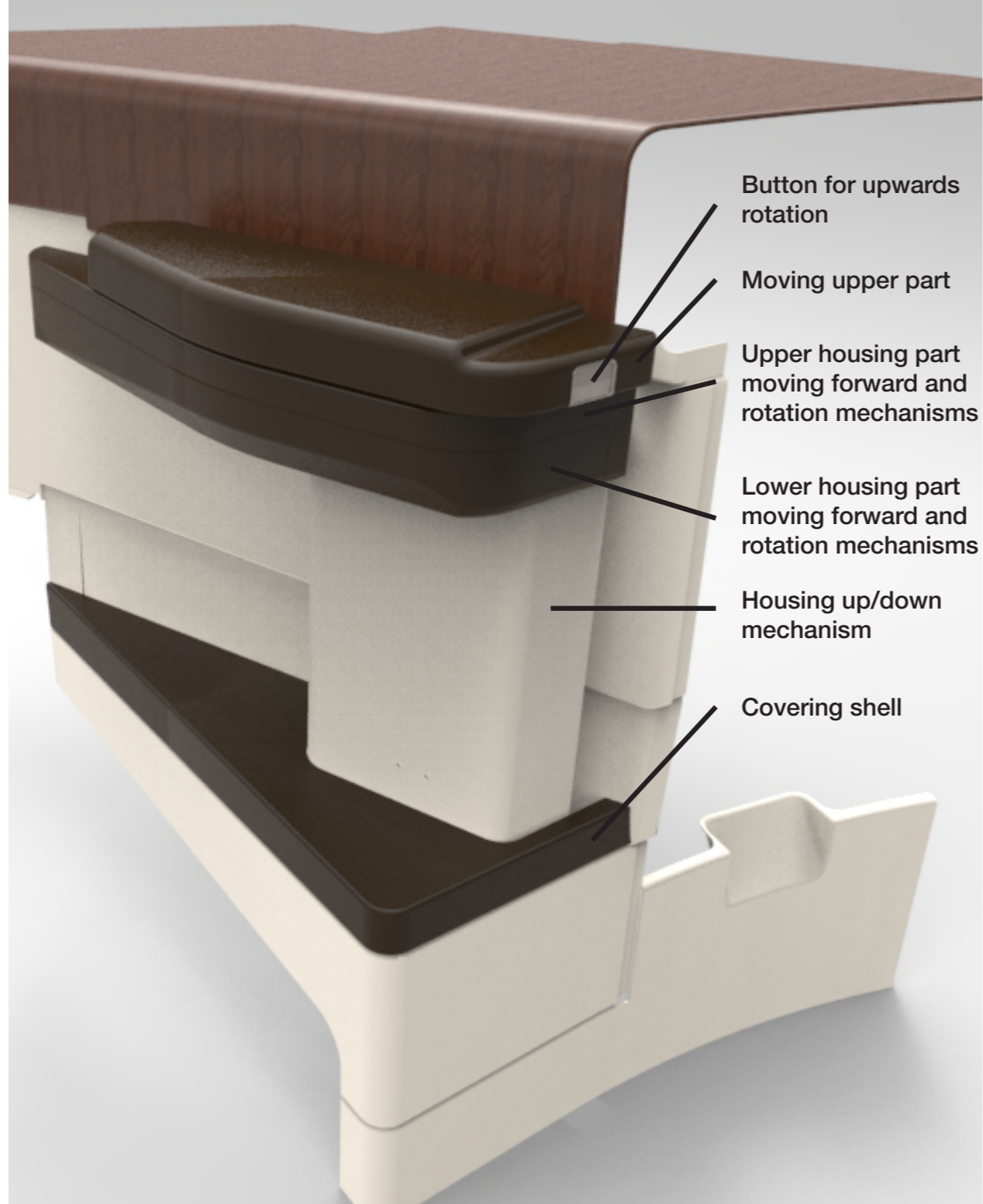


Figure 65: Console side armrest

Forward/backwards movement

Figure 66 and 67 shows how the mechanism is situated inside the housing of the armrest. Figure 68 and 69 shown all parts named for the non-console side armrest and the

console side armrest. This mechanism can be controlled through the console (as shown in the chapter 'use'). The cylinder fixed to the rack gear holds the mechanism for both rotation movements.

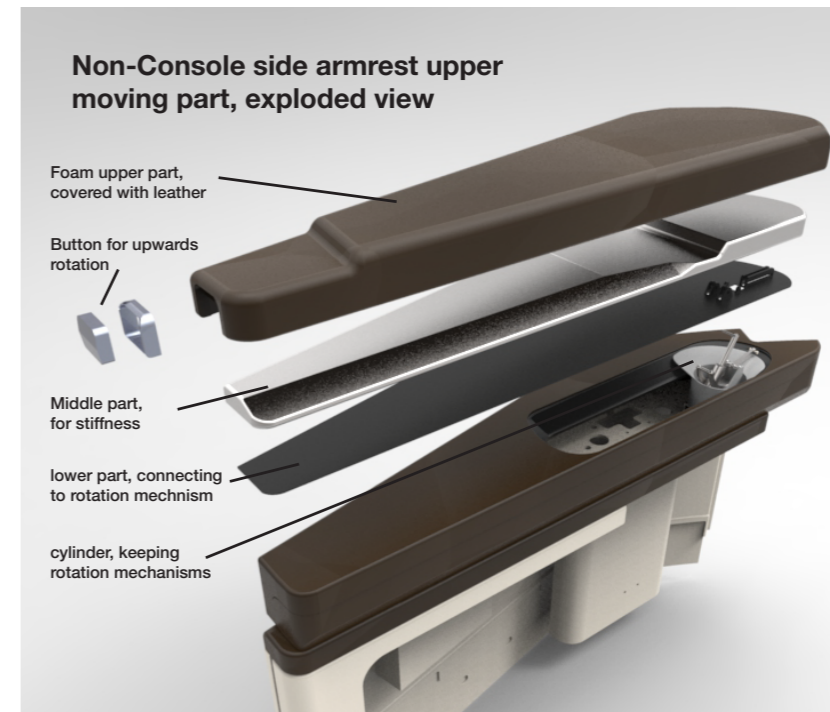


Figure 66: exploded view non-console side armrest

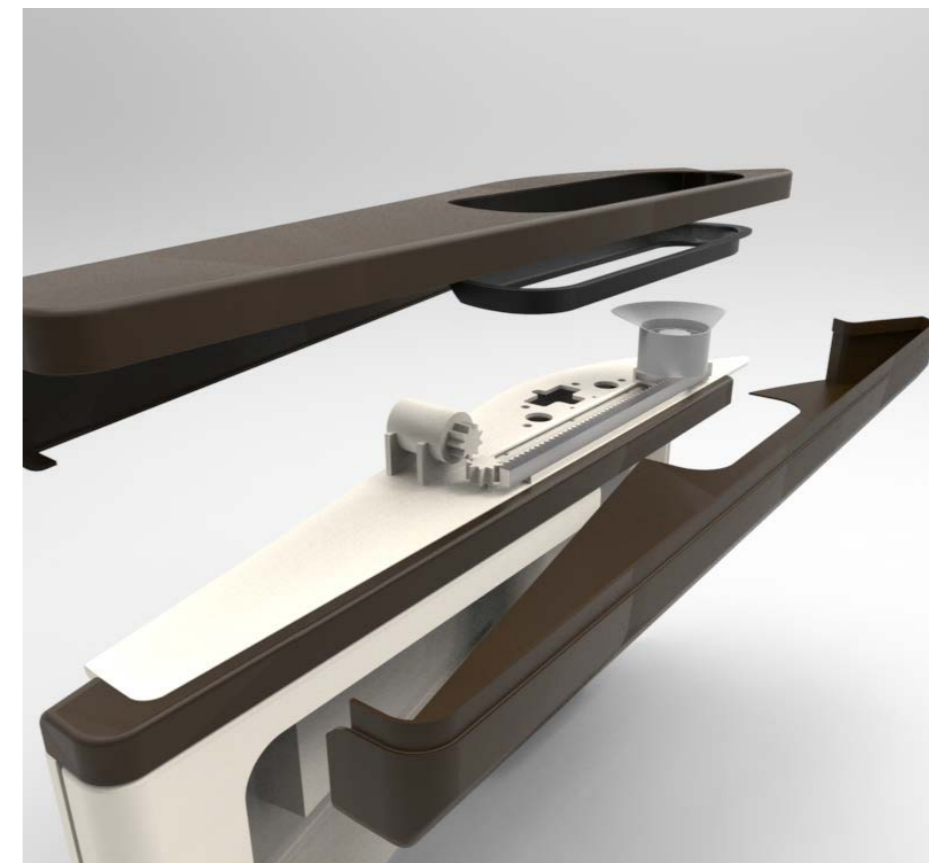


Figure 67: Location mechanism inside the housing



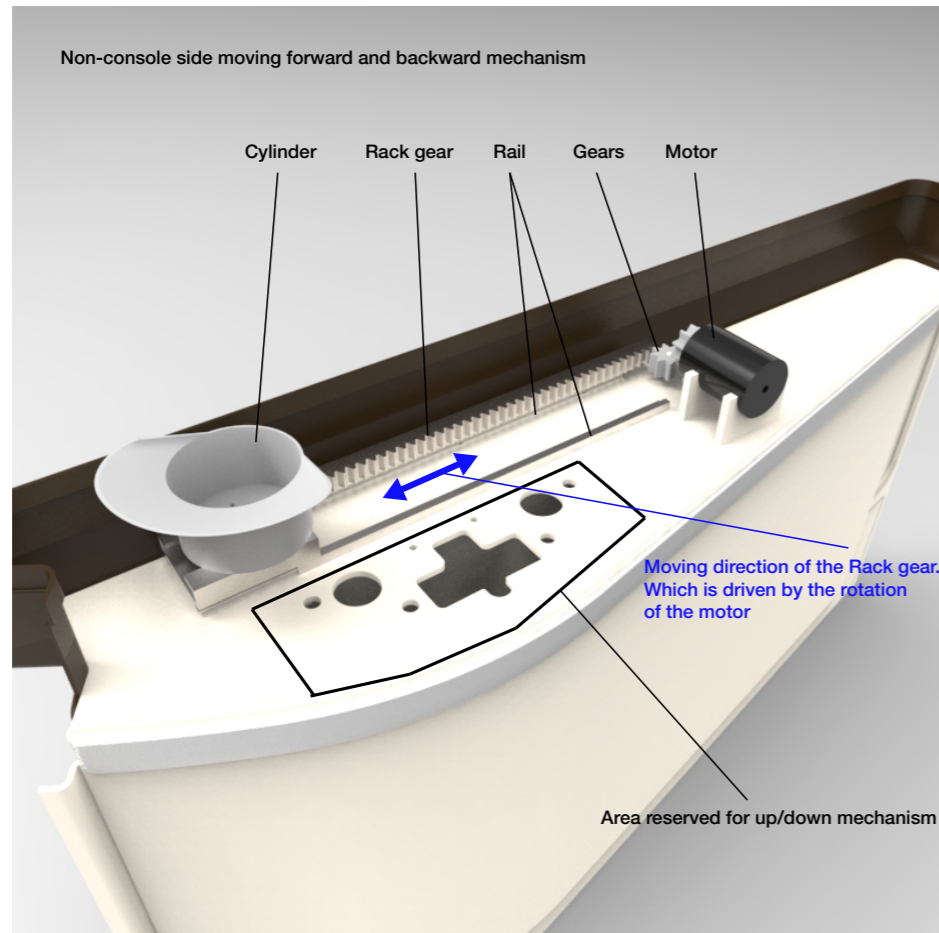


Figure 68: Moving forward mechanism non-console side

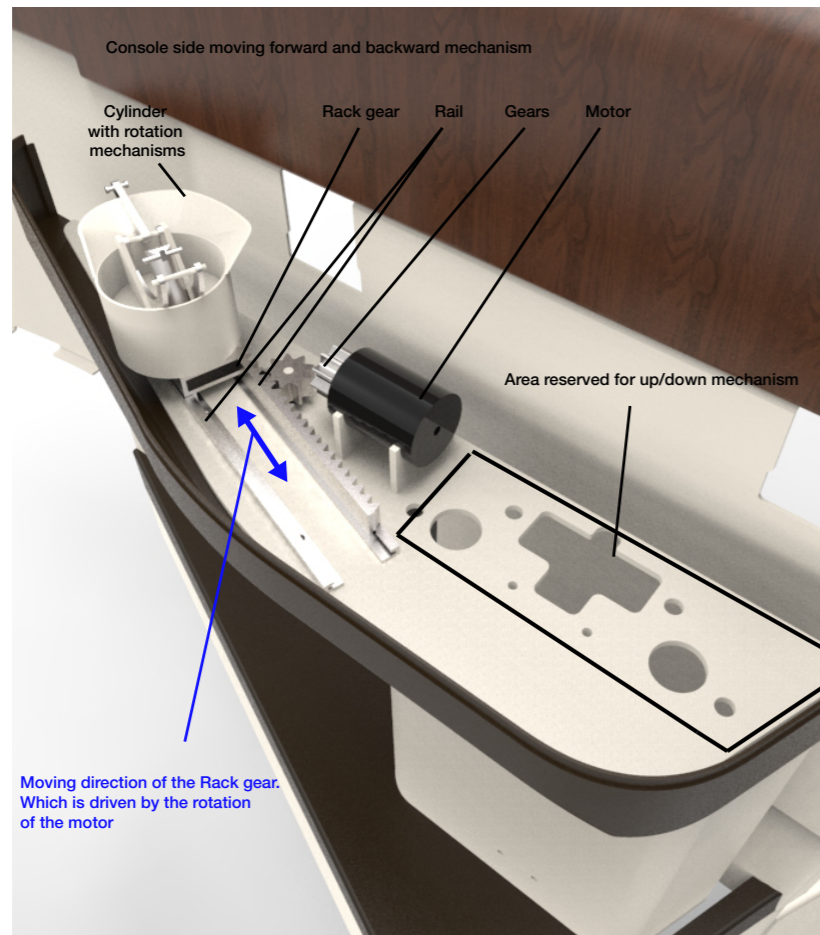


Figure 69: Moving forward mechanism console side

Rotating inwards

Figure 70 shows an exploded view of both rotating mechanisms. The inwards rotating mechanism is again shown in figure 71. This image shows that the mechanism consists of a rubber ball which is captured between an outer ring and an inner ring. The inner ring is fixed to the outer cylinder. The outer ring rotates and. The lid covering this mechanism

is fixed to the outer ring. Which means it rotates together with the outer ring. The ridges at the inside of the outer ring and the outside of the inner ring give resistance to the rubber ball when the outer ring is rotated. This force is given as explained in the chapter 'use' by pushing against the sides of the armrests.

