Designing a tablet holder to reduce discomfort among airline pilots.

A master thesis
by
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Breach

Master thesis

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Executive summary

This report is the result of an IPD (Integrated Product Design) master thesis at the faculty of industrial design engineering at the TU Delft. The company, for which the project was executed, is mainly focused on manufacturing flight-deck seating for the airline industry (pilot seats for airliners). Their biggest and main client is Boeing, for which they provide all airliner flight-deck seats.

A graduation report 'Back injuries among KLM pilots' (Vaart, 2009), showed that the graduation company's flight-deck seat pan and backrest contour does not provide a good sitting posture. They both initiate a slouched seating posture, which can lead to severe back problems (Al-Eisa, et al., 2006). Due to the lack of ergonomically designed flight-deck seats, pilots seemed to be more absent compared to other airline employees. In fact, KLM pilots report much more absenteeism (5,8%) due to back problems than the average KLM employee (4,4%) (Vaart, 2009).

The first goal of the master thesis was to highlight multiple ways of improving the flight-deck seats in order to reduce discomfort among airline pilots. This was achieved by analysing the seat, analysing the flight-deck, interviewing pilots and by co-operating in an extensive user research on Boeing 737 aircraft. It appeared that most airline pilots are obligated to use tablets, for filling in checklists and doing calculations. However, they do not have an assigned place for the tablet on board the flight-deck. Additionally, data from the user research showed that pilots perceive most discomfort in the upper back and often adapt into a slumped seating posture due to reaching for the flight-deck controls, using the tablet or during reading activity.

Furthermore, the pilots seemed to have a large area of visual attention, which causes them to move their heads from side to side. These findings lead to the final search area, formulated into the following design goal:

"Designing a tablet holder to reduce discomfort among airline pilots"

The following design value's were found and documented in a design brief. The values adhere to the findings from the analysis phase, among which the user research and trends analysis.

- **Create an ergonomically responsible way for using the tablet.**
- **Minimizing the area of visual attention by replacing the EFB (Electronic Flight Bag).**
- **Incorporating flight control systems.** in the far future, certain flight-control systems could be incorporated in the tablet, so that the pilots do not have to reach for flight-controls during cruise altitude.
- **Limit the added weight by replacing the EFB.**
- **Working towards a paperless flight-deck.**
- **Showing the benefits of a use-centred design** The product could show the benefits of a use-centred design by working towards a flight-deck that is easy to control and that supports the pilots in all their activities. For instance, this design should support the pilot in flying the airplane during cruise-altitude. An aspect which is not present in current flight-deck design.
- **Provide the ability to access seat adjustment settings through the tablet.**

After the design brief was defined, the conceptualization phase started. Concepts were made for three different parts of the tablet holder and combined into a final concept. During conceptualization, important improvements and design decisions had to be made. It became clear that current flight-deck design of Boeing is not suitable for a tablet holder design. Current steering column designs featured in Boeing airliners, makes a tablet holder impractical. It was decided to provide a tablet holder design that can be introduced to any aircraft. An additional implementation plan shows how the design could be introduced to the market while exploiting the value in the design.

Further embodiment of the design consisted of the top part of the tablet. This part makes sure that the tablet is fixed to the tablet holder. Furthermore, it should have multiple adjustment systems to adjust the orientation of the tablet within three positions that the tablet holder should provide.

The embodied design was validated in a strength analysis. Certain critical parts of the design were analysed in Solidworks Simulation. A proof of concept was made to show that the adjustment systems work.

The whole design was complemented with an implementation plan. The plan shows how to introduce the product to the market while further developing the design and stimulating market and revenue growth for the company.

figure 1 : A Boeing 737 in flight

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Definitions & abbreviations

- **C-7 spine** = A spinal segment at the beginning of the neck. It is the largest and most inferior vertebra in the neck region.
- **EFB** = Electronic Flight Bag. A fixed tablet in the flight-deck with protocols and manuals. It replaced former paper books.
- ERF-position = Eye-Reference Position. A certain position in which the pilot has to be seated when controlling the airplane manually.
- **Flight-deck** = The cockpit.
- **FMC** = Flight Management Controls. A navigation system that manages the flight plan during flight.
- **Galley inserts** = Integrated systems in the galley to of the aircraft such as refrigertaions, beverage makers, and ovens
- **P-5 users** = Refers to measurements of percentile five of the database used. For instance, the P-5 length of DINED 2004 Dutch adults age 20-60 is 1569 mm.
- **P-95 users** = Refers to measurements of percentile 95 of the database used. For instance, the P-95 length of DINED 2004 Dutch adults age 20-60 is 1917 mm.
- **Use-centred design** = A design approach in which the focus lies on the goals and tasks associated with the skill perfomance of specific work domains.
- **User-centered design** = A design approach which focuses on the needs, want and limitations of the end-user.

0. intro

The intro chapter covers the scope of the project and a process overview. The scope defines the initial project boundaries in a problem statement. The process overview clarifies the process described throughout the report.

In the picture: A Boeing 737 from transavia. The user research featured in the analysis chapter was executed along similar aircraft.

figure 2 : A Transavia Boeing 737 in front of the hangar at Schiphol

0. Intro

0.1 Scope

The thesis started with a broad scope. This scope describes the first goal and problem statement which initiated the analysis phase. It is important to note that the graduation company is a leading company in the manufacturing of flight-deck seats. On request of the company, their name is kept anonymous throughout this report.

A graduation report 'Back injuries among KLM pilots' (Vaart, 2009), showed that the company's flight-deck seat pan and backrest contour does not provide a good sitting posture. They both initiate a slouched seating posture, which can lead to severe back problems (Al-Eisa, Egan, Deluzio, & Wassersug, 2006). Due to the lack of ergonomically designed flight-deck seats, pilots seemed to be more absent compared to other airline employees. In fact, KLM pilots report much more absenteeism (5,8%) due to back problems than the average KLM employee (4,4%) (Vaart, 2009). Moreover, in a biomechanical analysis of multiple flight-deck seats, it appeared that none of the seats met basic biomechanical design criteria (Goossens, et. al., 1998). Along the five seats that were analysed two seats belonged to the graduation company.

The company turned to the TU Delft for the first steps towards a more ergonomic flight-deck seat. The TU Delft agreed to start a user research in order to provide the company with valuable data to be able to improve their flight-deck seat designs. This research generated quantitative data on perceived discomfort among pilots during flight and qualitative data through observational pictures. The research took place on Boeing 737 airliners and was conducted during the this master thesis.

By cooperating in the user research, certain data could be used as input for this thesis. **The initial goals was to highlight the most important causes of discomfort in the flight-deck, according complaints and improvements on flight-deck- and seat design.** This would form the foundation for defining search area's. The search area's describe the possibilities for a new or optimized design of part of the flight-deck seat.

Problem statement

At the end of the analysis phase the search area's should show solutions to the problem statement:

"How can a flight-deck seat be improved to reduce discomfort among airline pilots?"

the goal of the analysis phase is to eliminate causes of discomfort rather than improving comfort. Discomfort and comfort are two separate things based on different factors (Zhang, et. al., 1996). A feeling of discomfort is dominant over a feeling of comfort (Helander, 1997). Therefore it is more important to first eliminate discomfort through design, before trying to improve comfort. See appendix 1, for further elaboration on the meaning of comfort and discomfort and according theoretical models. See appendix 2 for discomfort relating to back complaints.

figure 3 : The flight-deck of a Boeing 737

Recap & continuation

Conclusively, this project started with a broad scope. A lot of decision making was necessary to work towards obtaining specific design boundaries. These **decisive moments** are highlighted in the process overview on the next page. The process overview, gives a clear overview of the structure of the report.

The proces overview is followed by the analysis phase that contains an internal and external analysis, further introducing the graduation company, the airline market and its stakeholders.

0.2 Process

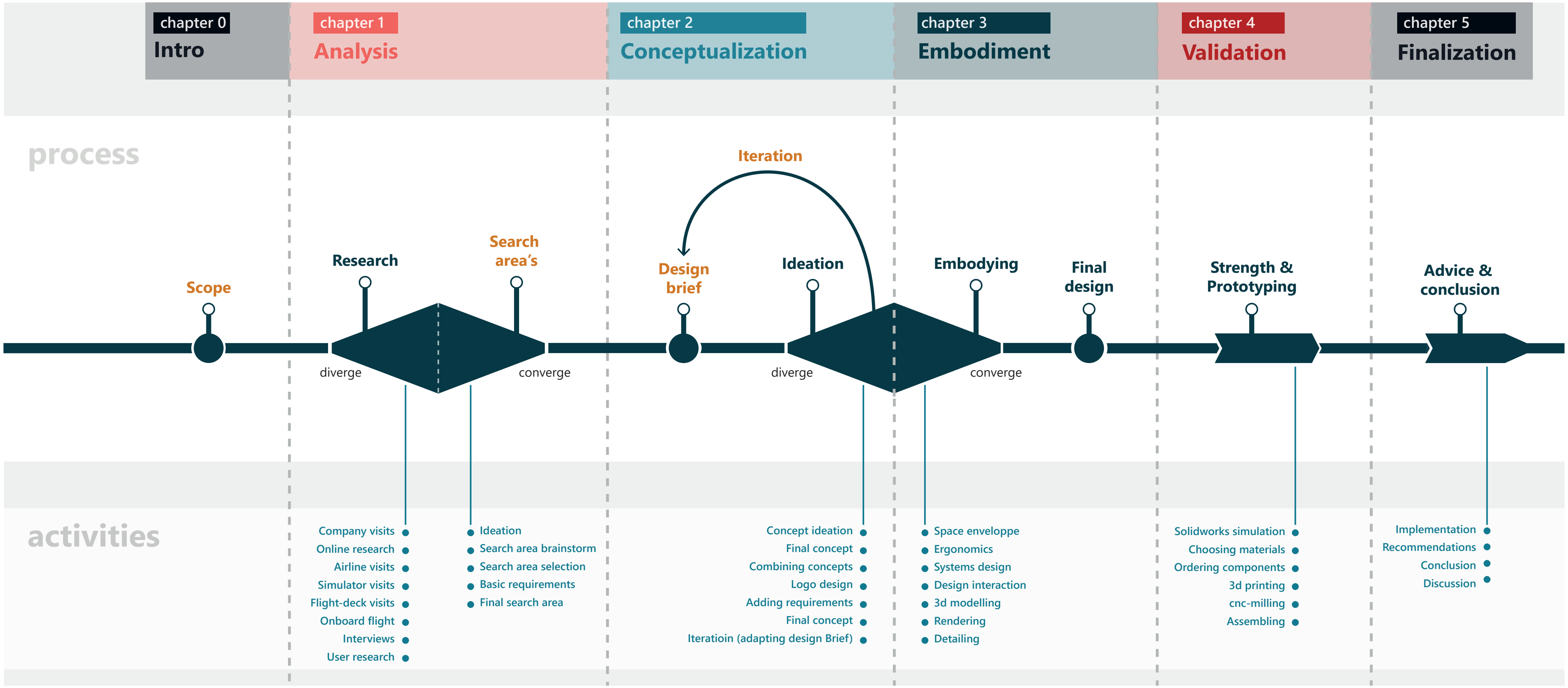


figure 4 : The master thesis process overview.

The chapters in the report correspond to the phases in the process overview (figure 4). Both in the analysis phase and the conceptualization phase there is a divergence in the process by collecting information or generating ideas. This is followed by converging to decisive moments on design boundaries or the actual design itself. The **decisive moments**, are highlight in orange in the process overview. These moments can be seen as the foundation of the process and determine the continuation of the process.

1. Analysis

During the analysis phase valuable information is gathered about the graduation company, the airline market, the user, the flight-deck seat and its context. Additionally, the analysis phase includes a user research toward causes of discomfort among airline pilots. All this information forms the input for the design brief and the following design phases.

In the picture:
The production line at the seat manufacturer.

figure 5 : The production line at the seat manufacturer

1. Analysis

1.1 Internal analysis

This chapter covers the products the company makes and their main clients. Followed by a marketing mix focused on the flight-deck seat market. For more specific information on the product portfolio, manufacturing processes and the marketing mix see appendices 4,5 and 6.

The graduation company

The company produces a big variety of products, with flight-deck seating being their main product output. The company also produces crew seating, business passenger seating, galley inserts, electronics, composites and precision engineering products.