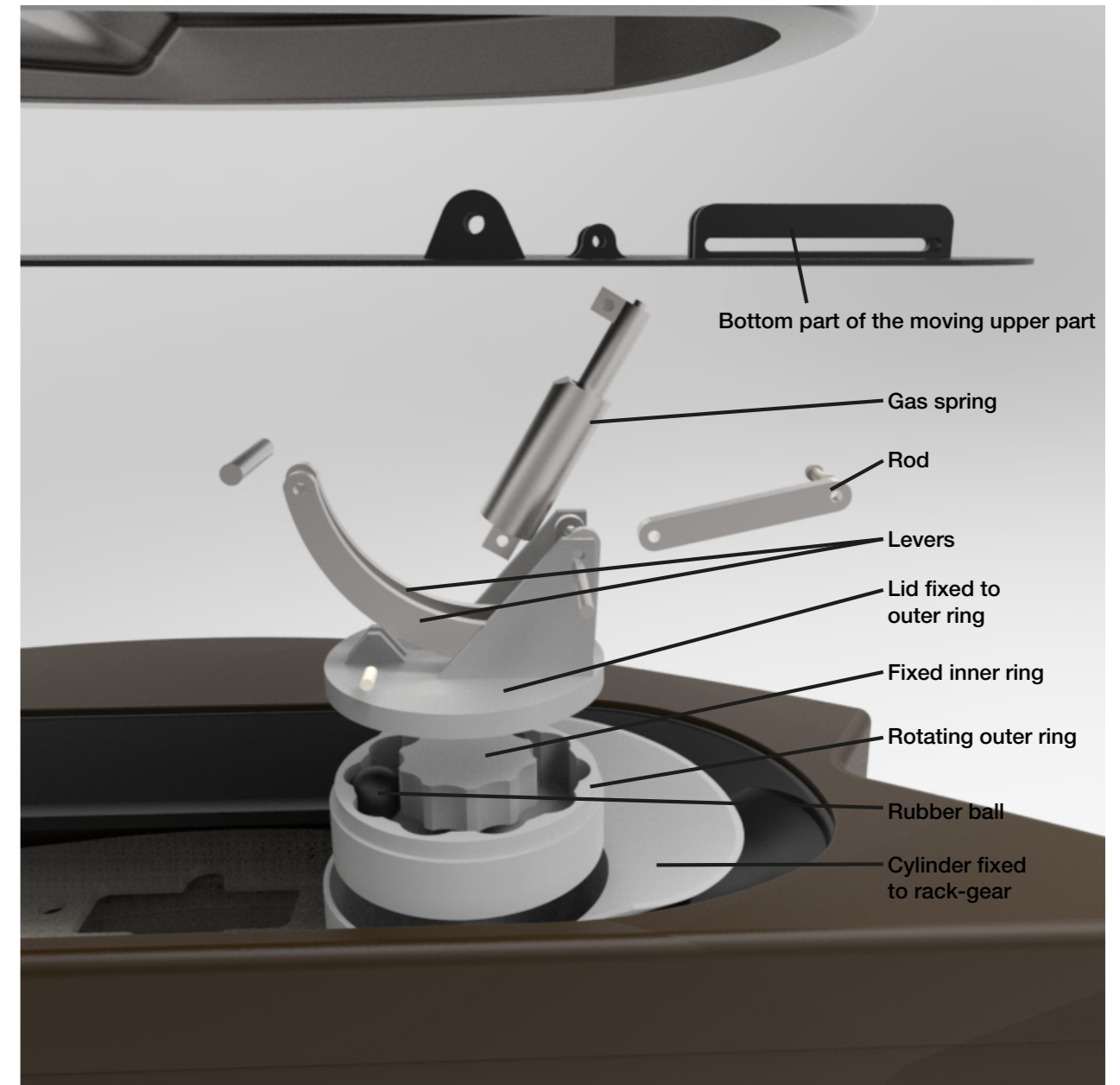


Figure 70: Exploded view inwards rotation mechanism and upwards rotation mechanism.



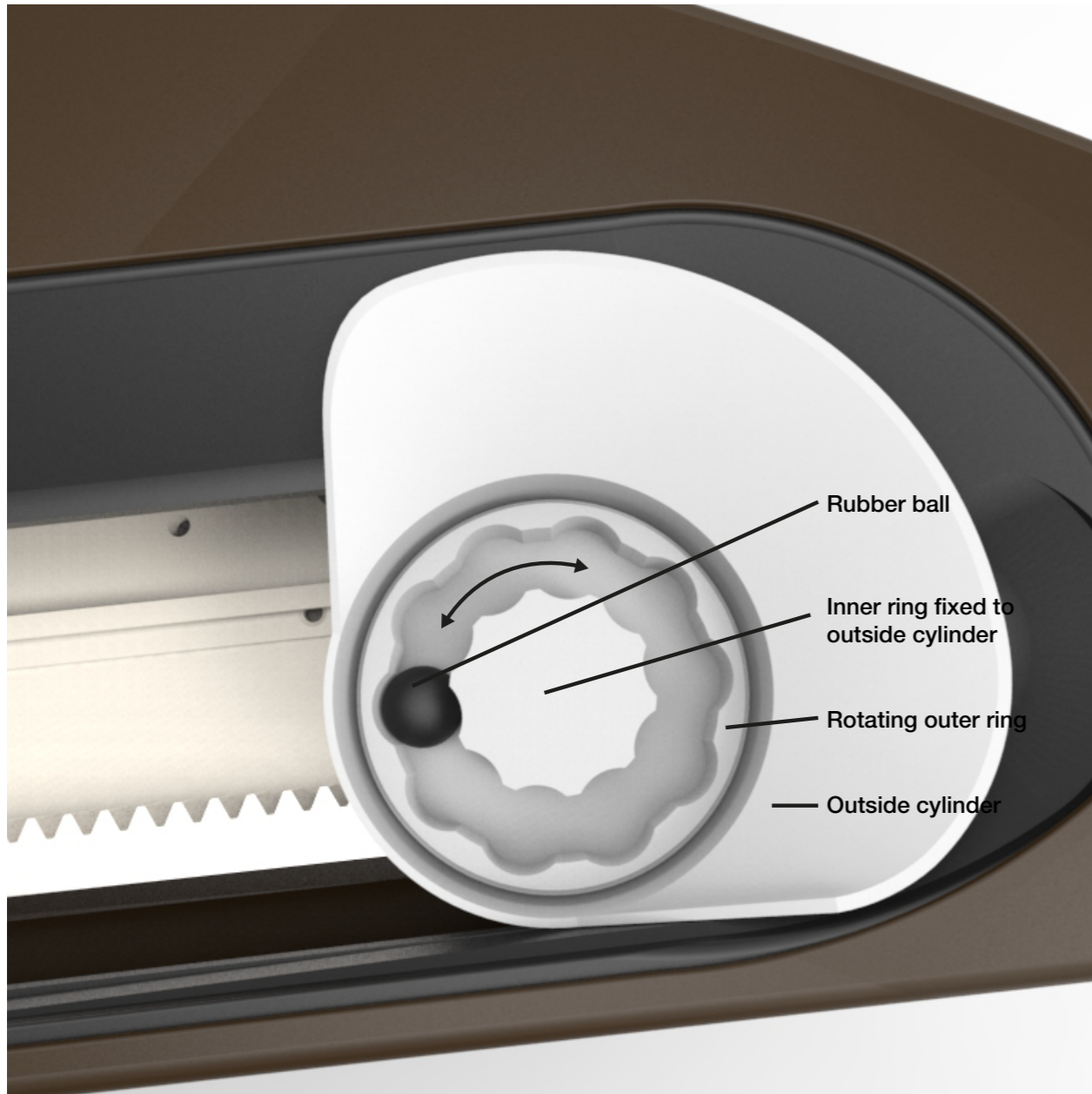


Figure 71: Inwards rotation mechanism

Rotating upwards

The parts of this mechanism are also named in figure 70. This movement is activated by the button on the front of the armrests (also see chapter use). By pushing the button the top of the gas spring is also pushed. A schematic view of this working mechanism is shown in figure 73. When the button on top of the gas spring is pushed the spring releases and pushes up, moving the armrest together with the levers and the rod into an angle. The amount of force the user has to give to pull up the armrest depends on the force the spring can give. Figure 72 shows

the mechanism when the mechanism is situated in an angle.

On the outside the cavities of the working mechanism are closed off by fabric (shown in figure 74).

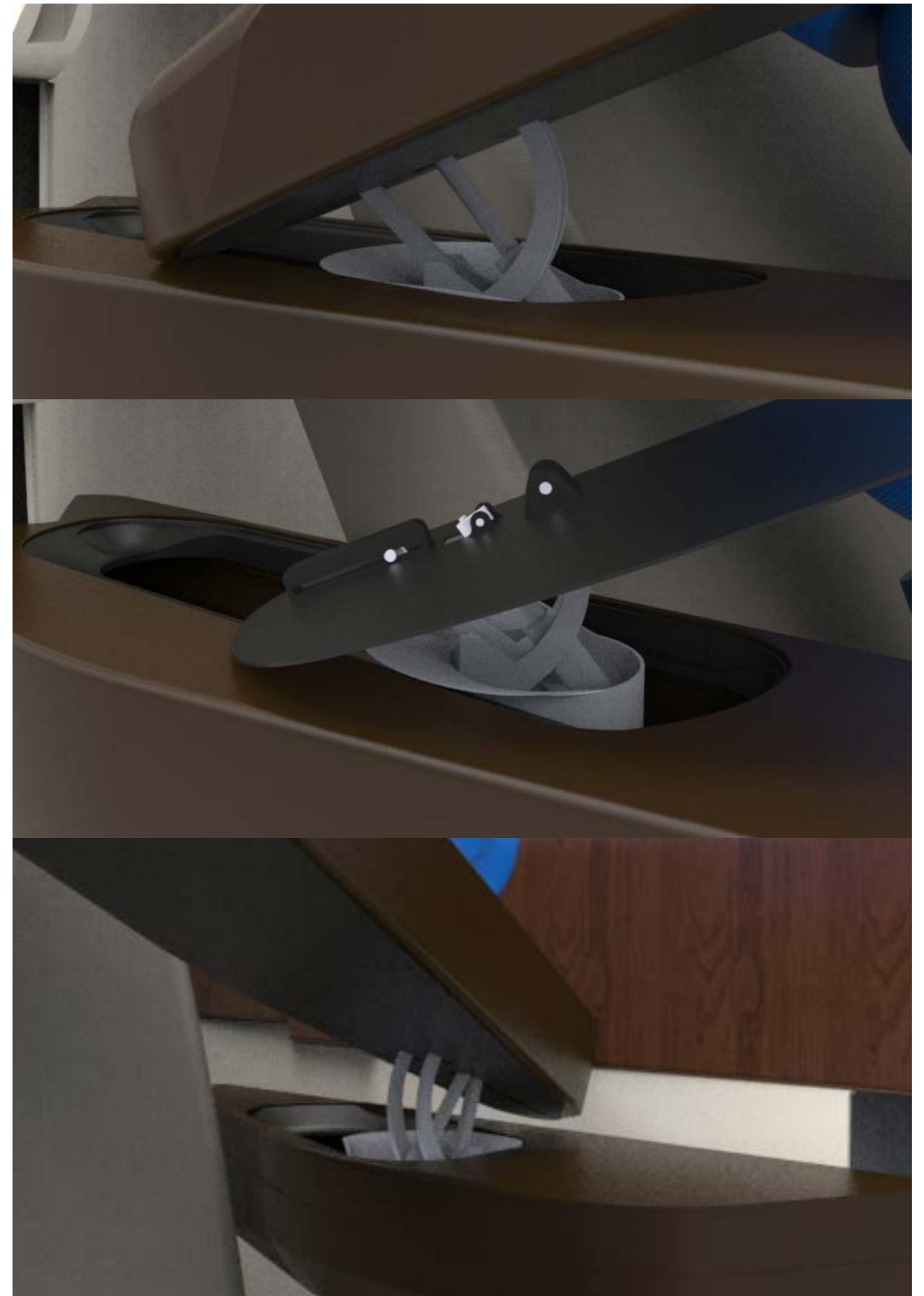
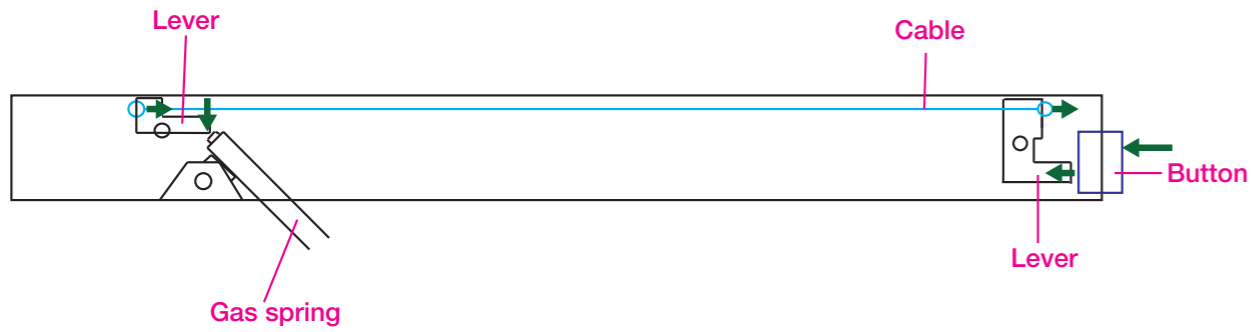


Figure 72: Upwards rotation mechanism shown in an angle.