The business passenger seating is a relatively new product diversification for the company. Business passenger seats are not as restricted by regulations as flight-deck seats. However, the quality demand of business passenger seating is much higher.

Their biggest client is Boeing, for which the company delivers all flight deck seats. This concerns airline airplanes as well as cargo airplanes. The company also delivers seats to Lockheed Martin, a company that builds a lot of aircraft used by military, such as the C-130. Another important client is Gulfstream, which builds business jets, such as the G650 (see figure 6).

figure 6 : The flight-deck of the Gulfstream G650

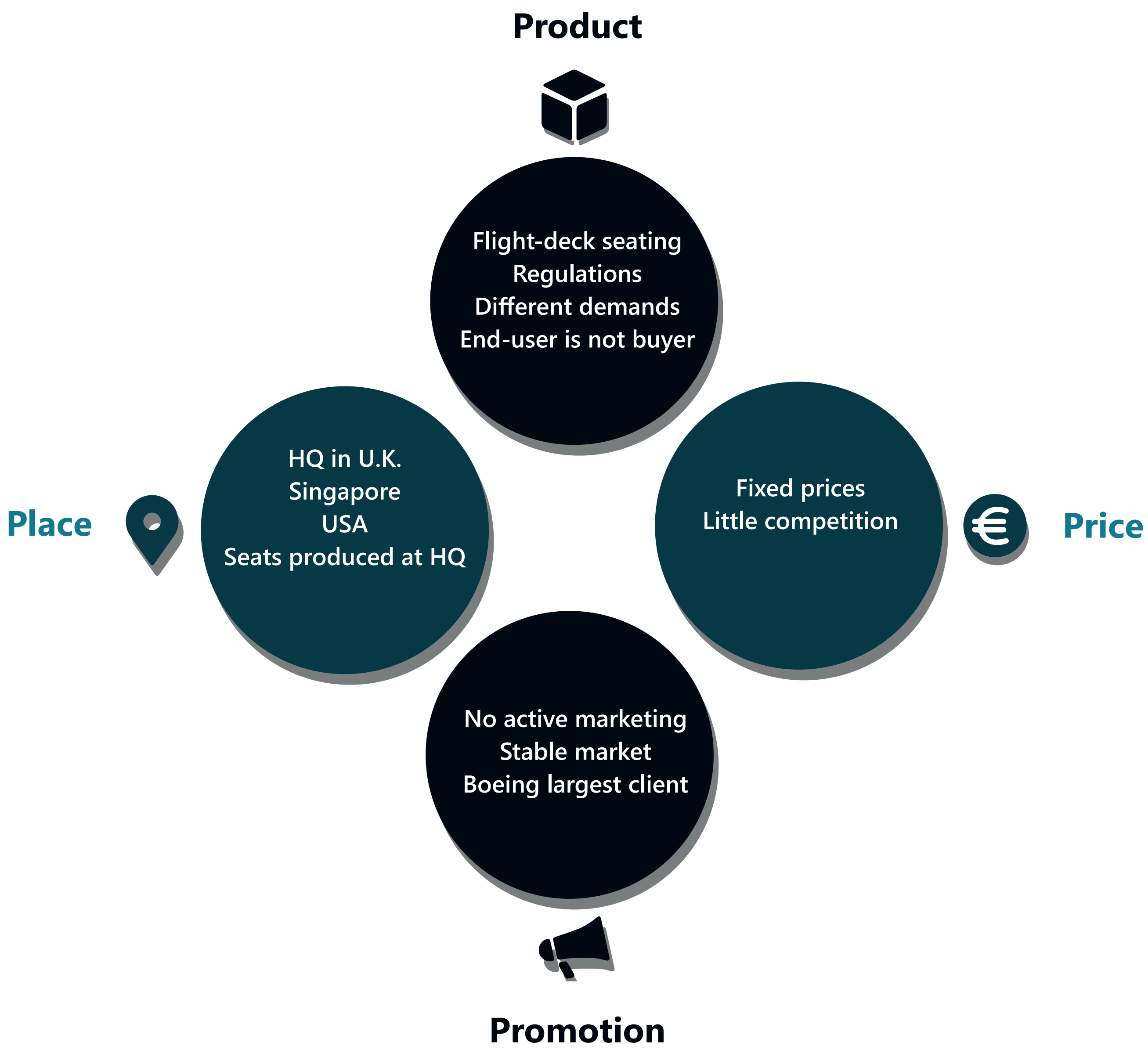


figure 7 : The marketing mix

Marketing mix

The marketing mix highlights different aspects of the company which relate to the market, also see figure 7.

The direct clients of the company (the aircraft manufacturers) are often concerned with cost-reduction. This translates to lightweight design and minimizing installation time. The airlines who will buy the aircraft are equally concerned with cost-reduction. Aside from lightweight design, minimizing ground time (for instance during repairs) plays a big role. The end-user, the pilots, have different demands. They prefer a comfortable seat. It is difficult to adhere to that demand, as the demands of the arirlines and aircraft manufacturer overrule the demand of the pilots. Making a seat lightweight and cost-effective is not beneficial for the comfortability of the seat.

The actual price of the seat is not a big concern. There is little direct competition in this market. Furthermore, there are a lot of regulations concerning the design of the seats which fixes the price.

Maintaining the reputation of the company is important. Although there is little competition and the company has a stable market position, they cannot afford to lose it. Because of this stable market position, they focus little on marketing their products.

1.2 External analysis

This chapter highlights the important stakeholders in the airline market and the relationship between them.

The airline industry is a complicated one. Regulations are very important. The EASA (European Aviation Safety Agency) is the agency which deals with all regulations and safety requirements concerning aviation. It replaced the former JAA (Join Aviation Authorities). The EASA is regulated through the European Commission, Council of the European Union and European Parliament. Any designs and products concerning aviation will always have to follow the regulations and standards enacted by the EASA.

Additionally, in terms of flight-deck seats for commercial airliners there is just one other company like the graduation company, which is Stelia. Stelia was formed in 2014 merging Sogerma and Stelia Aerospace (Gardner Business Media, 2014). The two are competitors, but the market is very stable. The graduation company manufactures and delivers seat for Boeing and Stelia for Airbus, which has been so for decades (Stelia Aerospace, 2016).

The supply chain

The most important player in the supply chain, is the aircraft manufacturer. They buy the actual seat from the company, and sell it as part of a plane to airlines. Boeing being the aircraft manufacturer is by far the biggest player within this supply chain. See figure 9 for a visualization of the supply chain.

figure 8 : The technology readiness levels

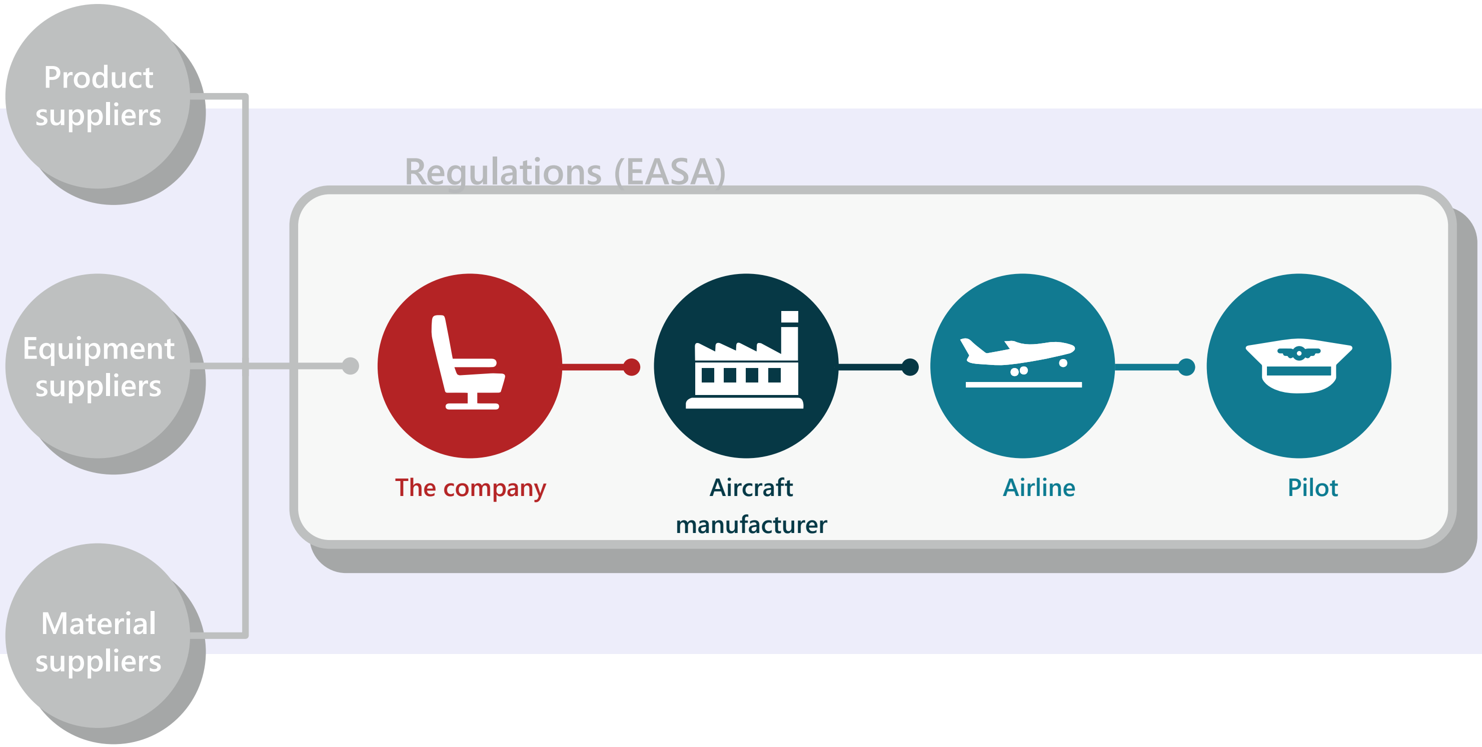


figure 9 : The supply chain

The flight-deck seat, will pass through three stakeholders: the aircraft manufacturer, the airline and the pilots. The aircraft manufacturer and the airline have the most power and influence. They demand cost-effectiveness and lightweight design rather than ergonomics. This caused ergonomics in flight-deck seat design to be neglected for decades.

However, since a few years some airlines start to demand improvements in ergonomics and comfortability of flight-deck seating. Such demands are undesirable for the aircraft manufacturer. Focusing on ergonomics requires new optimized designs and will increase a diversification of products. The aircraft manufacturer would prefer to only deliver identical products as this is more cost-effective. More diversification, means more suppliers, which makes communication and planning even more difficult than it already is. To give an idea, it takes about seven years to design a new commercial airplane and technologies need to be around TRL 9 (the highest Technology Readiness Level, also see figure 8) at the beginning of a design cycle to be able to implement it (Harris, 2017) (RTE Adviesgroep, 2017). Precise and careful planning is very important, as it is difficult to make changes during the actual design cycle.

Conclusively, the airline industry is a slowly adapting and conservative market and there is little transparency between businesses. Additionally, all the afore mentioned aspects of the market, makes it difficult to enlargen market share in the flight-deck seat market for airlines.

1. Analysis

1.3 Trends analysis

This chapter covers trends in the current aircraft industry. It could reveal opportunities for the seat manufacturer in the near and far future. The trends relevant to the end-product are adressed. For a more elaborate trends analysis, including a seat-design trends analysis, see appendix 7.

A major trend in the past half century has been de-crewing. In the 1960's airliners often featured four to five crew on the flight deck: A captain, a co-pilot, a flight engineer and a navigator/radio operator (see figure 10). During the last decades, this has reduced to two or three flight deck crew on board airliners (three during long haul flights). The trend relates to reducing the workload of pilots. Technology advances in aircraft design reduce the workload and systems are increasingly more able to assist the pilots in their tasks. A way to reduce the workload of pilots and work towards single pilot-operated aircraft is by a distributed, air/ground, socio-technical system (Neville A., et al., 2016). With this system ground crew can assist the pilot in controlling the airplane. In their article, they claim, that an aircraft using such a system could be ready within a decade.