— = Direction of movement

Figure 73: Schematic explanation of mechanism inside the upper moving part of the armrest

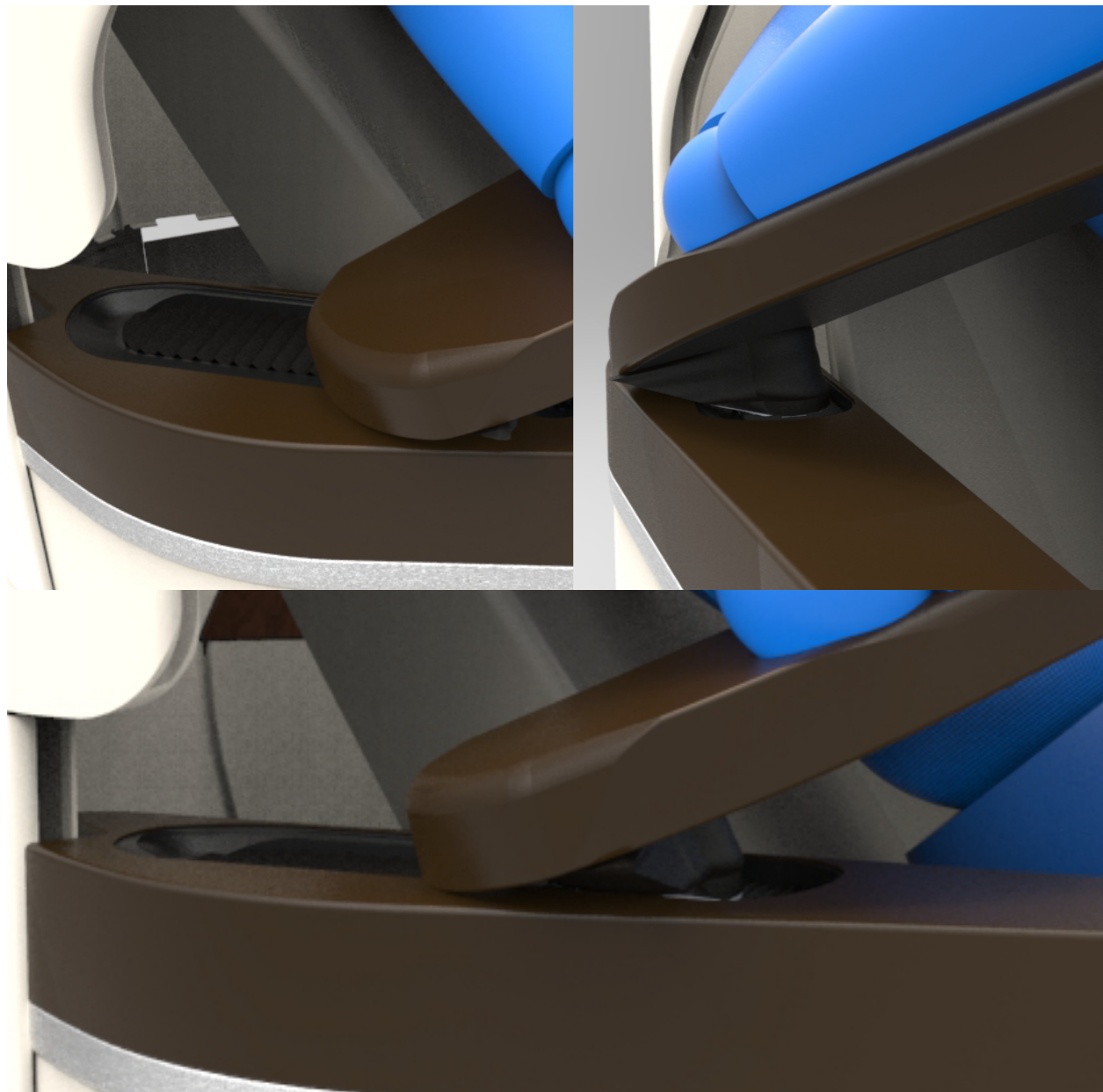


Figure 74: Cavities closed with fabric.

MATERIALS

A proper material selection still has to be made. The material selection is too much connected to mechanical properties the parts need to possess. Within the time of this project there was no possibility to optimize the material by doing load and impact calculations to the model. Furthermore, some materials regarding the comfort and aesthetics were chosen. But are mostly based on the materials RECARO is using at this moment. This means in further development these materials should be checked again to see if there are better materials available (for instance for the foam of the top part). Some of these materials are listed below:

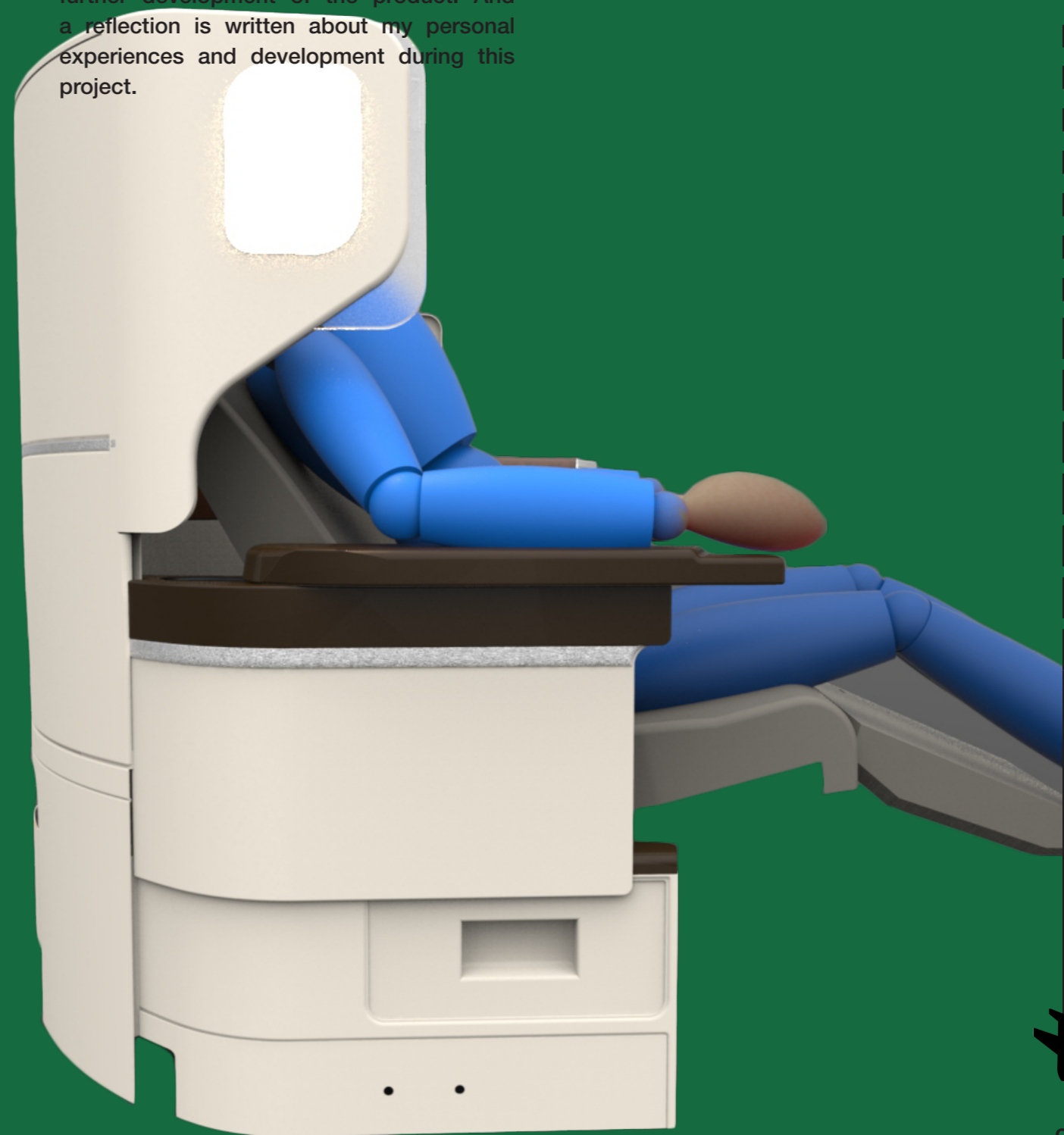
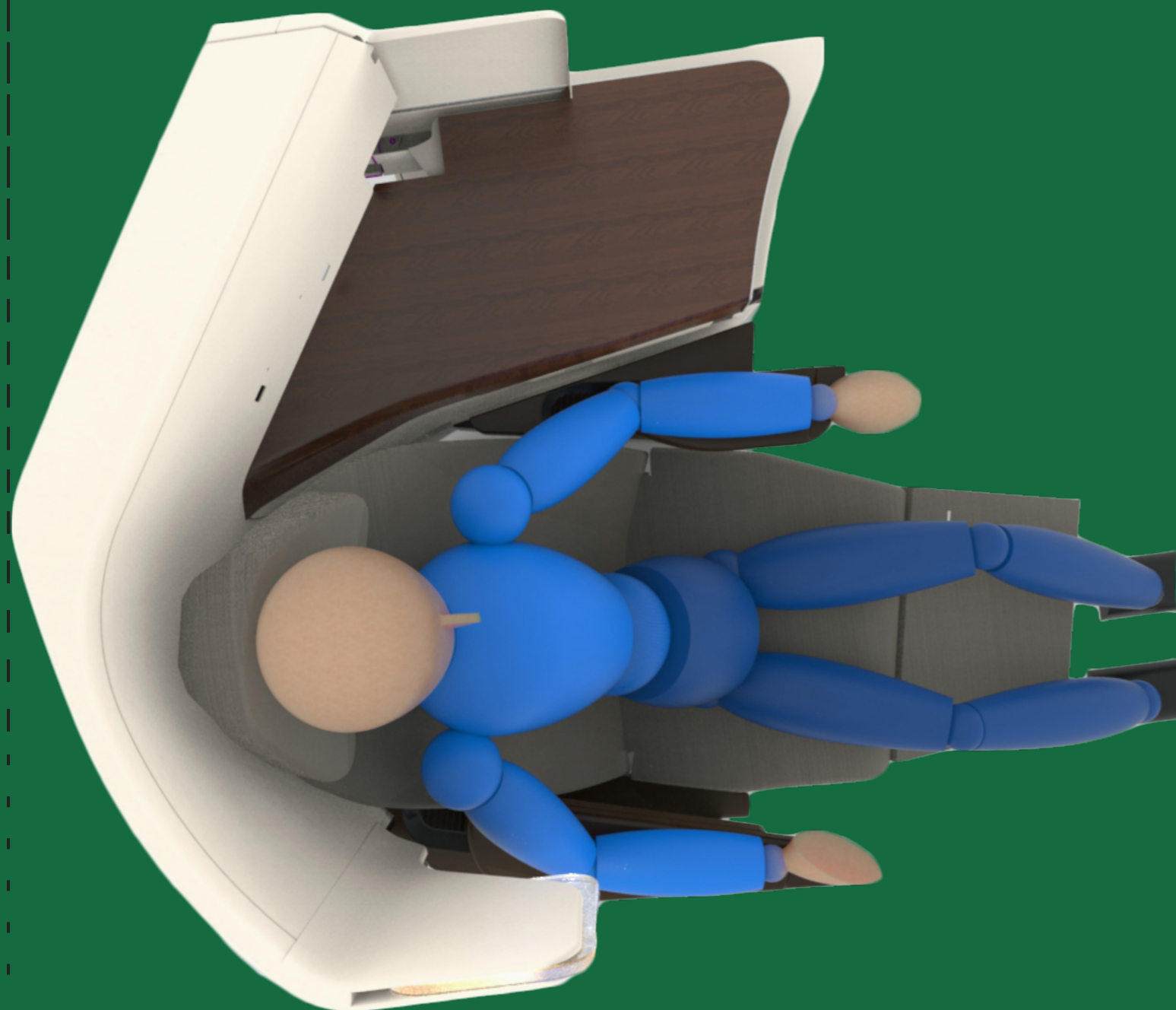
Part	Material	Description
The housing of the mechanism	Inner material is unknown, but the outside is covered with laminated leather	Laminated leather, is leather glued to a thin layer of foam. The laminated leather is glued to the underlying layer.
The top foam part	This part consists of PVDF foam (poly vinylidene fluoride) and is covered with leather.	The leather is glued to the foam. The foam is thermoformed to fit around the underlying part. And it is attached to the underlying part with double sided tape.





VALIDATION

In the following chapter the end product is evaluated. Compared to the assignment and the list of criteria composed during the analysis phase. Based on this evaluation a recommendation to RECARO is given for further development of the product. And a reflection is written about my personal experiences and development during this project.



EVALUATION OF THE DESIGN

In order to evaluate the design the design is reviewed using the assignment and the list of criteria.

The full checklist of the requirements and wishes can be found in appendix 9. Here an explanation behind the rating of the checklist is added. There are a few things that stand out when looking at the list of criteria. Of the most important criteria (as described in chapter 'Solving the problem'): the design is adjustable in as many directions as possible, the design fits within the boundaries of the current RECARO seat, the tablet can be held on eye height with support for the arms, the area where the arm can rest on is made bigger (figure 75) and the usability of the design is taken into account. But there are two of these criterion that are not fully met. The design does give an extra possibility to the passenger to separate themselves from others, but this option is only fully functional when the passenger is going to sleep and when the armrest is fully up. During the last visit to RECARO it was found out that most passengers like to sleep with the armrest fully down to have the most space to move around. Based on this information the conclusion has to be drawn that the privacy panel as designed in this project is not optimal and a better solution should be sought. Furthermore the criteria of functional symmetry has not fully been met. The adjustability options are the same, only the reach of the console side armrest is a little bit smaller. The rotation inside for the upper part of the armrest makes it possible to rotate the console side armrest parallel to the non-console side armrest. But the console side armrest is still a lot shorter than the other side. This was also noticed during

the last user test. The conclusion is that within this project the symmetry has largely been improved. Full functional symmetry has not been reached yet but can be a next step in development.

Besides the most important criteria, all technical requirements regarding materials, force loads, etc. cannot be reviewed yet since a proper material selection has not been done. The same goes for the force simulations. Therefore the reviewing of these criteria is something that has to be done in further development after the product has been worked out further.

Looking back at the assignment it can be said that the product is successful in improving the comfort of the armrests. Although not yet proven by tests the assumption is made that a larger area available for the arm to lean on leads to more comfort. In this case the comfort of the arms is improved in the relax position. Next to this, as described in the chapter 'user test of the chosen design' the comfort for reading is improved. All participants think the new design is more comfortable for reading compared to the current design. Thus the activities watching IFE and reading are better facilitated. The comfort of the armrest is improved and with that the comfort of the entire seat.

All together the assignment is partially met. A better privacy solution still has to be found. Furthermore the design is far from finished. Recommendations to RECARO how they can improve the design to further fit the criteria and to optimize the design are described in the chapter 'Recommendations'.

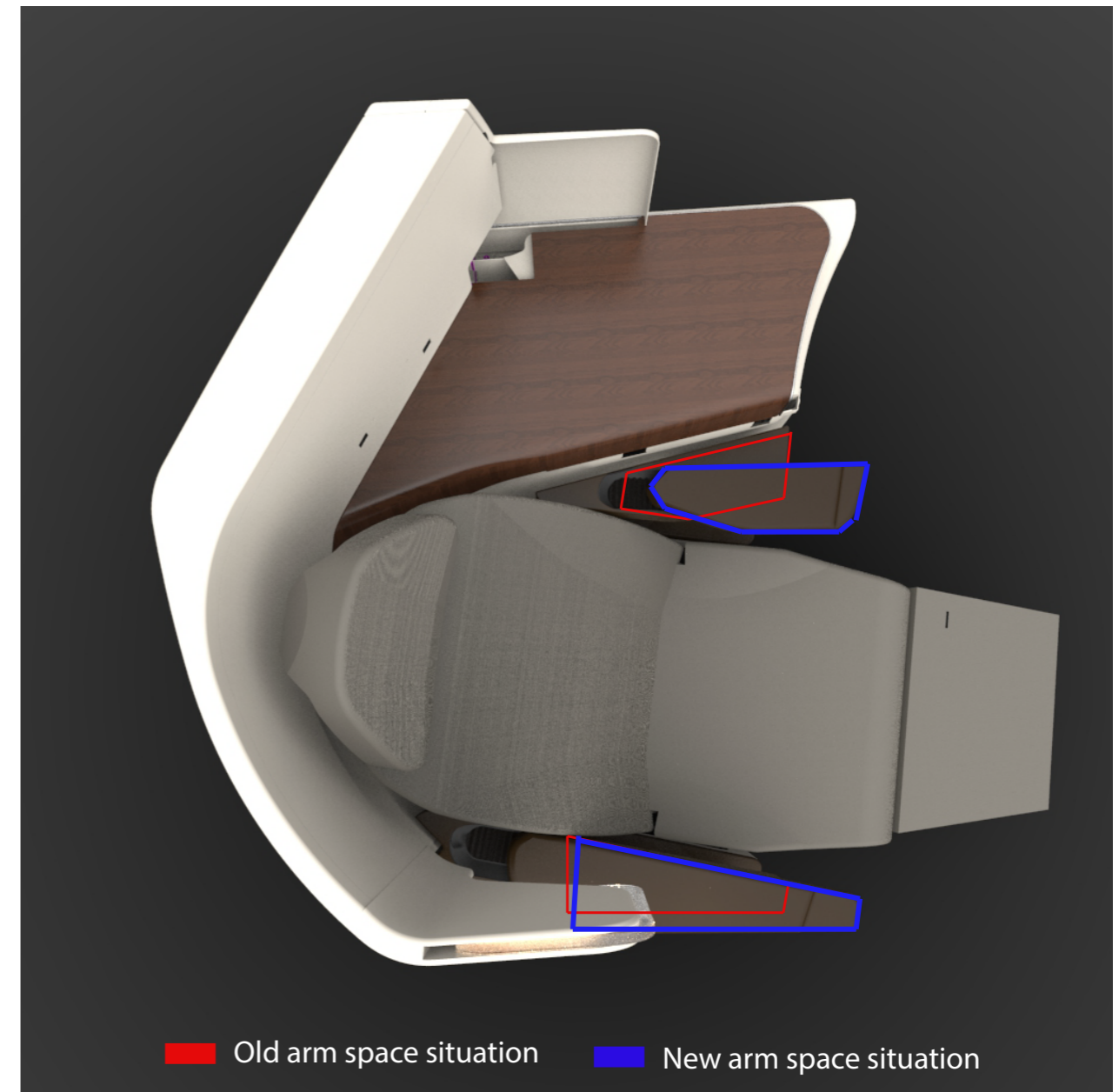


Figure 75: Comparison new and old design in the relax position



RECOMMENDATIONS

In conclusion of this report there are a few recommendations that can be given to RECARO.

- As earlier described in the chapter 'Solving the problem' The analysis phase gave a beginning insight into the location of the arms on the armrest. The participants of the research would only lean with their weight on the back of the armrest. And they would lean on the armrest with a high force only on their elbows or spread forces over their under arms. The rest of the armrest was used but for other things such as resting hands on the armrest, which requires different specifications of the armrest (for instance if the armrest was only meant to make sure the hands will not fall of the armrests, a different foam or structure of material could be used than for the elbow area). Optimizing the armrest according to these positions and complementing this with new data from pressure maps could be an interesting field to explore. The chapter 'Solving the problem' already shows a few ideas that were thought of. But this could be further extended also by connecting the different positions of the arms to different sitting positions.
- In the evaluation it was described that during the last RECARO visit the information came up, that most people sleep with the armrests fully down. This implicates that the design solution found for the privacy screen will not work in this situation. Due to the late discovery of this information working out whole new idea was not possible. My recommendation to RECARO will be to look further for other privacy options maybe only focussing on

improving privacy for sleeping in the full flat position. A possibility may already be to use the rolling screen suggested in concept 1. Figure 76 and 77 shows a visualization with the idea that it may be possible to close the screen in one of these ways. In width this may not give the same amount of privacy as the earlier suggestion, but the gap between the P-shape (already existing privacy screen) and the stowed away armrest can be closed. Furthermore using a curtain (flexible material) instead of a hard panel will make the experience more comfortable (the flexible moves with you when you turn around while sleeping instead of bumping into a hard surface). Making it possible to enlarge the privacy in sleeping position without compromising the moving space.

- As described in the evaluation the length of the console side armrest at this moment is not symmetrical to the non-console side armrest. In the reading position this is considered less comfortable. If the comfort in the reading position needs to be further optimized, this could be considered in further development. Some ideas may be to include a part that can slide out from the console side armrest to enlarge the armrest or find a way to connect the two armrests to each other in the middle to bridge the gap between the two armrests.
- We know now that moving forward is a good way of enlarging the area were the arms can rest on. In further development first exploring more possibilities of reaching this goal could be explored. During this project only two concepts were worked out.

- In the analysis phase different sitting positions were researched and studied. Also the relevance of changing sitting positions often was described. Improving difference in sitting positions can be an area that can be elaborate on also with a bigger scope than only the armrests. Furthermore the opportunity to facilitate for the legs in certain sitting positions can also be extended as an option.
- More focused on the final design, the recommendation is to further explore and evaluate the possibilities of supporting the tablet, optimize the location of the elbow support and test this aspect of the design (does this give enough support and grip to the elbows?).

- In further development the current solution for solving the conflict between usability and adjustability needs to be tested if it meets the requirements. If this is not the case the ideas should be further broadened, since this is a whole field that was minimally explored during this project.
- Finally it is recommended to RECARO to first work out the technical reachability of the project before continuing further development. Possibly checking the reachability for multiple scenarios to see which aspects of the project are really feasible. Considering the technical aspect of this design is worked out minimally at this moment.

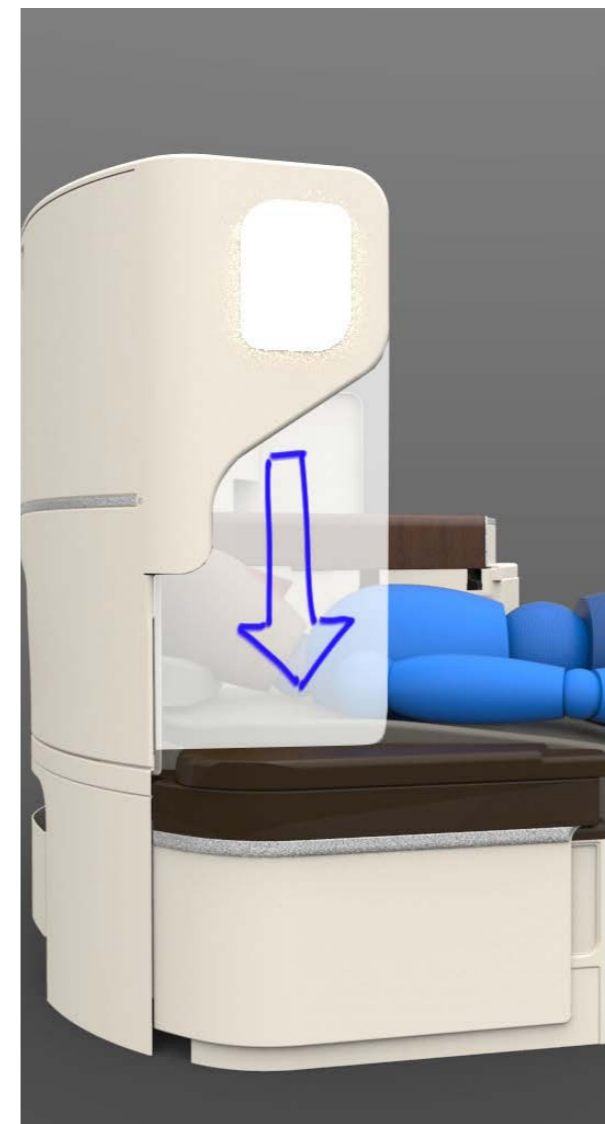


Figure 76: Privacy screen possibility

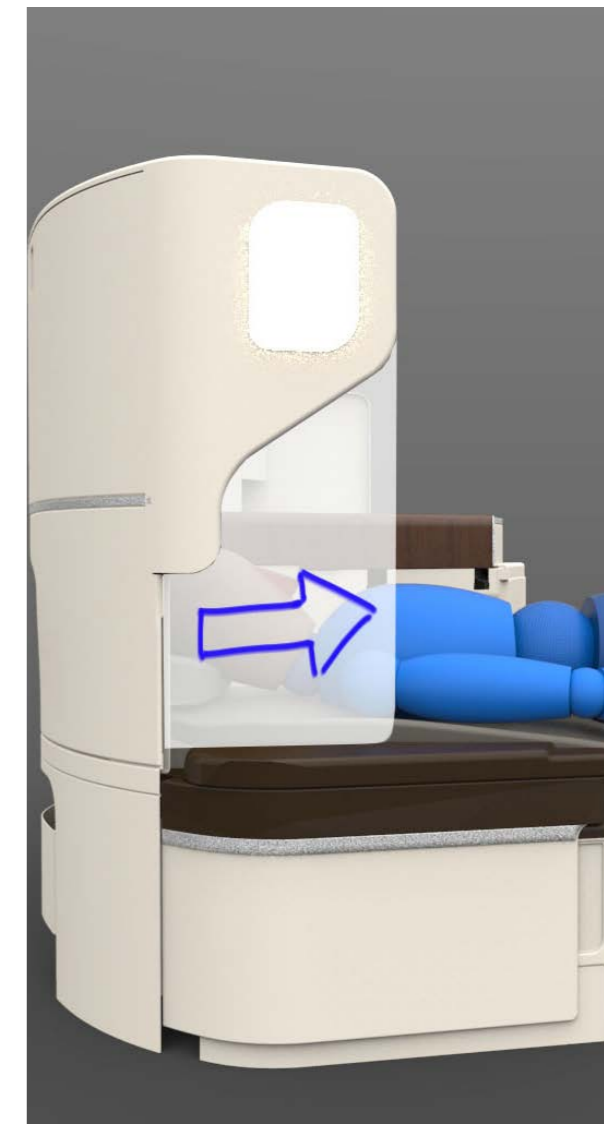


Figure 77: Privacy screen possibility





REFLECTION ON THE PROJECT

Looking back at this project and its process I can say that I look back with a positive feeling. At the beginning of the project in my first assignment suggestion I said the goal was to create something for RECARO that they may continue with or something that they can use for future reference. At this moment I do not know if the end result is something RECARO is going to continue with, but I do believe that some of my insights are interesting to them. Even if it would only be the fact that I tried something and they won't have to try it again. I also said in this same document that a personal goal was to deliver a working model which can be tested and evaluated for further recommendations. At this moment I do not have a working model, but I did make a model for the final user test, which already gave a lot of insights. Therefore this goal wasn't fully lost. Furthermore plan is to make a new model the coming two weeks that will even better represent the design. But also won't be a fully working model considering the time.

As described in the evaluation there are a few parts that I couldn't finish or things that did not work out. For instance the privacy panel that does not work sufficiently or the fact that most of the technical criteria couldn't be checked. Reflecting on these things, there were a couple of things that I realized and some things that I would do different next time.

One of the things that I struggled with was finding the right amount of focus. During the analysis phase I wanted to widen my perspective in order see which aspects of the armrest should be improved and to find opportunities. I think this was a good thing

to do. At the end of the analysis phase I continued into the ideation phase at first without having a clear focus. This was slow and gave me a lot of difficulties in knowing what I exactly had to design. In the future this could be avoided by forcing myself to make a clear goal at the end of the analysis phase. This could already be done by using an evaluation tool (maybe a SWOT) to find out which aspects give the best opportunities. Within the project the start of the ideation phase approximately coincided with the moment RECARO came in the picture officially. Having a good talk with them about their expectations and where they would see opportunities resulting from my analysis before entering the ideation phase would have helped. I eventually had this talk but this was already a few weeks into the ideation phase and at this point a step backwards was made, but not far enough back to start at the end of the analysis phase.

Another point of conflict was experienced between the delivering of a finished product (fully defined, producible, mechanically working including cost price, materials selection etc.) which I felt would be important for my master and for RECARO, or delivering a product completely focused on comfort and ergonomics but for which you are not sure if it would work. This is not a black and white situation, but finding the right ratio is hard. Looking back I should have focussed more on ergonomics and comfort in the last stage, enabling me to focus more on testing the product and coming up with iterations in this field and enabling me to evaluate more on earlier insights from the analysis, such as the anthropometrics data. This focus might have been more beneficial. In this case you

choose to end up with a concept instead of an end product. At this moment I have the feeling that my end result is something in between a concept and an end product. This conflict that I felt made me realize that in a company a whole team is working on a product. Within RECARO for five years whole teams were working on developing their current seat. Within a graduation assignment only a certain amount of aspects can be worked out and are possible to reach.

Looking back at the project, I now realize that the fact that the armrest moves forward together with the seat and in this way creating extra space for the arms is maybe one of the most interesting improvements. Only focussing on this aspect within the physical comfort (and not also focussing on improving reading for instance) could have brought me to different designs. I believe that within the focus that I had during the concept choice the final choice was made correct. But it is interesting to look back in this way and realizing what the impact is of these decisions. And realizing this I also noticed another opportunity for RECARO. Going back to search for ways of how to only make the armrest move together with the seat, could lead to interesting designs.

Considering the privacy divider the same mistake was made as for the physical comfort in the beginning. Where the focus for the physical comfort was eventually better defined during the ideation phase this did not really happen for the privacy aspect of the assignment. A solution was sought to improve the privacy in all positions of the seat. Which resulted in a solution only working in the full flat position. Of course it is really nice if this would work out, but the question really is if it was really necessary to focus on all positions. The design challenge became very big having to think of letting the privacy aspect work in all positions. If I did not think about the movement of the armrest for reading I would not have chosen this

design. I think the chance of success would have been bigger. At the end of the project I think I can say that I should have made the focus and together with RECARO discuss to which position they would give a preference to have more privacy.

During this project, I decided to graduate in Delft while I would work together with RECARO. Since RECARO is situated in Germany and transfer of information was difficult, the project sometimes was delayed by this. Within the time this was compensated by two weeks where I worked at RECARO in Germany. I am really happy that I did this. Internally situated in the company a lot of things become more clear quickly. These two weeks were helpful to give a boost to my project. During this time it was not possible for me to graduate full time in Germany, but looking back I think investing in going for a longer period of time (a month for instance) in the beginning of the project would have been very beneficial. The two weeks I spend there were the bare minimum.

Finally I want to mention that personally it would help me if I would start earlier on in the concept phase to think about the concept choice. This way undefined things can be found out earlier. The concept choice and the concept development becomes a parallel process. What I now noticed during the concept phase was that I worked out the concepts until a certain point until I felt a choice had to be made. But this choice could not be made yet because not all information needed for this choice was available. This made the process slow down and unnecessarily difficult.





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APPENDIX

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APPENDIX 1: FIRST IDEATION WAVE

The first wave of ideation is characterized by the start of formulating ideas and solutions for the problems that were selected in the analysis phase. The goal was to have some ideas to show RECARO during a one week visit. During the transition between the analysis phase and ideation phase the aspects that the final design should have were selected. The following criteria were selected as most important and were used as a starting point.