The trend of de-crewing goes hand in hand with the trend of pilot shortages. As cited from an article of CNN about the US airline business:

"Over the next two decades, 87 new pilots will need to be trained and ready to fly a commercial airliner every day in order to meet our insatiable demand to travel by air. That's one every 15 minutes." (Ostrower, 2017)


figure 10 : A boeing-707 Flight Deck and its crew.

The problem arises from the fast growing airline industry. Passenger and cargo airlines around the world are expected to buy 41,000 new airliners between 2017 and 2036. And they will need 637,000 new pilots to fly them, according to a forecast from Boeing (Ostrower, 2017).

A trend which directly relates to the problem of pilot availability, is the change to a use-centred design. Until now, flight deck design is based on user-perspective design. In other words, aircraft manufacturers base the design on the capability of pilots. However, if the airlines want to solve the problem of pilot availability, they should change to a use-centred design. This means that the aircraft manufacturer should strive to design a flight-deck that is as easy to use as current technology allows. In this way, it is easier to train pilots and the airlines can more easily select candidates for pilot training. However, current regulation is restricting such change (Harris, 2011).

Aside from the growing airline industry, the business jet industry is growing as well. According to Bombardier, the global business aviation fleet keeps expanding at an unprecedented rate and is expected to comprise 22 650 aircraft by 2023 (KlasJet.aero, 2017). Furthermore, Colibri aircraft showed that 21% of the pre-owned aircraft it has sold last year have gone to first-time buyers, a 50% increase on 2014 (corporatejetinvestor.com, 2017). Figure 11 shows a ten year forecast of the business jet industry. Although a drop is expected after 2021, it is estimated that it will increase again after 2024.

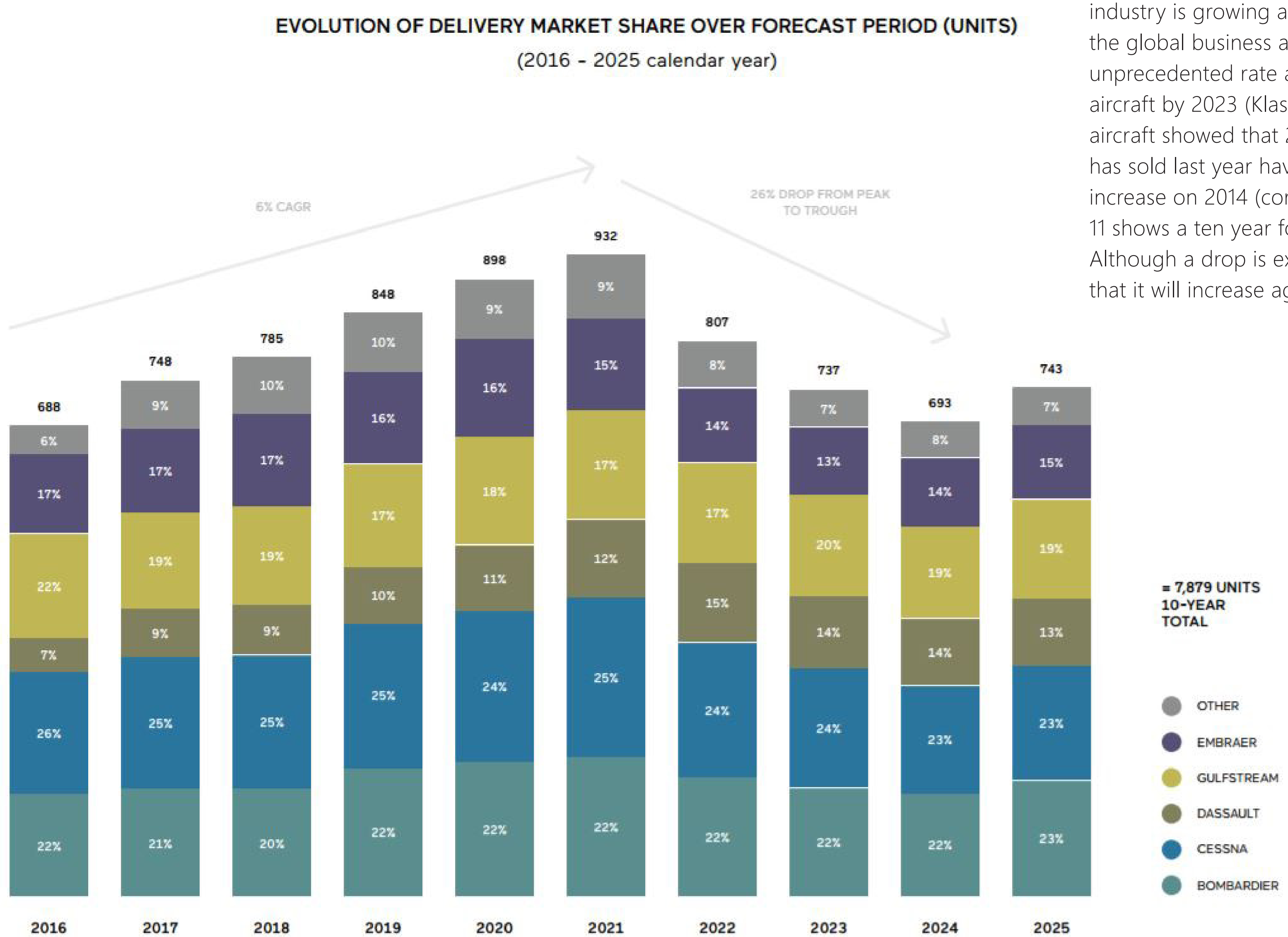


figure 11 : A ten year forecast of the business-jet industry

1.4 Context & product

In this chapter we take a look at the flight-deck of a Boeing 737 and how the pilot interacts with it.

The Boeing 737 flight-deck was analysed as the user research (page 24) took place in Boeing 737 aircraft. The reason for this choice was the fact that pilots perceive most discomfort along airplanes flying continental flights, among which the 737.

The 737 is a short haul airplane flying only continental flights. There are two pilots on board the airplane. Their workday consists of an outbound and inbound flight. During the flight, they will have to remain on the flight-deck and can only leave the flight-deck for a sanitary stop. Pilots along short-haul flights will have to remain seated for the longest consecutive periods of time. Pilots on long-haul flights can circulate, as these flights feature at least three pilots. The longest short haul flight may take up to 10 hours, such as the Tel-Aviv flight. This flight has an outbound and inbound flight of 5 hours, excluding the outbound airport stop, which often takes around 45 minutes.

The flight-deck of the Boeing 737 is small. A flight-deck is designed for the moment in which the pilot is controlling the plane by himself. At that moment the pilot is in Eye Reference Point-position, he is obligated to take this ERF-position, which makes sure he has overview of all systems and can easily reach all controls. The actual time that the pilots are flying the plane by themselves might be 20-30 minutes on a flight of three hours. The flight-deck features a seat for the captain and the co-pilot. They are not allowed to switch seats as some controls are positioned differently for both positions. All Boeing-planes feature a yoke (steering column) which takes up a lot of leg space.

figure 12 :The electronic flight bag on the outer side of the flight-deck

On the outward position of the pilot there is a fixed tablet called the Electronic Flight Bag (see figure 12). This tablet replaced books with protocols, which weighed up to 17 Kg in total. Next to this fixed tablet, most airlines provide their pilots with an additional tablet. On this tablet they are able to check weather forecasts, do weight and balance calculations and fill in certain checklists. There is no assigned place for this additional tablet and when using the tablet they often have it laying on their lap.

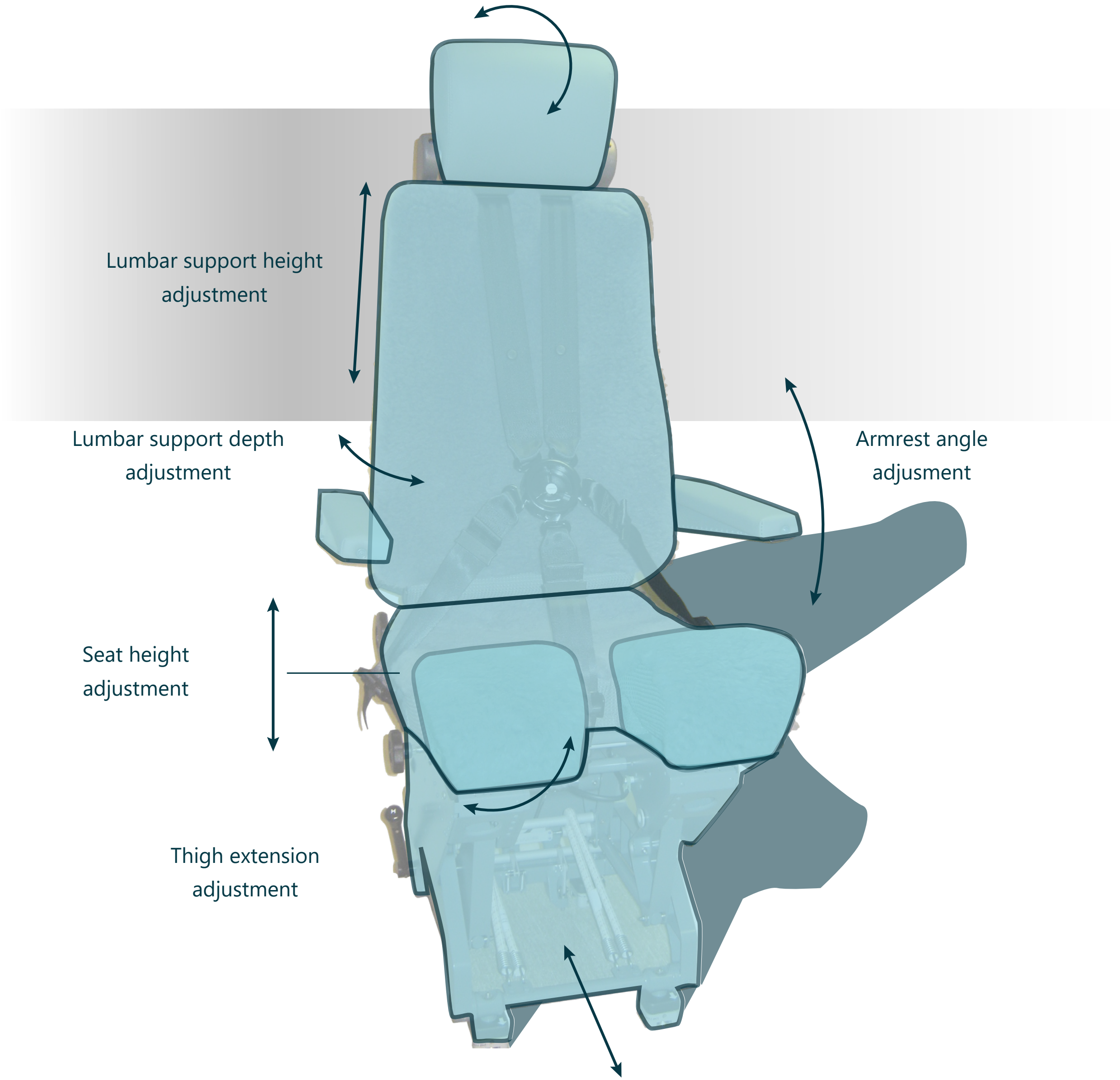


figure 13 : The adjustment systems of the 296 flight-deck seat, featured on a Boeing 737

The 737 flight-deck seat

There are different types of Boeing 737 airplanes. For all these types, the company produced two flight deck seats, the 226 and 296. The 296 and its features are shown in figure 13. From the report of (Vaart, 2009), it can be concluded that the lumbar support is inefficient. The system moves the whole backrest forwards, which makes the pilot slide off the seat. Also, the inability of the seat pan to incline can evoke numbness in the buttocks (Goossens, et al., 1994). It can also evoke a slouched seating posture as it makes the occupant slide forwards. Moreover, if the lumbar support is adjusted upwards then the backrest moves up. This is needed for taller pilots but it leaves a gap between the backrest and the seat pan. In that case, the buttocks and the lower back is not supported. Additionally, the armrest adjustment is inefficient. An armrest should be adjustable in height and not in angle (Goossens R., 1994). For more information about discomfort relating to seat design see appendix 2 and 3.