- The design of the armrest must take into account the factors support, space, material, position, aesthetics and shape.
- The design must give the passengers the opportunity to separate themselves from the other passengers and the surroundings. (And this must be better than the current seat)
- The armrest must not limit the passengers movements in any way during their activities.
- The arm supports must be symmetrical for the left and right arm.
- The design should try to integrate as many functions as possible to save and create space. (combination of light weight, comfortable, fitting in the space, giving privacy).
- The design should be adjustable in as many directions as possible. (inwards/ outwards, rotating inwards/outwards, height etc.) And this must be at least one more direction than in the current seat.

For the aspects adjustability, space divider/ partitioning, forming to arm shape, table integration and saving space a brainstorm was performed and they were then put together in a morphologic chart (see figure

1 and 2). From this morphological chart five idea directions were selected. These are shown in figure 3 and 4.



Figure 3: idea directions

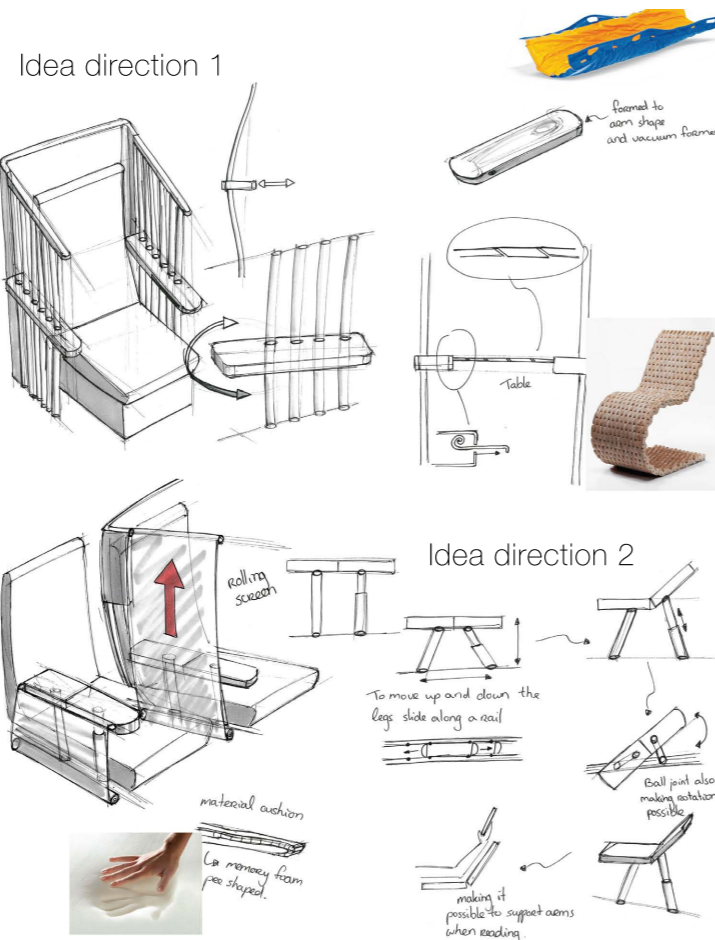
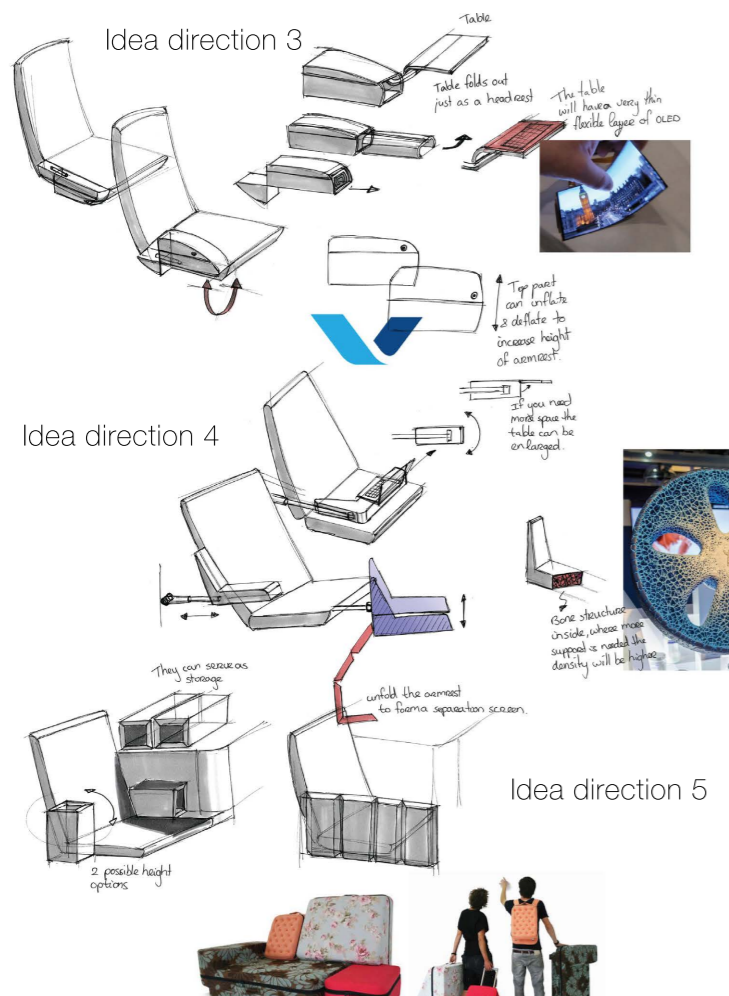


Figure 4: idea directions



When the idea directions were worked out, it became clear that from the functions that were selected in the beginning of the ideation phase a focus had to be made. What criteria are the most important and which functions does the design really need to have?

would require a whole new seat design all together with the armrest.

Some of the above named criteria are too broad. For instance 'the design should integrate as many functions as possible' This would mean the design should facilitate the activities: sleeping, watching IFE, reading, working, eating/drinking and maybe even more. This is too much to focus on. Therefore the proposal to RECARO was done to only focus on watching IFE and reading, since sleeping only requires space and privacy but no specific functions from the armrest, eating and drinking would require a new study to find out what this activity exactly requires and working would require an integrated table into the armrest which seems not necessary since the seat already has a functioning table. This functioning table could use some improvements but if it is not integrated into the armrest it is not within the scope of this assignment.

The following three criteria were proposed as suggestions to focus on during the meeting with RECARO:

- The design must give the passengers the opportunity to separate themselves from the other passengers and the surroundings. (This must be better than the current seat.)
- The arm supports must be symmetrical for the left and right arm.
- The design should be adjustable in as many directions as possible. (inwards/outwards, rotating inwards/outwards, height etc.) And this must be at least one more direction than in the current seat.

Furthermore the decision was made to ask RECARO for defining the scope. Since some of the ideas would be possible within the current seat of RECARO and other ideas



APPENDIX 2: RECARO VISIT

During the ideation phase a visit to RECARO was arranged. This visit gave the opportunity to gather information regarding the assignment. The goals of this week were:

- Together with RECARO defining a focus within the assignment.
- Gather specific information regarding their current Business class seat.
- Speak to the designers of the current business class seat to see what design choices they made and gather their knowledge.
- Organize a brainstorm session together with their designers aimed at solving the problem.

The visit to RECARO was very fruitful. The opportunity was given to look at their current seat and try it out. The assignment was discussed with one of their engineers and one of their designers which worked on their current seat from the beginning of the development. This gave many insights. Eventually the week was also concluded with a small brainstorm. A collection of the ideas thought of during this brainstorm can be found in figure 1.

Some of the main findings of the visit where that RECARO prefers the armrest to fit within their current business class seat. This considering they have just brought this design to market and the coming few years they will not work on a fully different design yet. The criteria for symmetry was changed to functional symmetry. Full symmetry in the design will be hard to reach since the shape will always differ in the current setting. Also the conclusion was made to only focus a privacy option on the non-console side armrest. Adding a privacy option to the other

side would either take away living space of the passenger or it would not be part of the armrest. Furthermore when trying out the current seat in Relax position, it was experienced that the space where you could leave your arms was very small (mostly on the non-console side)(console side armrest and non-console side armrest, see figure 1). Even more than in the TTL position. So the conclusion was made that this was something that had to be focussed on. Considering this and the earlier reasoning to choose to focus on the activities of reading and watching IFE (and that these are also mostly done in the relax position), the assignment was changed to focus on improving the comfort or watching IFE and reading both in the relax position. All criteria added after the visit to RECARO are listed in Figure 2. The most important criteria after the visit where defined as:

- The design must give the passengers the opportunity to separate themselves from the other passengers and the surroundings.
- The armrest must not limit the passengers movements in any way during their activities.
- The arm supports must be functionally symmetrical for the left and right arm. (in placing arms parallel, in space provided to the arms and in the same adjustability options to both sides)
- The design should be adjustable in as many directions as possible. (inwards/ outwards, rotating inwards/outwards, height etc.)
- The design of the armrest should fit within the boundaries of the current RECARO seat CL6710.
- The design must find a solution for the tension between the tablet on eye height

and supporting the arms.

- The design should give enough space to the arms to rest on.
- The functioning and use of the design must be clear to the passengers. (usability)



Figure 1: explanation console side and non-console side.





Requirements	Wishes
The arm supports must be functionally symmetrical for the left and right arm. (in placing arms parallel, in space provided to the arms and in the same adjustability options to both sides)	The privacy function should be a part of the armrest and shouldn't be a separate solution.
The design of the armrest must fit within the boundaries of the current RECARO seat CL6710.	the design should consist of at least as possible parts (production costs reasons).
The material used for the design must be easy to clean. (either easily removable covers which can be washed or a material that can be cleaned with a cloth)	The design should give enough space to the arms to rest on.
There must be no contact between the cabin and the seat other than the connection of the seat to the cabin underneath the seat. (RECARO only delivers the seat and has no influence on anything else present in the cabin)	The design should take the visual integrity of the seat into account. (Currently the seat has clear visual lines in the design, these lines are made by a change in colour and material.)
The armrest must be able to survive 25.000 cycles of use (adjustments of moving parts).	
The design must be able to be used for a duration of 37.000 FH (Flight Hours).	
The design must not have cavities that are hard to reach for crew before and after a flight. If cavities (in the form of storage maybe) is unavoidable the cavities should be easy accessible and easy to clean with a cloth.	
One armrest must be producible for 700 euros. (Their current in height adjustable armrest costs around 650 euros and their non-adjustable armrest costs around 200 euros.)	
The design must be producible for a batch size of 1000 a year.	
The total weight of the design (one side armrest) must not exceed the weight of 4 kg. (the current retractable armrests weighs 3,776 kg including mechanism, plastic shield and cover)	
The walls of the "cubicle" around the seat cannot be higher than 54".	
The armrests may not surpass the height of 25" from the floor.	
The armrest on the aisle side must be able to go fully down or it should be able to be taken out entirely. (this is to give the possibility to people in wheel chairs to get into the seat.)	
The usability of the armrest should not suffer from too many adjustability options. A balance between usability and adjustability should be found.	

Figure 2: Criteria added to the list of criteria after the visit to RECARO.



Figure 3: Selection of RECARO brainstorm ideas.



APPENDIX 3: SECOND IDEATION WAVE

Following the visit to RECARO the new criteria were used to generate ideas. This was accomplished by organizing a brainstorm session together with a few other students. Figure 1 gives an impression on the ideas and the setting. These ideas were combined with the ideas generated during the brainstorm at RECARO and ideas from the first ideation wave. Together two concept directions were formed. Both covering the aspects adjustability, privacy, increasing surface area and improving the top layer/cushioning. The first direction (shown in figure 2) is fixed to the backrest and in this way moves forward when the seat moves to the relax position. The second direction (shown in figure 3) has more similarities with the current armrest. It is fixed to the shell in the same way and can move up and down in the same way, but it has a top layer which moves forward automatically when the seat is moved to the relax position.

When moving towards the conceptualization phase there were still a few things unknown. Mostly the privacy options for both of the concept directions were not defined yet, this was done during conceptualization because this needed a bit more ideation and is very specific to the way the armrest moves, since the privacy option needs to be attached to the armrest. Big considerations for the privacy option was the fact that the width of the seat could not be more than in the current seat (also see requirement 48 from the list of criteria). This would mean in many cases that improving the privacy option above 25" would probably take away moving space created for the arm rested on the armrest. The way this is eventually solved is shown in the conceptualization phase.

Also during this phase the decision was made to look at the improving of the top layer/cushioning as a separate part. All ideas that were generated for the top layer could be applied to both concept directions. The three top layer options are visualized in figure 4. The ideas for the top layer need more research and working out than is possible within this project. The top layer would need to fulfil the requirements shown in figure 5. Determining the best top layer would require a new study regarding the distribution of loads over the armrest and where the support of the armrest would most be needed. Furthermore testing which top layer would be perceived as best would ask another study, which is not reachable within the time of this project. This is why it was decided to only give this opportunity as a recommendation for further research to RECARO.



Figure 1: Impression of university brainstorm.

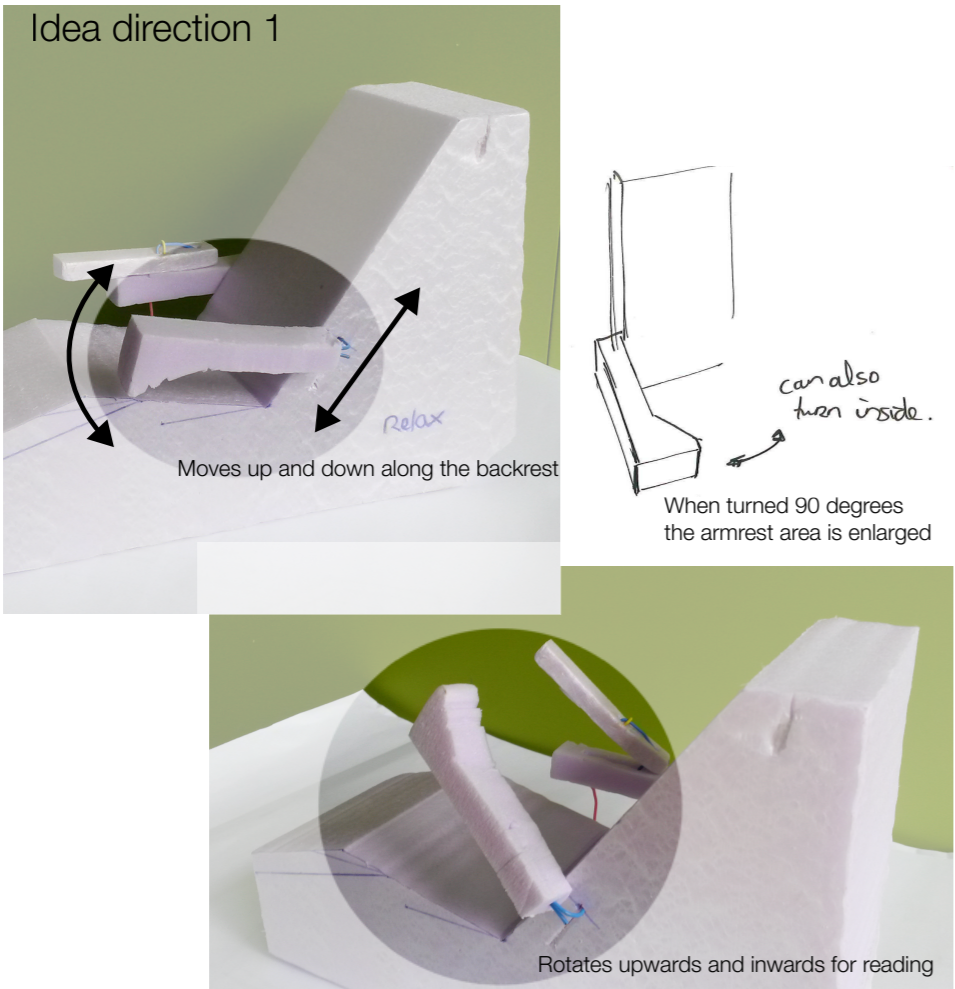
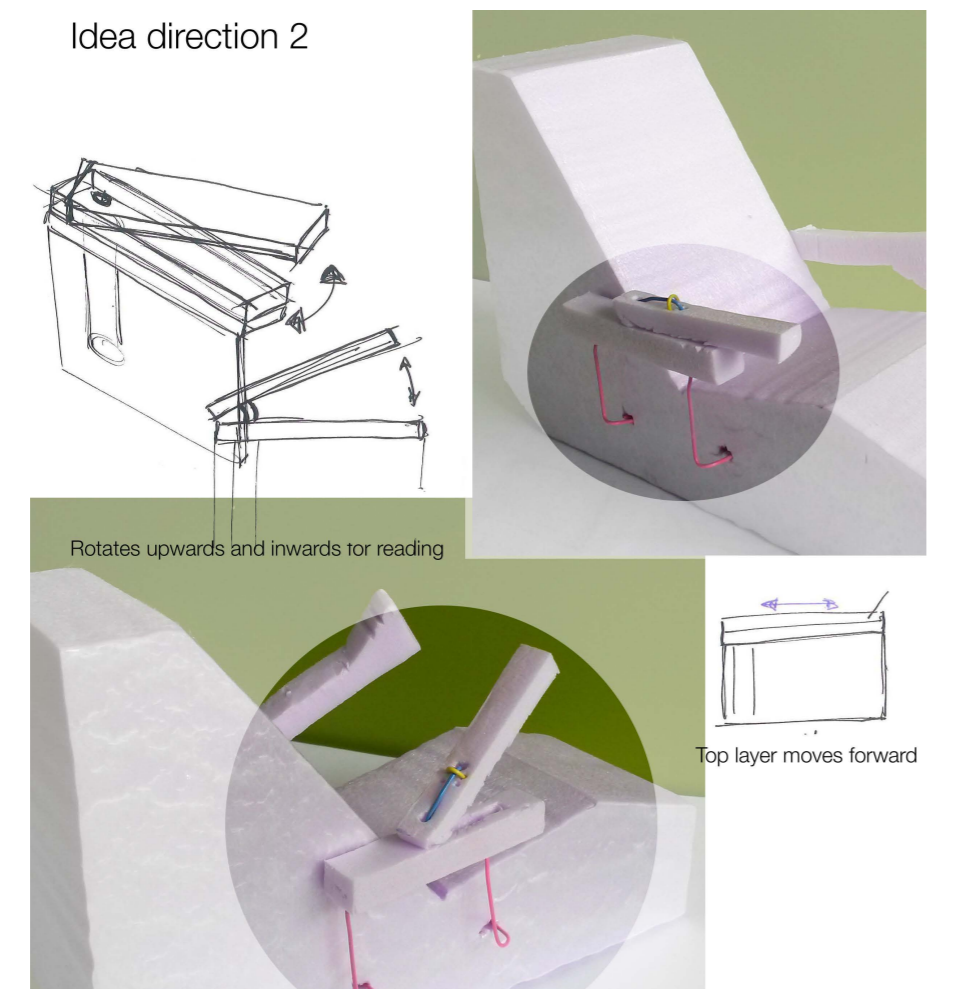


Figure 2



118 Figure 3

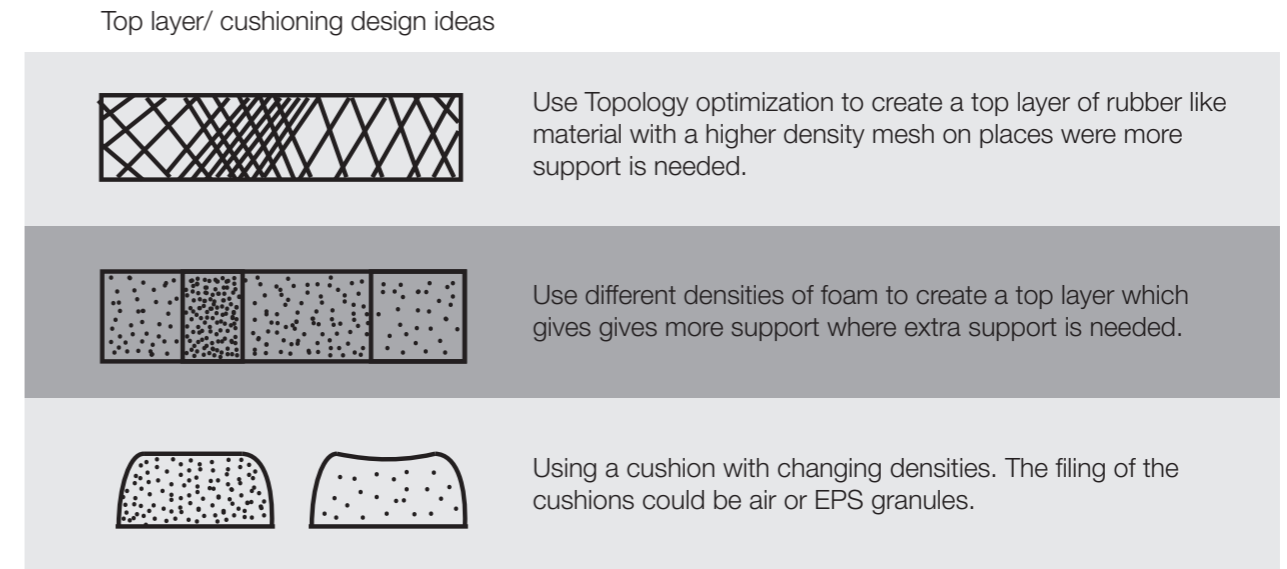


Figure 4

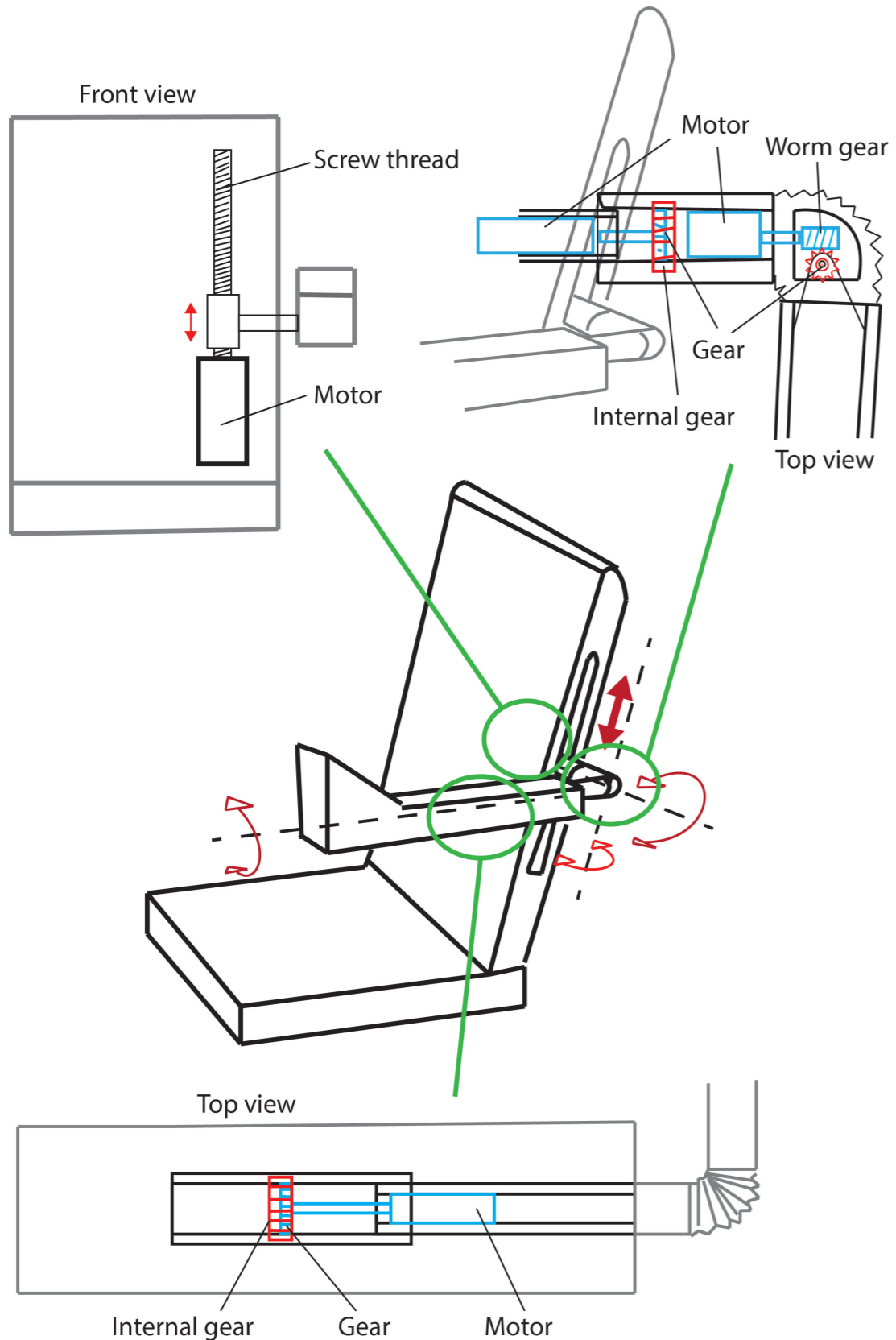
- The armrest should take into consideration the areas where the elbows and underarms are placed based on the arm positions research**
- The surface of the armrest must be more ergonomic than the current seat (referring to softness of the surface and shape).**
- The armrest should fit the human contour of the arms.**
- The material of the armrest should feel soft and comfortable and give sufficient support at the same time.**
- The material of the armrest must give sufficient grip and therefore support to the passengers arms. The material must avoid slipping away. To be determined after concept selection**

Figure 5

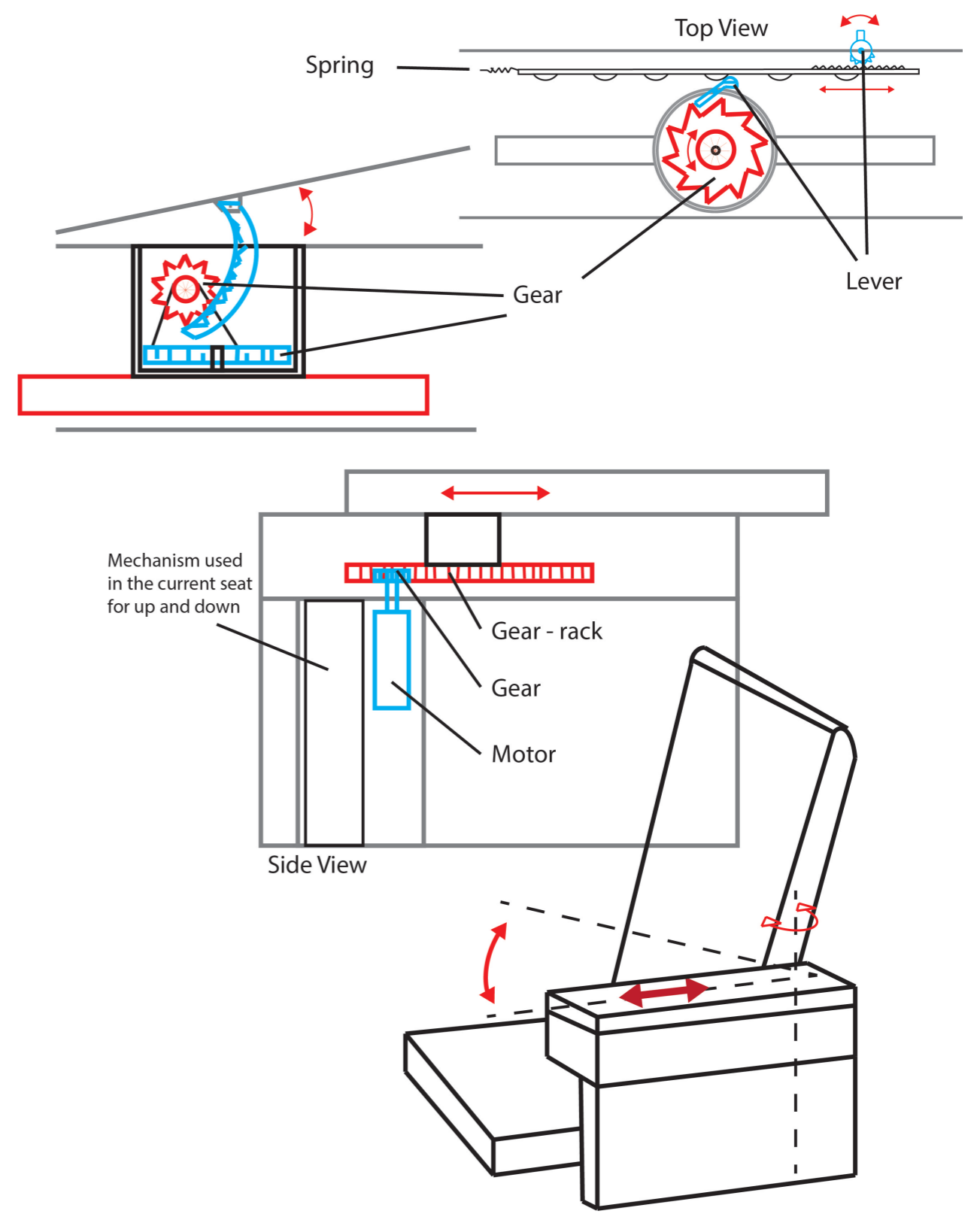


APPENDIX 4: FIRST SKETCHES

WORKING MECHANISMS



First drawings of a moving mechanism for concept 1



First drawings of a moving mechanism for concept 2





APPENDIX 5: QUESTION SHEET FINAL

USER TEST

Fine tuning test question sheet									
General info									
Participant number:									
Gender:									
Weight:									
Length:									
Part 1: flat armrests									
10 min. Reading									
Comfort score:									
Very uncomfortable	1	2	3	4	5	6	7	very comfortable	
What did you find very comfortable or very uncomfortable during this activity?									
Part 2: own model armrest angles									
3 min reading each									
1st angle ()									
comfort score:	1	2	3	4	5	6	7		
2nd angle ()									
comfort score	1	2	3	4	5	6	7		
3rd angle ()									
comfort score	1	2	3	4	5	6	7		
comfort ranking angles:									
1									
2									
3									
if the most preferred angle of this model and the previous position is compared, which one would you prefer to use?									
Why?									
What did you find very comfortable or very uncomfortable during this activity?									