1. Analysis

1.5 A flight on a 737

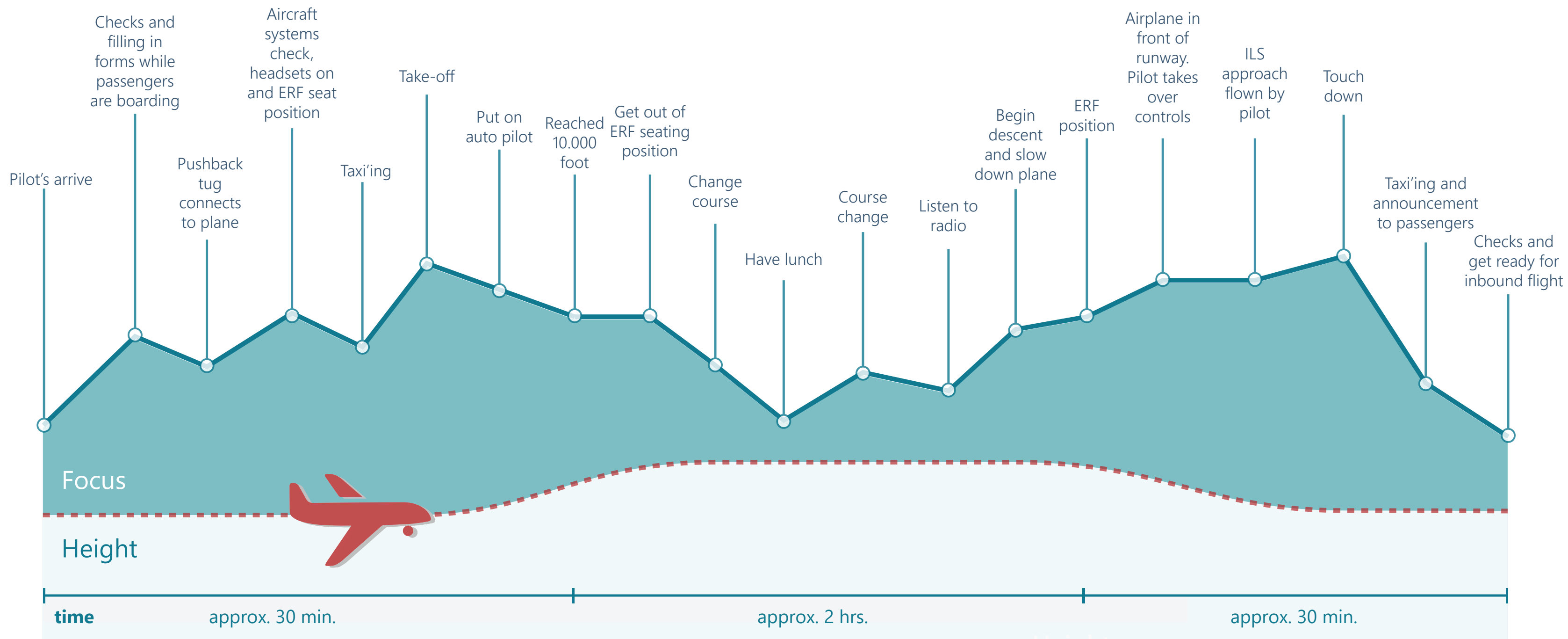


figure 14 : Pilot activity during flight. Note, cruise time is about four times as long as the periods below 10.000 feet. Additionally, this figure is not based on any scientififc data. See appendix 8 for an elaborate customer journey.

This chapter gives an overview of the activities of pilots during flight and how focused they are during these activities. It is based on observations during a flight on the flight-deck of a Boeing 737.

A flight consists of taking-off, cruising and landing. With taking-off and landing being the part below 10.000 feet. During take-off and landing, the pilots are focused and constantly communicating. Taking-off and landing takes about one hour in total, the actual flight time for this flight was around three hours.

Before taxi'ing pilots are busy with filling in lots of forms, doing checks and putting in the flight plan in the FMC (Flight Management Controls). Finally, the tug-car pushes the plane in a position which enables the pilots to drive towards the taxi-lane, this is also the moment in which the pilots take the ERF-position. During actual take-off there is one pilot controlling the plane while the other is constantly checking systems. Once the plane is in the air, the pilots switch to the autopilot. With the autopilot, they will follow a certain take-off flight plan until they are at 10.000 feet. This is where the pilots leave the ERF-position.

Above 10.000 feet, the pilots have time to relax. They read on their tablet, have lunch and are often chitchatting with each other or with other staff. Occasionally, they communicate with ground control after which they adapt the autopilot to set it to the next waypoint. The cruise part during this flight took around 2 hours. The pilots seemed to experience most discomfort during cruise. The flight-deck is not designed for this part of the flight and the pilots have difficulty getting into a comfortable position.

figure 15 : Me and the pilots in the flight-deck of the Boeing 737-700

Once they approach the 10.000 feet mark, the pilots take the ERF-position. The pilots follow a certain approach flight plan with the autopilot. When the airplane is aligned in front of the runway, one pilot will take over the controls. The other pilot keeps checking the systems until the plane has landed. The pilots then drive the plane towards the gate.

The pilots on this flight were both tall (1.93 and 1.99 meters). The captain had a severe upper back injury. According to him, this is caused by being in the same seat every flight. Which makes him always turn his head to the right side when communicating with the co-pilot. Additionally, the captain noted that the yoke inhibits the pilots to straighten their legs. Their legs are always bent outwards, which makes the knees hurt after a while The co-pilot explained that he is too tall to get into a comfortable position. After talking to an ergonomist of an airline, it seemed that it is not possible for him to perfectly adjust the seat to the size of his body.

Additionally, the co-pilot complained that the flight-deck changed compared to the previous version. The mid-panel was widened and the flight-deck seats were shifted outwards. He is now almost touching the ceiling with his head while in ERF-position. Also, the raised floor just in front of the rudder pedals, inhibits the pilots to stretch their legs. They rather put their feet on the ground just before this raised part. In order to do this they have to fully retract the thigh-support, which makes the thigh-support useless for them.

1.6 User research

This chapter covers the user research towards experienced discomfort among airline pilots. The research was conducted by the TU Delft. The undersigned author cooperated in the research and analysed the data of the first 6 pilots as input for this thesis.

During flight the pilots had to fill in questionnaires. These questionnaires resulted in quantitative and qualitative data. The quantitative data consists of ratings on perceived discomfort among the pilots, the qualitative data on improvements on the flight-deck seat. In addition to the questionnaires, pilots were instructed to mount camera's inside the flight-deck. These camera's made pictures every second once the airplane was above 10.000 feet. The picture observations were used to make an overview of the most occurring postures among pilots. The research was conducted along Boeing 737 aircraft, flying continental flights. For the complete research document see appendix 9.

1.6.1 Quantitative results

During the flights, the participants (pilots) were asked to fill in a questionnaire on perceived discomfort every hour. Each questionnaire contained a map of the human body. The participant could rate his/her perceived discomfort on different body parts, such as the shoulder (see figure 16). It is important to emphasize the importance of the discomfort scale (top left, figure 16), a rating of five is seen as high discomfort and is perceived as painful. Additionally, a rating of two is considered to cause long-term musculoskeletal complaints. The participants filled in the questionnaires during the outbound and inbound

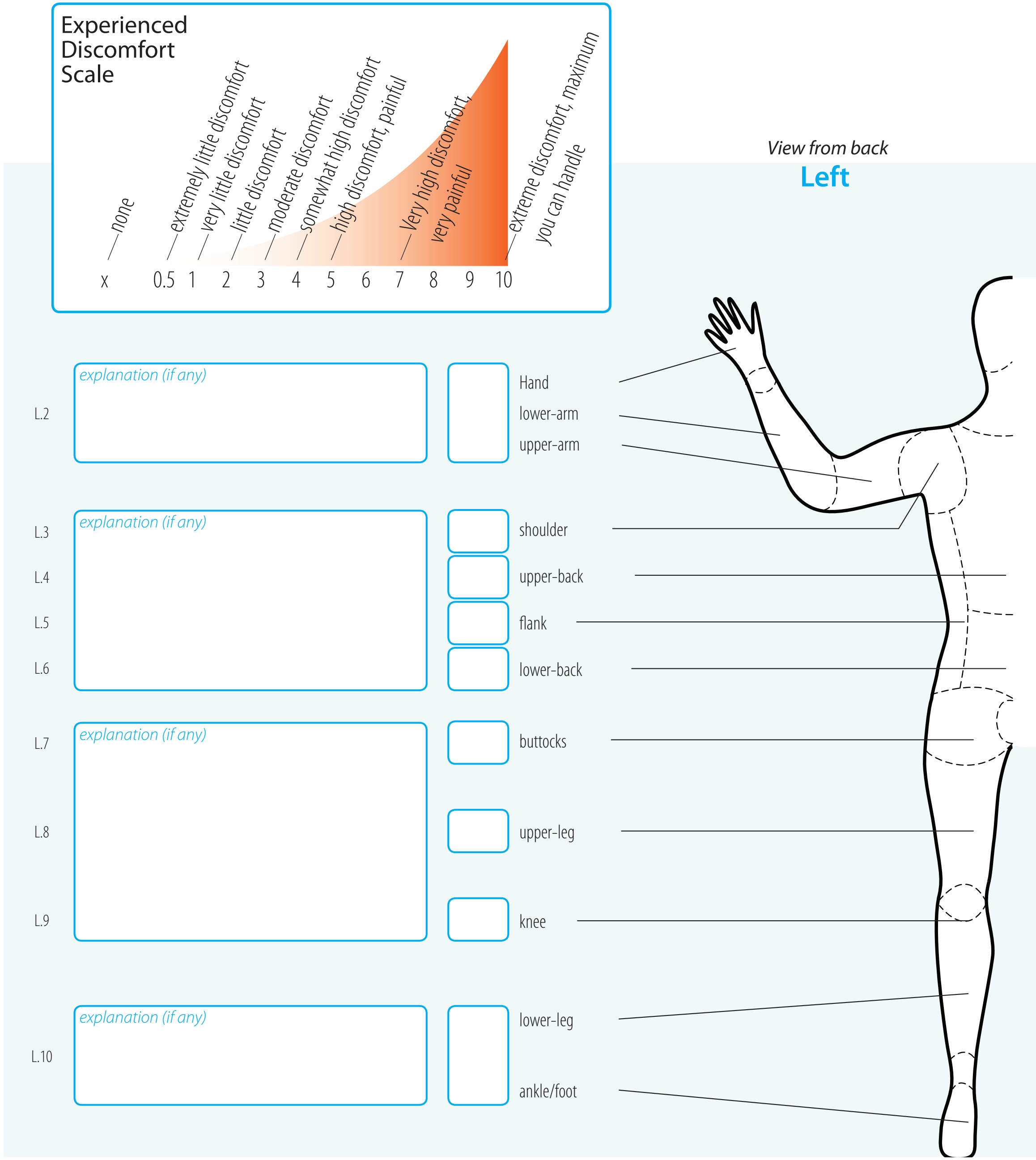


figure 16 : An example of the perceived discomfort questionnaire. Pilots could rate their perceived discomfort on each bodypart and add a comment if necessary. The discomfort scale is shown on the top left.

flight. Figure 17 shows when the pilots had to fill in a questionnaire.

The results of the perceived discomfort ratings were plotted in graphs showing the relative perceived discomfort (see the figures on page 26); in which the first rating given (before flight) is substracted from the other ratings. The most striking results were found in the buttocks and upper back region.

The upper back

For the upper back region four out of six pilots perceived relative discomfort. Two pilots scored a rating of three during the flight. One pilot scored a rating of 4 (somewhat high discomfort) before the flight started. See the graphs on the next page showing the results of the first three participants. Two pilots suffered from upper back and neck injuries. The pilots related this discomfort to the fact that they turn their body and neck to the centre of the flight-deck when paying attention to the other pilot or crew members. One pilot, also mentioned that it could relate to the position of the EFB, which is on the outer side of the flight-deck. It could be a combination of factors, pilots have a big 'field of attention' (see figure 20 on page 27). It is known that for such a field of view a person needs to move its upper body to be able to see the object (Oudendijk, M.L.W. & Buchem, P.J.A., 2005). This could contribute to the discomfort in the upper back and neck area. However, other factors could also contribute. Many pilots commented on the fact that the backrest is inefficient. A tall pilot also commented that the backrest does not suit his posture. In the observational videos it can be seen that this pilot constantly has a slumped posture (a hollow upper back). This posture is also seen with other pilots, but then often when reading, writing and using their tablet. Additionally, pilots often have to reach for controls during cruise altitude as they are sitting far away from the controls, which also causes their back to bend.

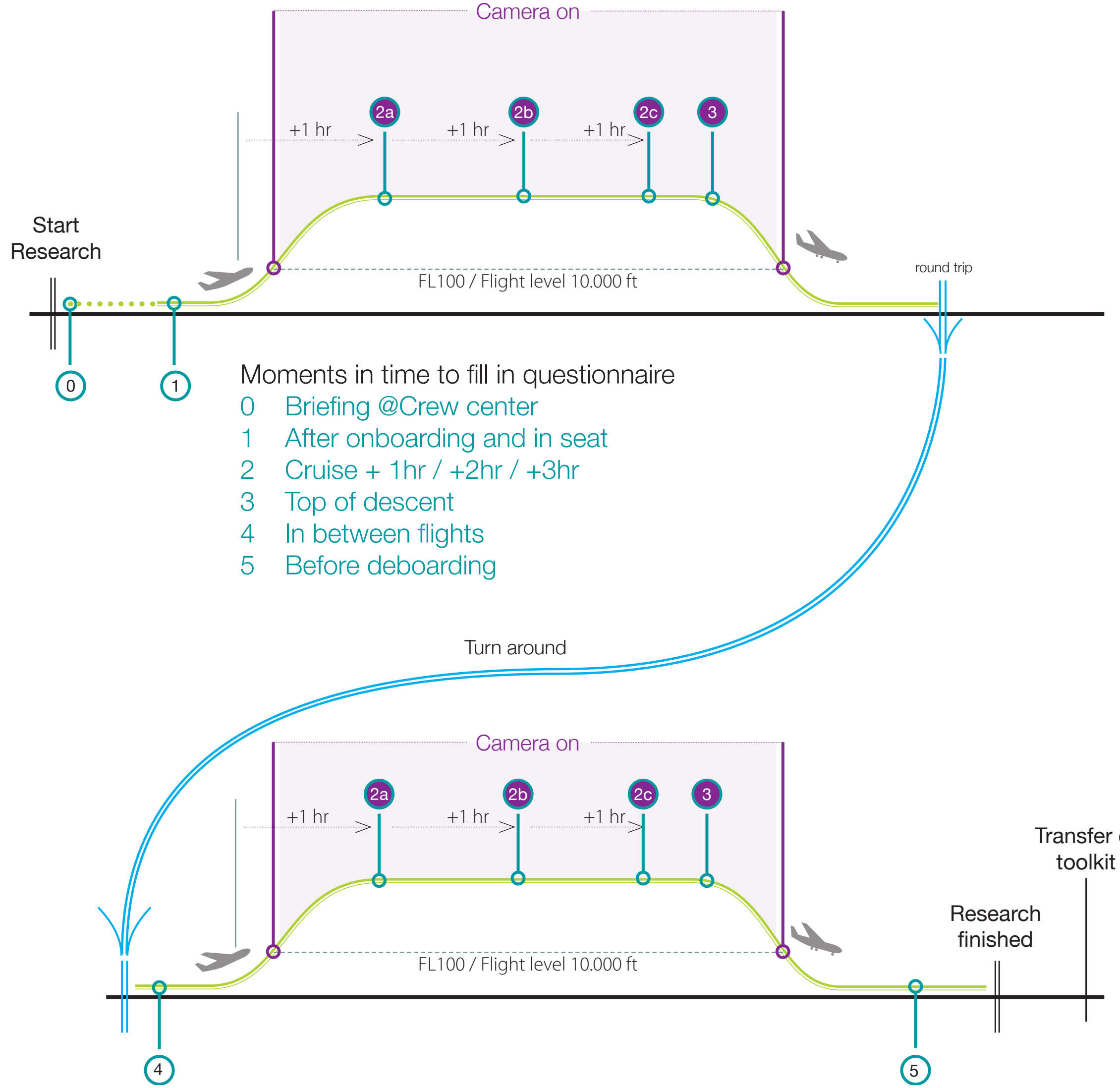


figure 17 : The figure shows all moments on which pilots had to fill in certain questionnaires. The questionnaires were numbered according to the numbering in the figure.

The buttocks

For the buttocks region all three pilots which scored on relative perceived discomfort in the buttocks, showed a drop in discomfort during the turnaround (at the outbound airport). The questionnaire OBF.4 (Outbound Flight questionnaire 4) had to be filled in during the turnaround, these are higlighted in the graphs. The scores show that getting out of the seat diminishes the perceived discomfort. However, one hour into the inbound flight, two pilots started to perceive discomfort again. This could indicate that pilots might need to get out of the seat more often.

The design of the seat pan and backrest could also relate to the problem. Research has shown that a seat with a backrest and a levelled seat pan causes friction forces on the buttocks which could cause a feeling of numbness (Goossens, 1994). Results of the questionnaire also showed that four out of six pilots were perceiving numbness during the flight. Additionally, five out of six pilots felt an uneven pressure from the seat during the flight. Thus, the discomfort might also relate to a bad pressure distribution in the seat pan. Additionally, the adjustment system of the backrest might also be related to this problem. When adjusting the lumbar support, the backrest shifts forward. This creates less space on the seat pan. The pilots then might have little support for the buttocks and upper legs.

Another thing to address is that from the posture mapping (also see page 30), it can be seen that pilots almost do not stretch their legs while they are in their seat. It is known that the taller pilots are not able to stretch their legs. This keeps the pilot in a static leg posture, which might evoke a feeling of discomfort and numbness in the buttocks.

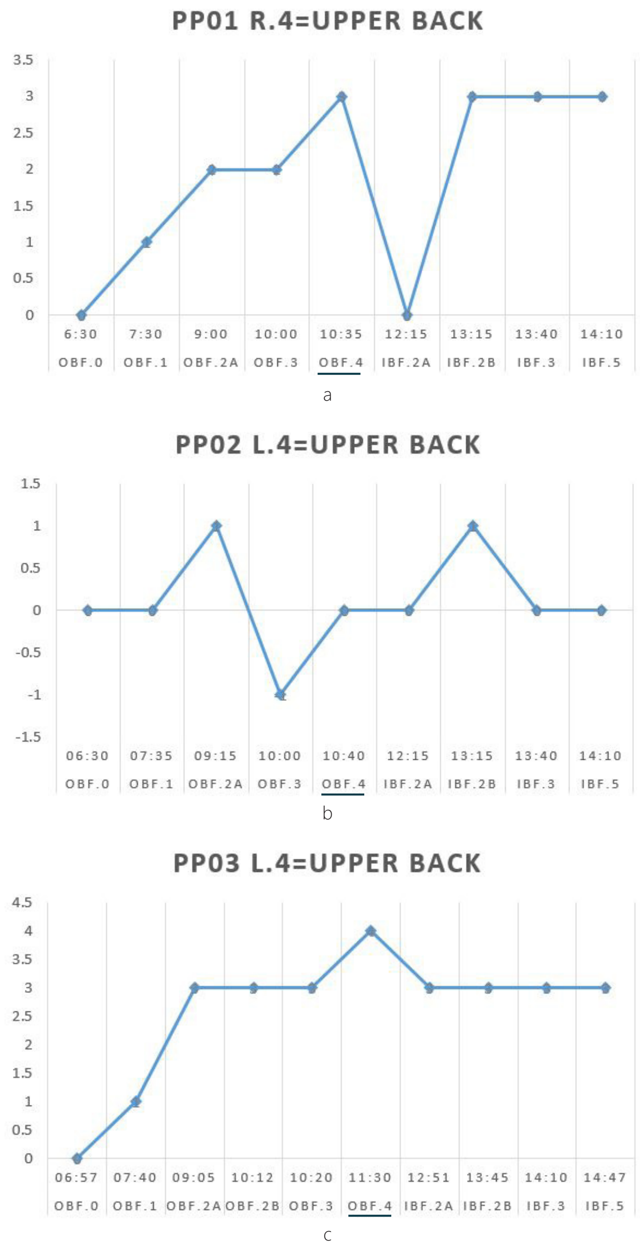


figure 18 **a,b and c**: These graphs show the relative perceived discomfort in the upper back on the y-axis. Which is the perceived discomfort score with the rating scored before the flight subtracted. The horizontal axis shows the time and the code belonging to the specific questionaire.

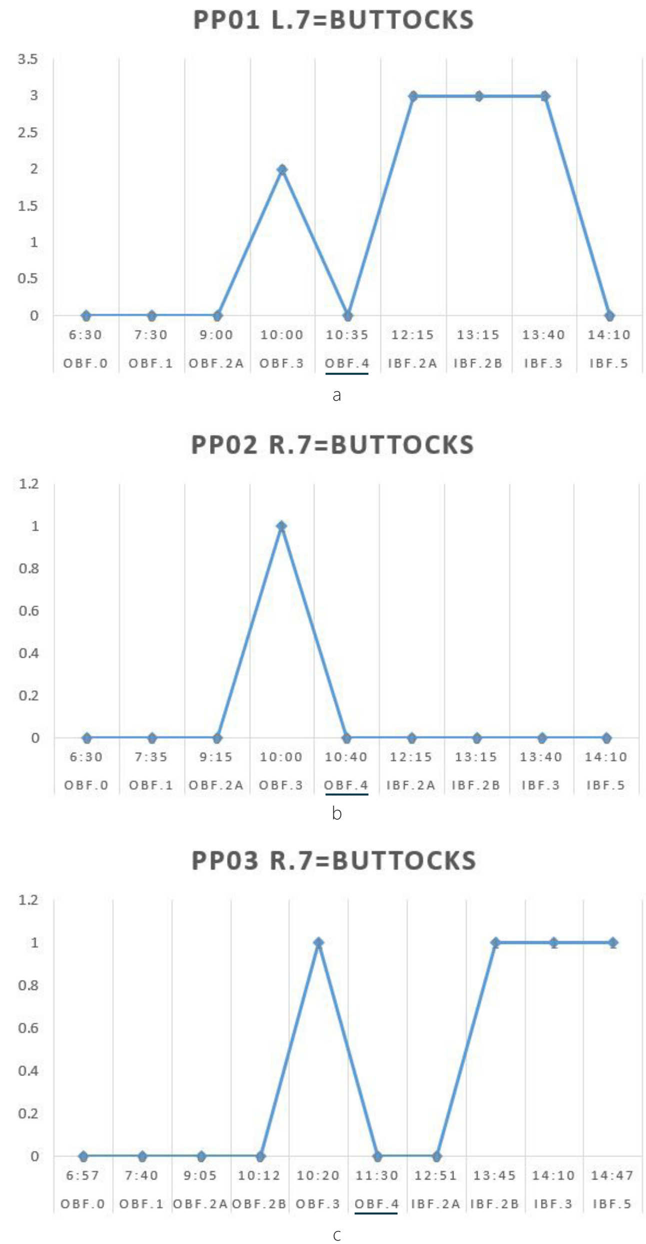


figure 19 **a, b and c**: These graphs show the relative perceived discomfort in the buttocks on the y-axis. Which is the perceived discomfort score with the rating scored before the flight subtracted. The horizontal axis shows the time and the code belonging to the specific questionaire.