Can you stand up out of the seat on the aisle side and show me how you would do this? (Can you think out loud while you are doing this?)									
Part 3: inwards rotating seat									
3 min reading each									
1st angle ()									
comfort score:	1	2	3	4	5	6	7		
2nd angle ()									
comfort score:	1	2	3	4	5	6	7		
3rd angle ()									
comfort score:	1	2	3	4	5	6	7		
comfort ranking angles:									
1									
2									
3									
Comfort ranking overall seating position:									
1									
2									
3									





APPENDIX 6: RESULTS FINAL USER TEST

Fine tuning test results						
Participant number	1	2	3	4	5	
Gender	male	female	female	female	male	
Length (cm)	180	172	186	178	194	
Part 1						Mean:
comfort flat armrests	3	5	5	5	4	4,4
Part 2: own model armrest angles						
comfort score 100	5	6	6	6	5	5,6
comfort score 90	4	3	4	4	4	3,8
comfort score 80	6	5	3	7	2	4,6
comfort score 90 + wedge			5	6	5	5,3
comfort score 80 + wedge			6	5	2	4,3
comfort ranking						
1	80	100	100	80	90+	
2	100	80	80+	90+	100	
3	90	90	90+	90	90	
Preferred	80	100	100	80	90+	
Part 3: Sigrid's seat						
comfort score 10	5	4	5	4	5	4,6
comfort score 20	7	4	6	6	6	5,8
comfort score 24	7	5	6	7	6	6,2
comfort ranking						
1	20/24	24	20	24	20/24	
2	10	20	24	20	10	
3		10	10	10		
overall ranking						
1	3	3	3	3	3	
2	2	2	2	2	2	
3	1	1	1	1	1	

Comments and answers for the questions of the final user test

Part 1: the current situation

What was comfortable/uncomfortable?

- The tablet is quit heavy, it topples from your hand. This makes that you are feeling your wrists and you have to watch down too much.
- If you lean to the back you cannot look at the tablet.
- armrests are not symmetrical. The surface is hard on your elbows.
- The sitting angle of the seat is good, the width between the armrests is exactly right, but it is quite tiring for your neck.
- The seat angle is nice, but the leg part is not long enough. You are feeling your neck because of the reading.

Part 2: own model, armrest angles

Why did you prefer this angle the most?

- (80) You have to bend over less.
- (100) Holding the tablet is tiring for your arms.
- (100) In this position your arms are less tense.
- (80) You can lay your head on the headrest nicely.
- (90+) You can hold your head a bit higher and you can hold the tablet with two hands.

What was comfortable/uncomfortable in these positions?

- The armrests took over the weight of the tablet, that was nice.
- 80 degrees is too high, the tablet becomes heavy and you cannot switch to the other arm because the armrest is shorter.
- Without the wedge you need force to keep your arms high. The armrests are asymmetrical that is still not nice.
- The tablet is quit heavy.
- My arms fall to the outside with the last angle (80) and my shoulders are too high.

Actions observed in order to get out of the seat:

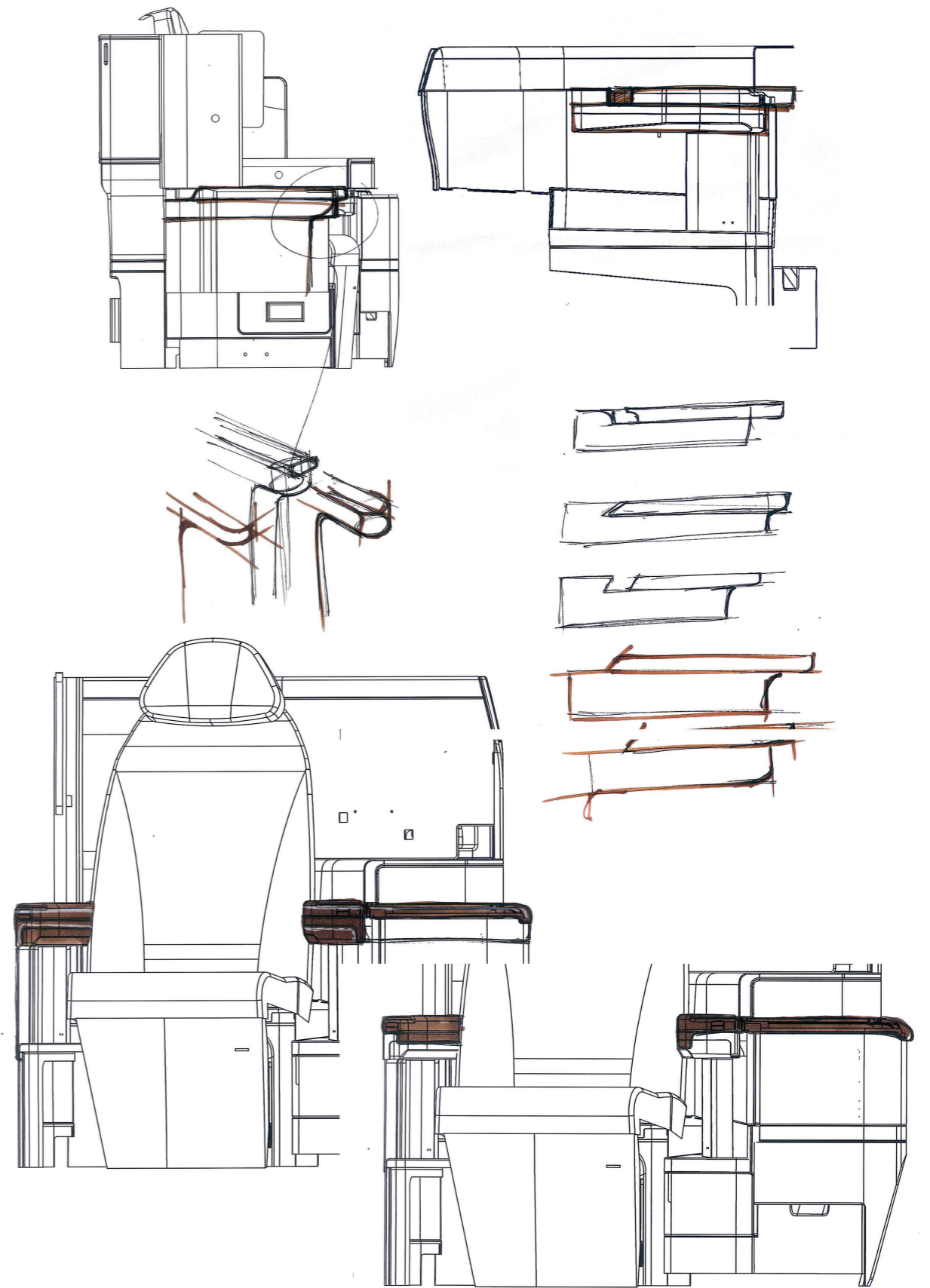
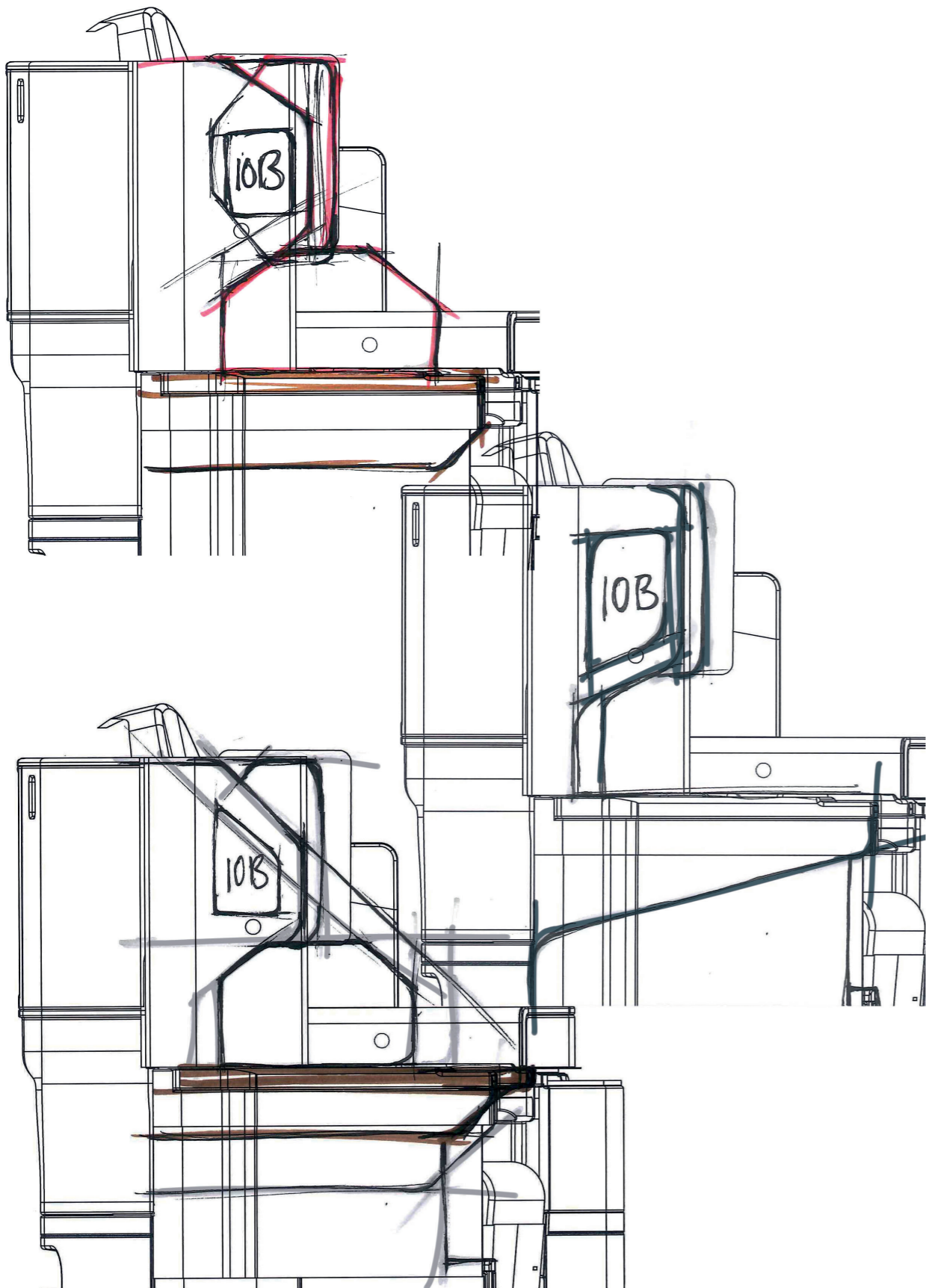
- dug underneath the armrest or slide it to the back.
- Turn up to stand up.
- Turn down to use the armrest to push yourself up from the seat.
- the armrests to the outside, but first use it to push yourself up from the seat.
- the armrest up and push up from the horizontal part.

General remarks regarding the overall ranking of all positions

- The seat from part 3 is sitting more upright that is nice for reading.
- The third angle is nice, you have to lift your arms less.
- 100 for relaxing and 80+ for reading.
- The width of the armrests in the last model are nice and the ridges for the tablet also. Maybe something for your neck would be nice.