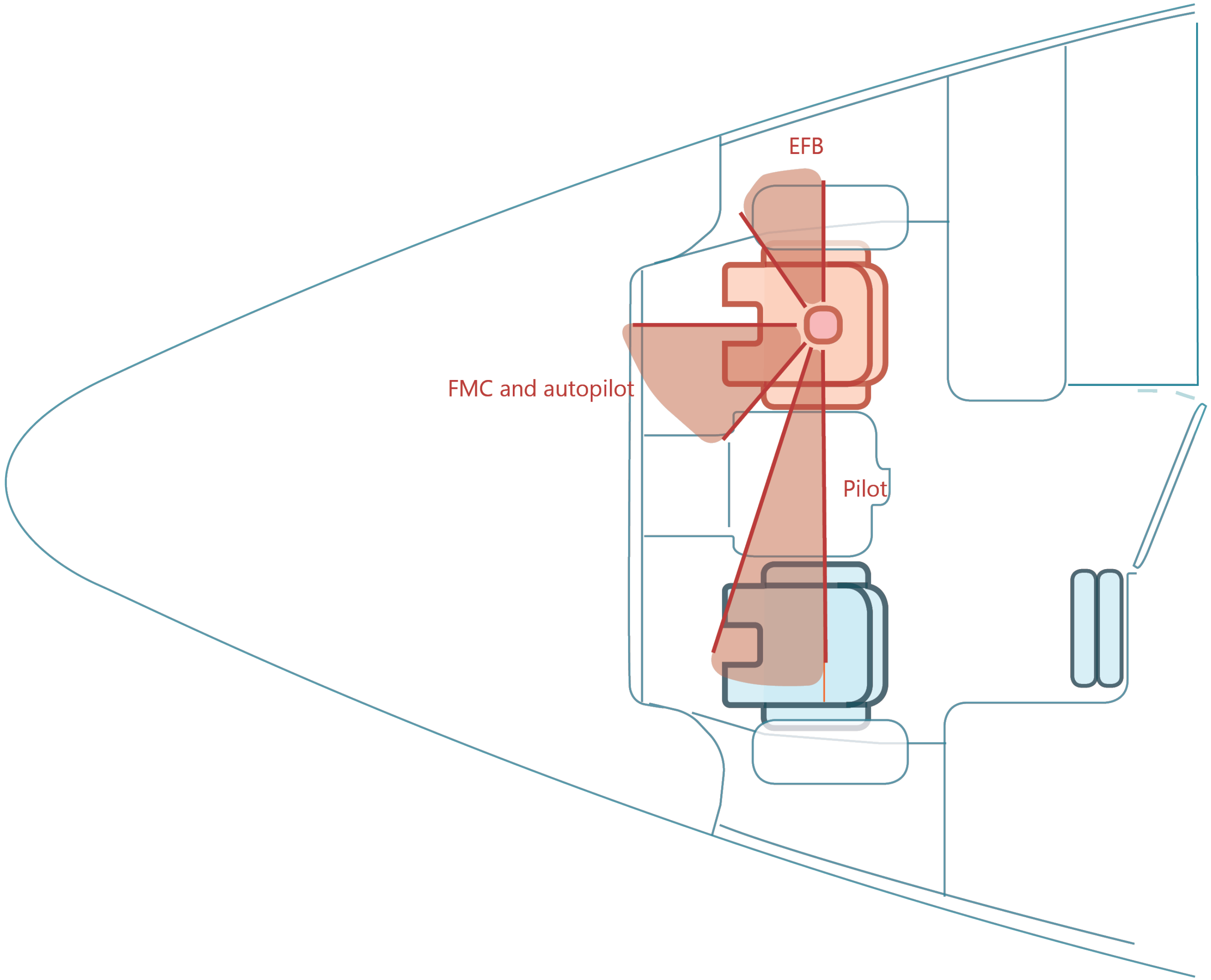


figure 20 : This picture shows the "area of attention" of the pilots. Neck injuries might be caused due to positioning of the EFB and the other pilot, which is on the opposite side of the seat

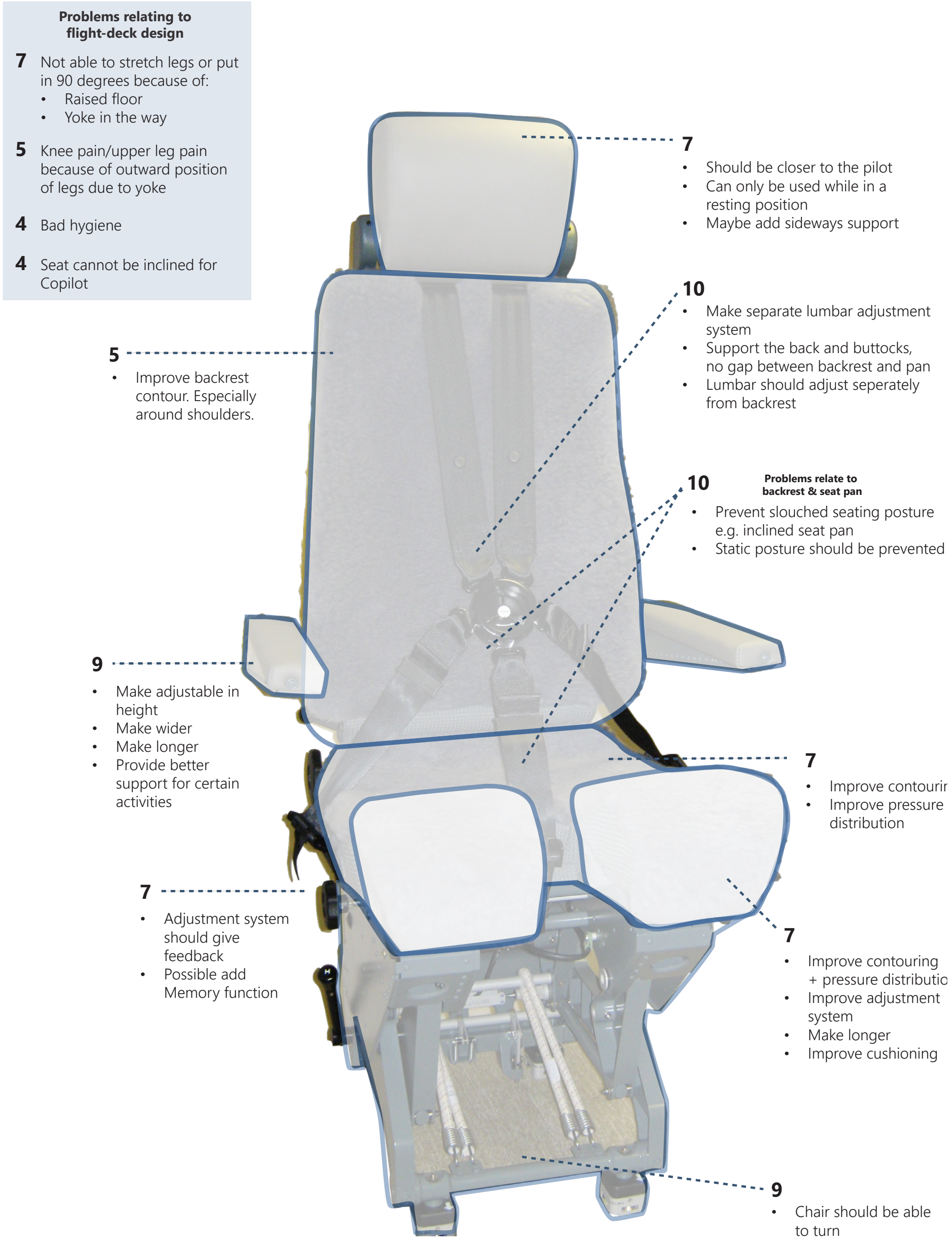


figure 21 : A visual showing the rated improvements for different parts of the seat.

1.6.2 Qualitative results

The improvements shown in figure 21, is the result of a longer list of improvements. This list sums up the improvements suggested by pilots in the questionnaire and improvements suggested by myself. Each improvement belongs to a specific part of the pilot seat. The improvements by pilots were ranked according to the number of pilots which suggested improvement on a certain part, with a maximum of 5. The improvements suggested by myself, were rated on a scale from 1 to 5, the higher the number the more important the rating. These scores are summed up and shown in the visual. The following parts with according improvements were given the highest score:

- The backrest (a score of 10)
- The armrest (a score of 9)
- The ability to turn the chair (a score of 9)

It is important to note that from the questionnaires it seemed that most pilots knew that the backrest could be improved. However, they did not seem to relate it to feelings of discomfort. It seemed that the pilots often related feelings of discomfort to how the design of the seat supports them in doing certain tasks. Another reason for pilots to suggest improvements was inefficient adjustment systems. Many pilots suggested that the armrest should be adjustable in height and that it should be longer. Additionally, a pilot suggested that an unfolding table from the armrest could assist the pilot in doing certain tasks. For the whole list of improvements on which this figure was based on, which also shows relating complaints and injuries, see appendix 10.

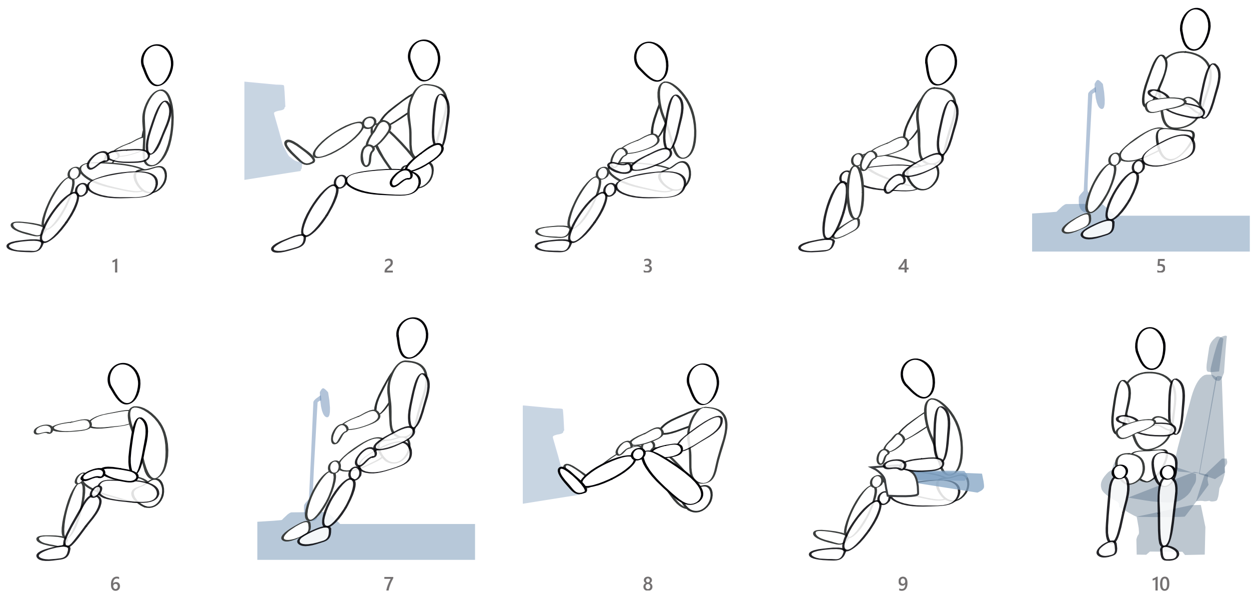


figure 22 :The 10 most occuring postures resulting from the posture analysis.

Posture analysis

The TU Delft will analyse the picture data by doing behavioural observation analyses. Unfortunately, there was not enough time during the thesis to wait for these results. However, the picture observations were used to make an overview of the most occurring postures among the first six participants (see figure 22). This was done by watching the observations at high speed and checking when a certain body posture occurs. The duration of the postures were not taken into account.

The postures in the overview represent the co-pilot and is portrayed from the centre of the flight-deck. It can be seen that the pilots often have their attention focused towards the captain's side (postures 2, 4, 5, 7 and 10).

The posture overview also shows that pilots often adapt into a slumped sitting posture (an arched back). For instance when using their tablet (posture 3), when using certain flight controls (posture 6) and when reading (posture 9).

The posture in which the pilot uses the EFB, which is on the outside of the flight-deck, does not seem to occur. It could be that these postures were missed due to the high speed at which the pictures were analysed. It does not exclude that the position of the EFB contributes to upper back injury. It requires the pilot to completely turn his head to the outside of the airplane (see figure 20 on page 27).

Recap

To keep overview over the results of the user research, the most important results are summed up.

Upper back

- Perceived discomfort ratings on the upper back were relatively high
- This could relate to an inefficient backrest design
- Most likely relates to the pilot being in the same seat ever flight
- Most likely relates to over-stretching of the neck due to the position of the other pilot and the EFB

Buttocks region

- Discomfort was perceived but not that high
- Getting out of the seat most likely diminishes discomfort

Improvements on flight-deck seat design

The following most important improvements were identified:

- The backrest (a score of 10)
- The armrest (a score of 9)
- The ability to turn the chair (a score of 9)

Postures

- Pilots are often paying attention to the centre of the flight-deck
- Often have an arched upper back due to reading, using the tablet or reaching for controls.
- Pilots often adapt into a slumped sitting posture

1. Analysis

1.7 Search area ideation

This chapter includes the ideation sketches and processes towards finding the search areas.

Collecting valuable data during the analysis phase ended with the user research. Thus far, valuable opportunities for flight-deck seat improvements have been collected. However, to make sure that other opportunities were not overlooked ideation sketches were made. The idea was to put any flight-deck seat improvement on paper. Other, new opportunities might arise this way.