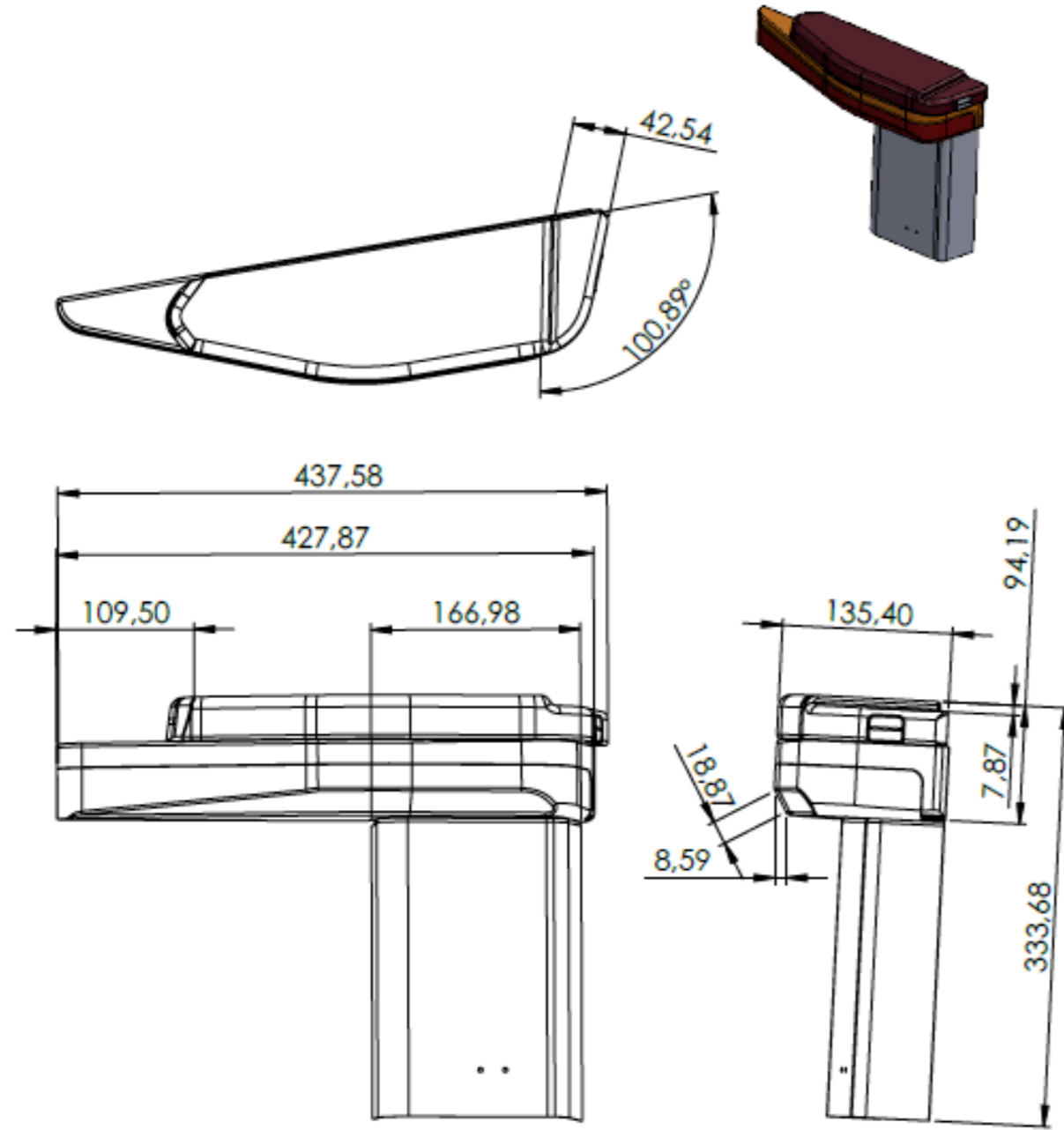


✈️ APPENDIX 7: FORM STUDY SKETCHES

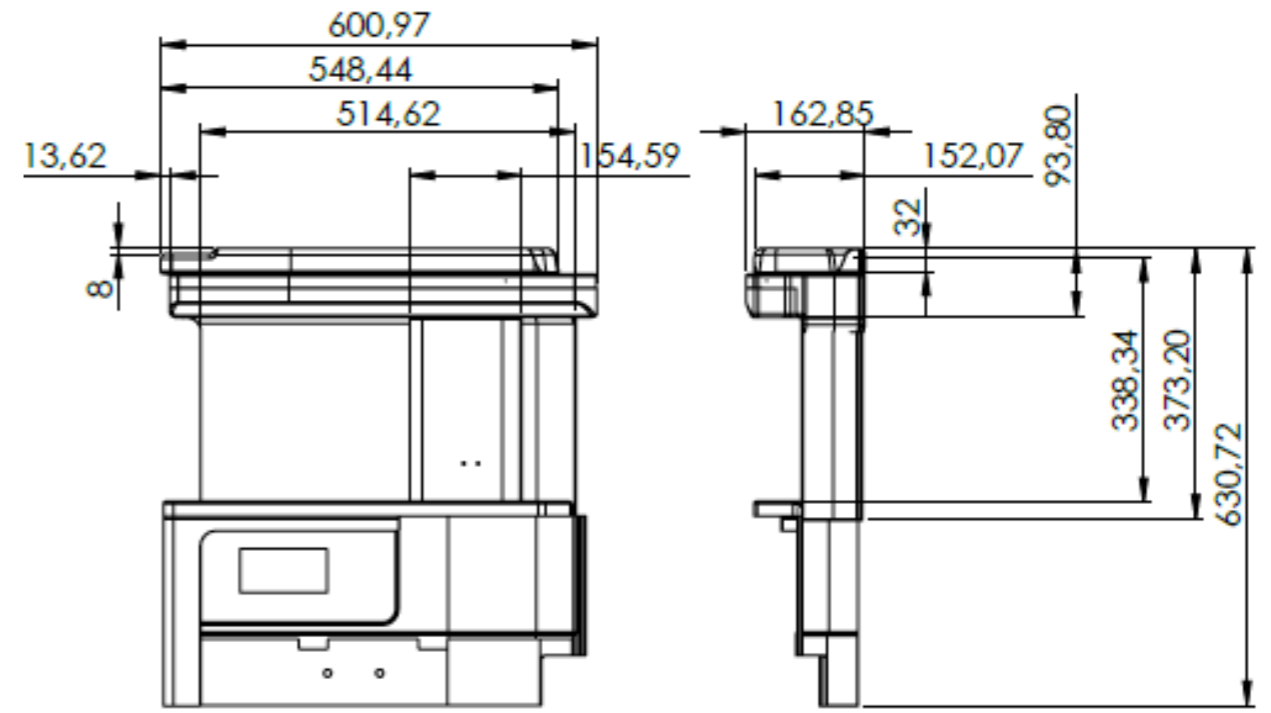
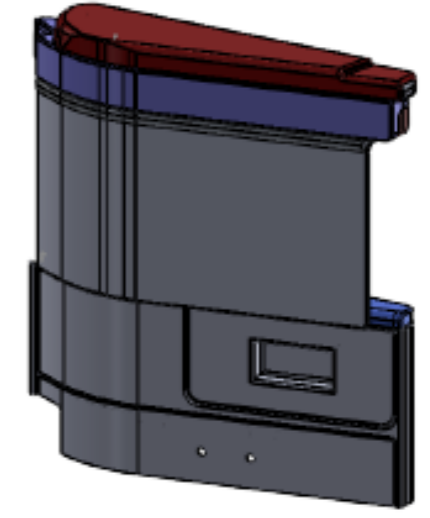
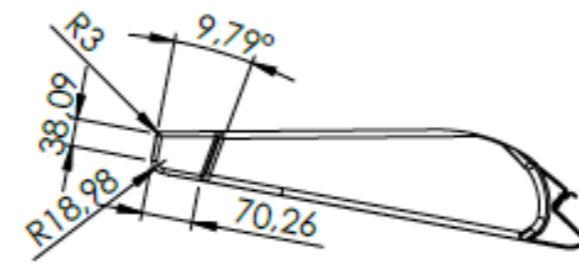




APPENDIX 8: OUTSIDE MEASUREMENTS



Console side armrests, measurements in mm.



Non-console side, measurements in mm.





APPENDIX 9: LIST OF CRITERIA

CHECKLIST

Requirements	complies	complies	Wishes
<i>Most important criteria are bold</i>			
Performance/functions			
1 The design must give the passengers the opportunity to separate themselves from the other passengers and the surroundings. (Separating themselves from other passengers must be an option and not a standard fixed solution).			
2 The design must give more adjustability possibilities than the current seat. (both armrest adjustable in height would already fulfil this requirement.)			The design should be adjustable in as many directions as possible. (inwards/outwards, rotating inwards/outwards, height etc.)
3 The armrests must improve the comfort of the passenger while watching IFE in the relax position.			
4 The armrest must not obstruct the movements of the passenger while sleeping in the full flat position.			
5 The armrest must support the arms of the passenger while reading on a tablet/book.			
6			The privacy function should be a part of the armrest and shouldn't be a separate solution.
7 The movement of the seat (from TTL to sleeping for instance) must not influence the comfort of the design.			
8			The access to the seat should be as easy as possible (the ingress and egress should be as easy as possible meaning: less as possible obstacles/ easy to remove obstacles).
9 The design must provide more privacy than in the current seat. (The armrest in the current seat only gives more privacy when sleeping).			The design should provide as much privacy as possible.
10 The arm supports must be functionally symmetrical for the left and right arm. (in placing arms parallel, in space provided to the arms and in the same adjustability options to both sides)			
11 The design of the armrest must fit within the boundaries of the current RECARO seat CL6710.			The design should take away at least as possible living space from the current seat (e.g. space for legs and feet).
12 The armrests must avoid giving the passenger a cramped feeling during watching IFE and sleeping.			The design should give the passenger as much space to move around as possible during relaxing (watching IFE) and sleeping.
13			The armrests should not give the passenger an unsafe and un-private feeling during their activities and specifically during sleeping.
14			The design should give the passengers as much as possible the feeling that they are able to personalize their seat to their needs.

Explanation behind the rating of the checklist

- R1: The solution partially gives the opportunity to the passengers to separate themselves. It does not give a sufficient separation to passengers in TTL and relax position, but in the full flat position the privacy is largely improved when the armrests is up. But since the seat positions for which the separation device should work is not defined, the result should be looked upon critically.
- R3: This is still an assumption, based on the extra space created for the arms. But this should be tested with a model and participants. Figure 75 in the main report shows the bigger arm area.
- W6: the privacy function is integrated into the current privacy panel, but is still near the armrest and works optimal combined with the armrest moved upwards.
- W8: Since the armrest is easy to rotate side wards ingress and egress is taken into account. Further testing should show how users experience this solution.
- R10: The adjustability options of both armrests are practically the same. Only the reach of the console side armrest is a little bit smaller. The rotation inside for the upper part of the armrest makes it possible to rotate the console side armrest parallel to the non-console side armrest. But the console side armrest is still a lot shorter than the other side. Which was also noticed during the last user test. Therefore this requirements is only partially met.
- R12, W12: It is really hard to review this requirement and wish. But considering the extra functionalities that are integrated, the most space is saved. And the passenger has in this situation the most possible space to move around in.





Ergonomics			
15	The design must address the tension between raising the screen of a laptop/tablet to eye height and supporting the arms.		
16	The surface of the armrest must be more ergonomic than the current seat (referring to softness of the surface and shape).		The armrest should fit the human contour of the arms.
17			The armrest should take into consideration the areas where the elbows and underarms are placed based on the arm positions research
18	The armrest must not clamp down the median, ulnar and radial nerves of the passengers around their elbows and wrists.		
19	The armrests must integrate the shape of the legs when passengers sit with their one leg crossed over the other (see arm positions research).		
Materials			
20	The material of the armrest must give sufficient grip and therefore support to the passengers arms. The material must avoid slipping away.		
21	The material used for the design must be easy to clean. (either easily removable covers which can be washed or a material that can be cleaned with a cloth)		
22			The material of the armrest should feel soft and comfortable and give sufficient support at the same time.
Environment			
23	The design must be able to hold the weight of passenger when he/she leans or stands on it with its full weight (131 kg, Dutch adults p99.99, Dined.nl) (aisle armrest: 130daN downwards load, other armrests: 110daN downwards load, Airbus guidelines for abuse, handling, impact and mounting loads see 7)		
24	The design must be able to withstand the force of a person or bag falling or bumping into the design from the side (aisle armrest: 90daN sideways load, other armrests: 65daN sideways load, Airbus guidelines see appendix 7).		
25	There must be no contact between the cabin and the seat other than the connection of the seat to the cabin underneath the seat. (RECARO only delivers the seat and has no influence on anything else present in the cabin)		
Life in service, product life span			
26	The armrest must be able to survive 25.000 cycles of use (adjustments of moving parts).		
27	The design must be able to be used for a duration of 37.000 FH (Flight Hours).		

- R16, W16 and 17: Earlier in the report it was described that requirement 16 and the wishes 16 and 17. Would not fit within this project. And another project is needed to explore the possibilities to meet these criteria.
- R19: The thighs are taken into account within the design through the extra chamfer added underneath the mechanism casing. But other leg positions are not included.
- R20: As earlier described in the chapter materials. The upper material for the armrest was copied from the current RECARO seat. Therefore no extra grip is added with use of the material. But the area where the arms can lean on is made bigger. Therefore before considering other materials in further development. A test has to be done to see if extra





Maintenance			
28	The design must not have cavities that are hard to reach for crew before and after a flight. If cavities (in the form of storage maybe) is unavoidable the cavities should be easy accessible and easy to clean with a cloth.		
Target product cost			
29	One armrest must be producible for 700 euros. (Their current in height adjustable armrest costs around 650 euros and their non-adjustable armrest costs around 200 euros.)		
Production			
30			the design should consist of at least as possible parts (production costs reasons).
Quantity			
31	The design must be producible for a batch size of 1000 a year.*		
Size and Weight			
32	The design must support a tablet with the dimensions: max. 270x190 depth 13 mm and min. 150x84 depth 6,1 mm ("List of tablet PC dimensions and case sizes", 2017)		
33	The seats must fit into an airplane with width 208", the minimal aisle width must be 17" (also see picture)		
34	The width between the two armrests must not be less than 21.1" (current CL6710 seat).		
35	The design must facilitate for the population of p5 to p95 of international travellers between the age of 20 and 60. (elbow height sitting: 178mm t/m 301mm, see chapter Anthropometrics)		The design should fit as many international business travellers as possible (in dimensions, as many nationalities as possible).
36	The minimum width of the arm support is 2" (50,8 mm)		The width of the armrest should be as broad as possible.
37			The design should give enough space to the arms to rest on.
38	The length of the armrests must be sufficient so the passengers arms will not fall off (min. 273 mm, elbow grip length see chapter anthropometrics).		The length of the armrests should be as long as possible.
39	The total weight of the design (one side armrest) must not exceed the weight of 4 kg. (the current retractable armrests weighs 3,776 kg including mechanism, plastic shield and cover)		The weight of the design should be as light as possible.

grip is still needed when the area is already bigger.

- R28: The cavities of the mechanism, that show when the armrest moves to the front and when the armrest is rotated are closed off with material.
- R32: The armrests are based on the current seat, so if all measurements are used well. It should be able to fit into this measurement.
- R34: This did not change compared to the current seat.
- R35, W35: The non-console armrest has a height range of 0-306 mm. Considering het elbow height this meets the requirement. The extra adjustability options does make the armrests better available for more postures. The armrests can come closer through rotating them and both sides can be changed in height. But other anthropometric data were not considered taken into account the time that was available for this project , despite the fact that they were looked up during the analysis phase. Proving there is still room for optimization.
- R36, W36: The smallest width of the non-console side armrest is around 53 mm, taking into account the rounded corners this will be 46 mm.
- W37: The area were het arm can rest on is made bigger see figure 75 in te main report. But if this is enough that should be determined by a user test.





Aesthetic, appearance and finish			
40	The design must have the possibility of customization in appearance for the different airlines.		
41			The design should have an aesthetically pleasing effect on the passenger.
42			The design should look comfortable.
43			The design should take the visual integrity of the seat into account. (Currently the seat has clear visual lines in the design, these lines are made by a change in colour and material.)
Standards, rules and regulations			
44	Anything up to 35" in front of the seat and half of the armrest cannot have any hard materials or surfaces that will cause injury to the passenger. This rule applies in the direction of the flight during taxi, take off and landing. (see picture 43 and 44 in appendix analysis report).		
45	The armrest must be latched in place so it cannot move unintentionally. Applicable if the armrest is adjustable.		
46	The seat in general must be able to withstand a 16G dynamic crash test.		
47	The walls of the "cubicle" around the seat cannot be higher than 54".		
48	The armrests may not surpass the height of 25" from the floor.		
49	The armrest on the aisle side must be able to go fully down or it should be able to be taken out entirely. (this is to give the possibility to people in wheel chairs to get into the seat.)		
Safety			
50	The design must not contain hard non rounded corners (sharp corners).		
51	The design must not contain protruding objects.		
Installation and initiation of use			
52	The functioning and use of the design must be clear to the passengers.		<i>The use and functioning of the design should be as clear as possible to the passengers.</i>
53			The usability of the armrest should not suffer from too many adjustability options. A balance between usability and adjustability should be found.

- R38: The length of the console side armrest is 328mm.
- R40: material and colour of the armrests can be changed. Also het aluminium line on the side can be given an own preferred material or colour. Adding to that the lighting on the side of the privacy panel can be given a colour or maybe even a screen can be installed showing a preferred picture.
- W41 and 42: Wishes 41 and 42 were both taken into account during the design of the product. But if they look comfortable enough or if they are aesthetically pleasing still needs to be tested.
- W43: See chapter form giving.
- R45: Considered that in that in further development a locking system is added to the privacy panel
- R52, W52 and 53: the usability was taken into account during the design of the product. But further development and research is needed to optimize the usability. And to test if all passengers understand the use.