This ideation session shows solutions for the backrest, seat pan, seat layout but also the use of new materials.

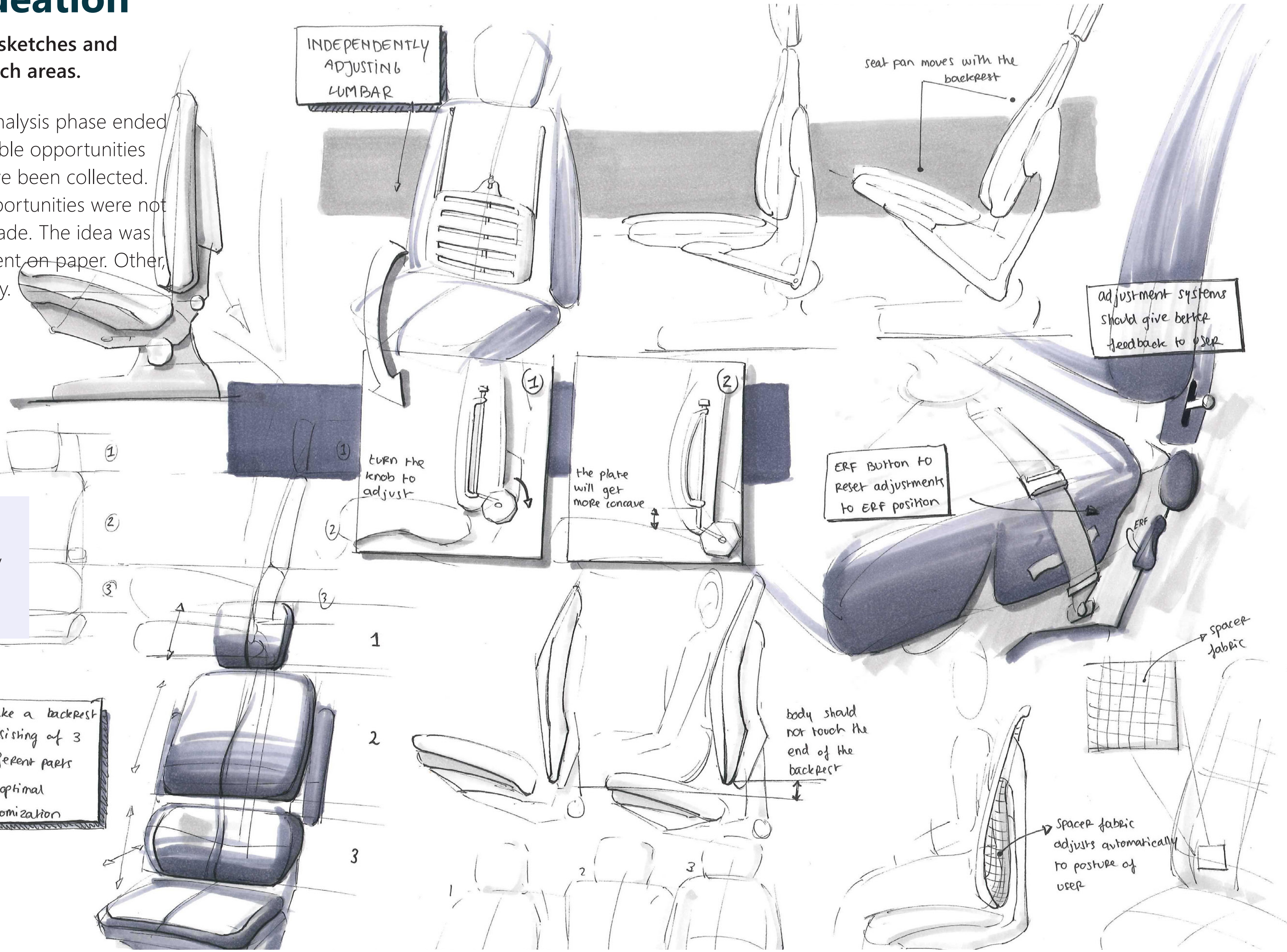
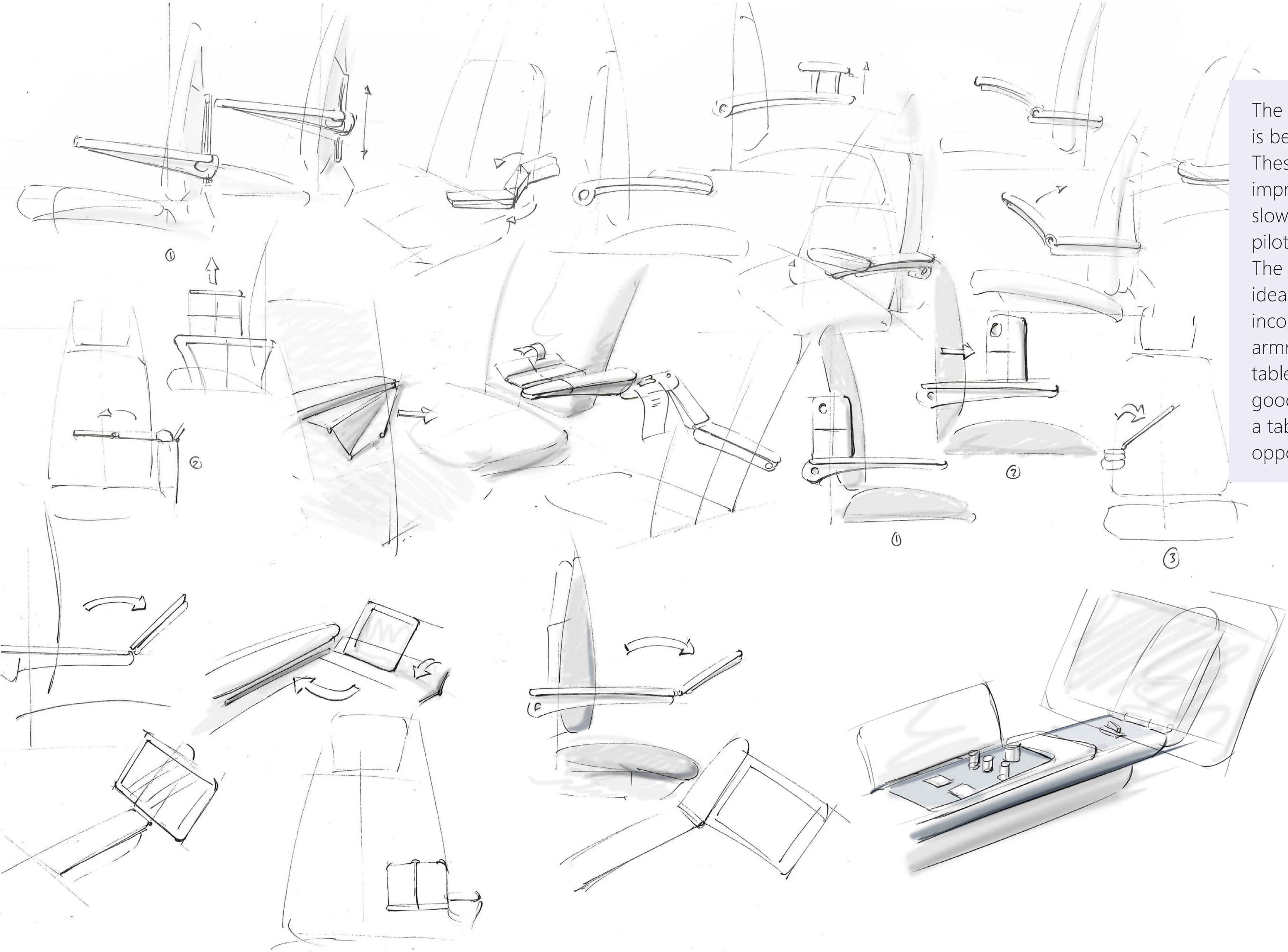


figure 23 : Ideation session backrest, seat pan, seat layout and material use



The purpose of these ideation sessions is best seen in this second ideation. These sessions began with ideas about improving the armrest (upper left). This slowly turned into ideas to support the pilot in reading, writing and eating. The ideation session ended in an idea to support the use of a tablet by incorporating a tablet holder in the armrest. Although incorporating a tablet holder in the armrest was not a good solution, supporting the use of a tablet turned out to be a valuable opportunity.

figure 24 : Ideation session armrest improvement

1.8 Search area's

This chapter covers the findings of search areas and the selection of the final search area. The values of the final search area will be adressed in detail.

The search area's were found with the help of the search area ideation and the information documented in chapter 1.4 (context & product), 1.5 (A flight on a 737) and 1.6 (user research). After brainstorming the following four search area's were chosen:

1. **Improving the lumbar support and the transition to the seat pan.**
   Seat improvement towards an independently adjusting lumbar support and a better transition from seat pan to backrest. The current lumbar adjustment is inefficient as it pushes the user from the seat. Additionally there is a gap between the seat pan and the backrest when the backrest is adjusted upwards, which leaves the buttocks unsupported.
2. **Support the use of a tablet**
   Providing a fixed place for the tablet that enables the pilot to ergonomically interact with the tablet. All pilots, from the airliner involved, are obligated to use a personal tablet in the flight-deck. However, the use of a tablet is not supported in current flight-deck design.
3. **Supporting the pilot while eating, reading and writing**
   Support the pilot in activities during cruise, mainly eating, reading and writing. Positions in which pilots, currently, often adapt into a slumped upper back posture.
4. **Cushion optimization**
   Cushion optimization for a better pressure distribution in the seat pan and directive feedback which pushes the user in his seat. This to prevent a feeling of numbness in the buttocks and to prevent the pilot from adapting into a slumped posture.

Initially, there were two other search areas; one focused on improving the armrest and the other on designing a turnable seat. However, during the process, it was decided to not include these search area's. A turnable seat can not be realised, as there is simply too little space in any flight-deck design for such a solution. The options in improving the armrest were found to be too limiting. As it came down on widening the armrest and making it adjsutable in height.

The search area's and their possibilites were discussed with the graduation company. It became clear that the company was already working on optimizing the cushion's pressure distribution and contouring. Additionally, they were working towards integrating an independently adjusting lumbar support. Aside of that, these search area's required more technical solutions than design solutions, solutions which the company might better find and create by themselves. In other words, search area 1 and 4 were least valuable for the company. They made clear that the second search area would be most valuable. Sooner or later a tablet holder would be required in the flight-deck. Most pilots already require a tablet on the flight-deck and the use of tablets will most likely keep growing.

It was clear that the second search area would be the right choice. It is important to note that the main underlying goals of supporting the use of a tablet is still to reduce discomfort among airline pilots The search area will be the input for the design brief in the next chapter and will be transformed into a specific design goal with according values and requirements.

My workplace in the applied labs of the faculty of Design Engineering. The green wall was used as inspiration during conceptualization.

figure 25 : : My workplace at the faculty of Design Engineering at the TU Delft

2. Conceptualization

This chapter covers the process towards the final concept. The chapter begins with the design brief which defines the boundaries for ideating concepts. The chapter will end with the final concept. This concept is evaluated too highlight important improvements and challenges in the design.

In the picture:
The picture shows an ideation session towards supporting the use of a tablet in the flight-deck. A brainstorm session with this ideation drawing as the main subject resulted in valuable important requirements and demands from the graduation company. These are incorporated in the design brief *see page 36.*

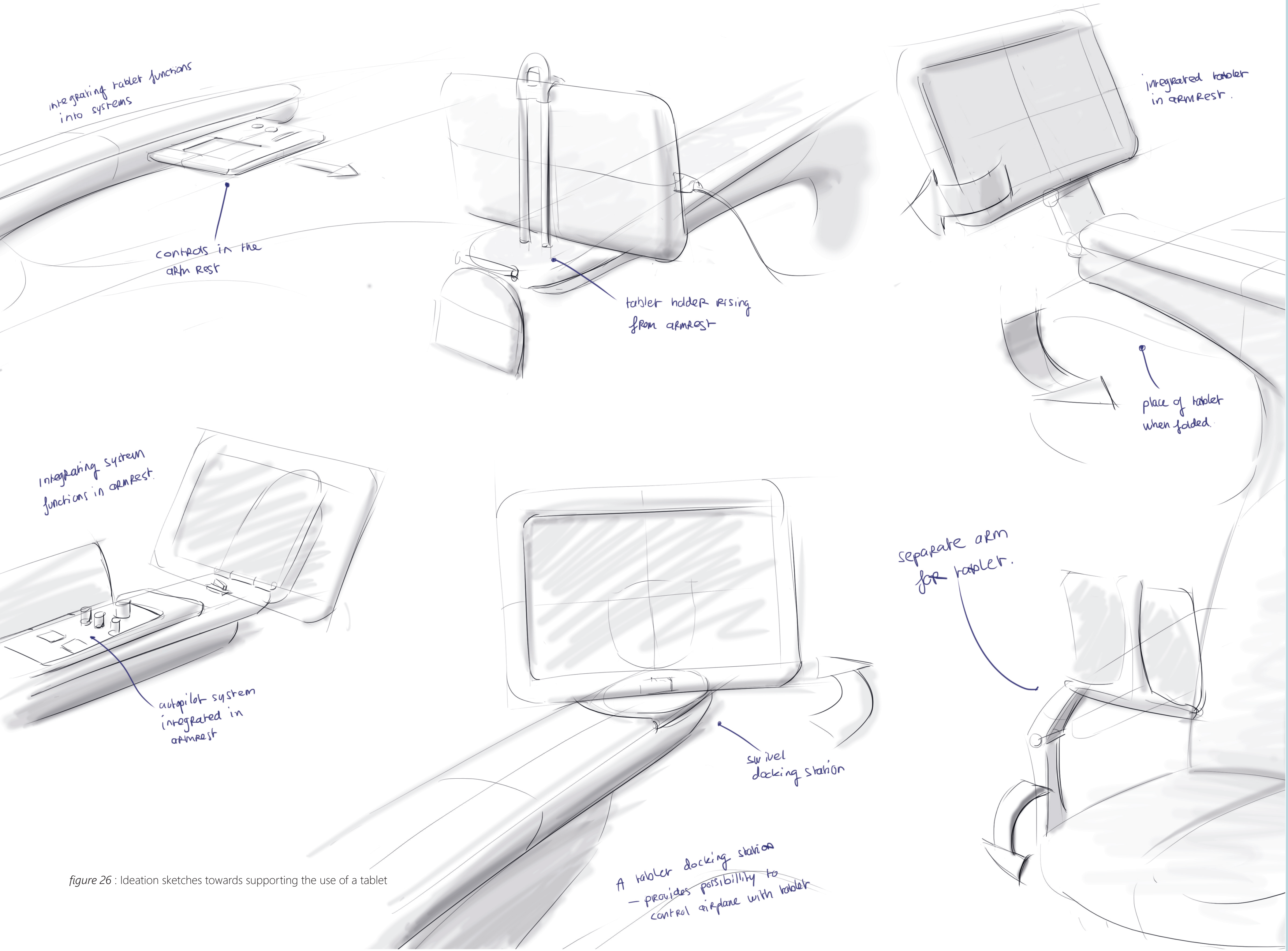


figure 26 : Ideation sketches towards supporting the use of a tablet

2. Conceptualization

2.1 Design brief

This chapter covers the design brief. In the design brief a design goals is defined. This is supported by certain design values and design requirements which should be implemented in the design

Before actual conceptualization starts, it is important to make the design goal of the final search area more specific. Additionally, it is important to identify the specific value within the search area and come up with basic design requirements before actual designing starts.

The graduation company

When discussing the possibilities with the graduation company, it became clear that the embodiment of a product to support tablet use would take the form of a tablet holder. Additionally, the main goal would be to reduce the discomfort among airline pilots. The goal was adapted into the following:

"Designing a tablet holder to reduce discomfort among airline pilots."

This can be seen as the main design goal for the final product.

Design value

While designing, it is important to keep in mind the main value that should be present in the design. By discussing possibilities with the company and looking back on information retreived during the analysis phase, the following design value's were found:

1. **Create an ergonomically responsible way of using the tablet.**
   This to diminish discomfort in the upper back.
2. **Minimizing the area of visual attention by replacing the EFB.**
   In most airliners the EFB is positioned somewhere to the side of the flight-deck. By having an assigned place for the tablet, it could take over the function of the fixed EFB. The tablet holder could provide a more ergonomic way of using the EFB and could minimize the area of visual attention in the flight-deck which could prevent over-stretching of the neck. See page 27 for the current situation in the Boeing 737.
3. **Incorporating flight control systems.**
   in the far future, certain flight-control systems could be incorporated in the tablet, so that the pilots do not have to reach for flight-controls during cruise altitude.
4. **Limit the added weight by replacing the EFB.**
   The pilots will have an assigned fixed place for their tablet. The tablet can therefore take over the functions of the EFB. This is important for aircraft manufacturers and airlines as lightweight design is an important requirement for them.
5. **Working towards a paperless flight-deck.**
   A tablet holder creates the opportunity to more extensively use tablets. It can support the pilot in reading and making notes on the tablet, Additionally, the tablet creates the opportunity for the airline to fully digitalize documentation on the flight-deck
6. **Showing the benefits of a use-centred design**
   By incorporating all this value in the design. The product could show the benefits of a use-centred design (also see page 18), by working towards a flight-deck that is easy to control and that supports the pilots in all their activities.
7. **Provide the ability to access seat adjustment settings through the tablet.**
   getting the tablet connected to the flight-deck creates the ability to provide access to seat adjustments through the tablet. An app on the tablet can make it possible for the pilot to save certain pre-set adjustment settings. In that way, the pilot can adjust the seat to a perfect setting by one click on the tablet.

The first three values relate to the overall goal; reducing discomfort and are based on information documented in chapters 1.4, 1.5 and 1.6.

The third value can in the long run significantly enhance the comfort of the pilot as he does not have to reach for controls during cruise altitude (such as the FMC and autopilot). Such a change can act as the first step towards use-centred design, showcasing the transition towards making a flight-deck easier and effortless to control. This is beneficial for airlines as they will have to deal with the rising demand of pilots and need to be able to more easily select candidates for pilot training. Additionally It could be the first step towards a distributed air/ground, socio-technical system. A system in the tablet from which certain flight-deck functions are controlled could be the foundation of a platform which makes it possible to control the airplane from a distance. Which in turn is the first step towards single-operated aircraft, which would further solve the problem of the growing demand of pilots. See page 18 for more information on a distributed air/ground, socio-technical system and the growing demand of pilots.

Basic design requirements

The ideation sketch (see page 35) showing possible designs was discussed with the company. This resulted in important demands from the company:

- The tablet holder should consist of a separate arm. Incorporating the tablet holder in the armrest would not work. Pilots would not be able to use the armrest anymore. Additionally, there is not enough space as the armrest already has the maximum length at which it can be used in the most forward position of the seat without touching other components of the flight-deck.
- The company rather not incorporate actual buttons in the armrest to use for flight control. As this makes them directly responsible for the failure of flight control systems.
- The tablet holder should be fixed to the flight-deck seat as it is difficult to get approval of aircraft manufacturers to attach a tablet holder to anything else in the flight-deck. This is due to the fact that the graduation company, only delivers flight-decks seats.

These were the most important demands from the graduation company. For the whole list of requirements see appendix 11.

Continuation

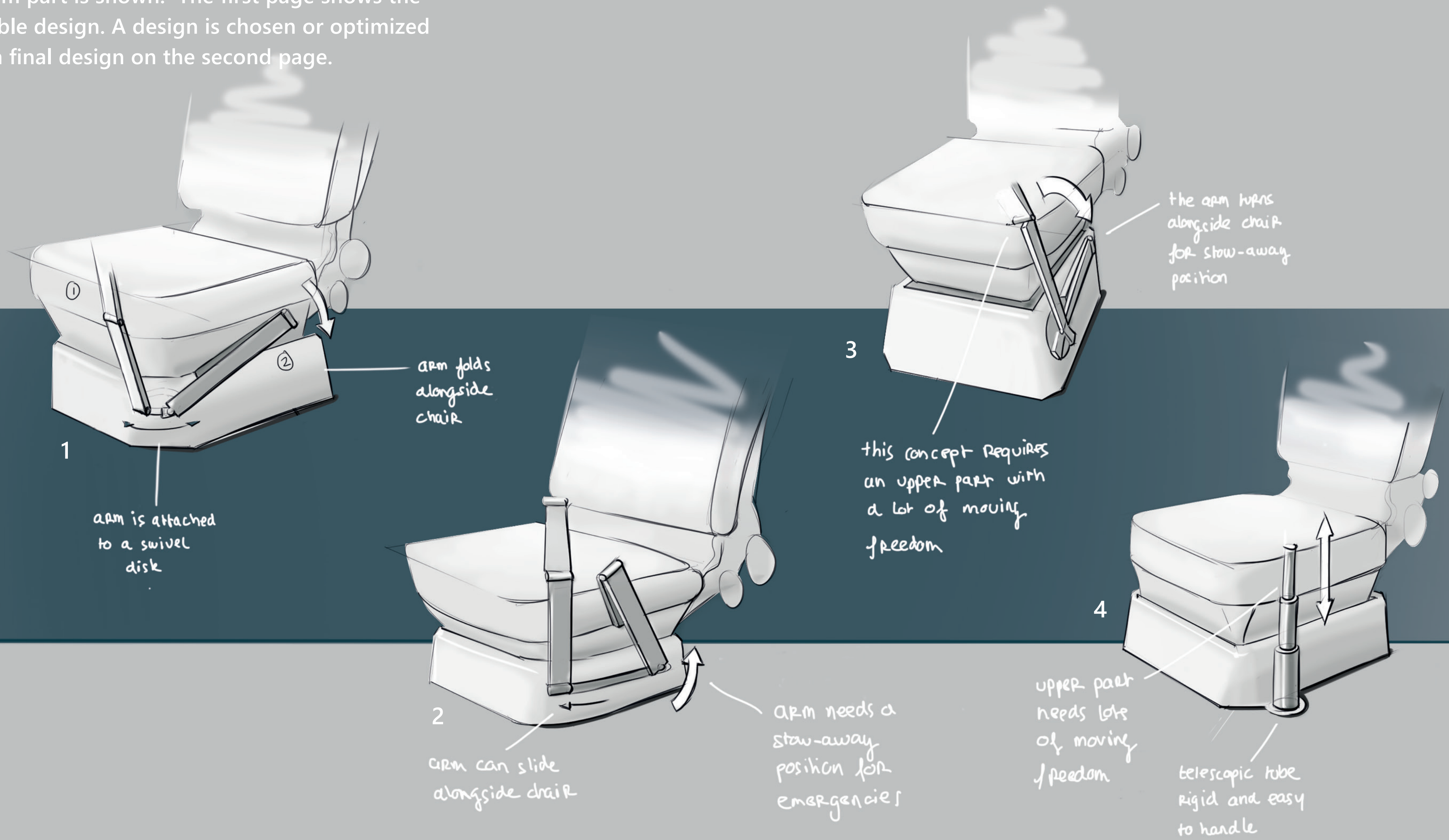
A few important decisions were made to make conceptualization and embodiment easier and to be able to keep a clear overview over the process during these phases. **During the conceptualization the tablet holder is split into three parts: the bottom part of the tablet holder, which is attached to the seat, the middle part which creates freedom of movement and the top part on which the tablet is attached. Each part will be further conceptualized separately.** The design values will be kept in mind during conceptualization. However, these will not be fully implemented in the design during the conceptualization phase. It was decided to first make and rate concepts based on the following practical design aspects:

- Lightweight design
- Easy to handle
- Freedom of movement
- Simplicity

Due to design constraints it will not be possible to fully embody the whole tablet holder, more on this in the iteration part (page 46). One of the three parts of the tablet holder will be selected and will form the main focus during embodiment..

2.1 Concepts bottom part

The following pages show the conceptualizationg of the three different parts of the tablet holder. On these two pages the conceptualization of the bottom part is shown. The first page shows the possible design. A design is chosen or optimized into a final design on the second page.



Concept 1 and 2 are quite complicated. This makes the product difficult to handle for the pilot. Additionally, these designs feature a lot of moving parts which increases the chance of the product breaking down. Furthermore, concept 3 features a telescopic tube which is often heavy as it is made of thick steel components.

Concept 3 will be used as input for the final design. This concept provides lots of freedom of movement.

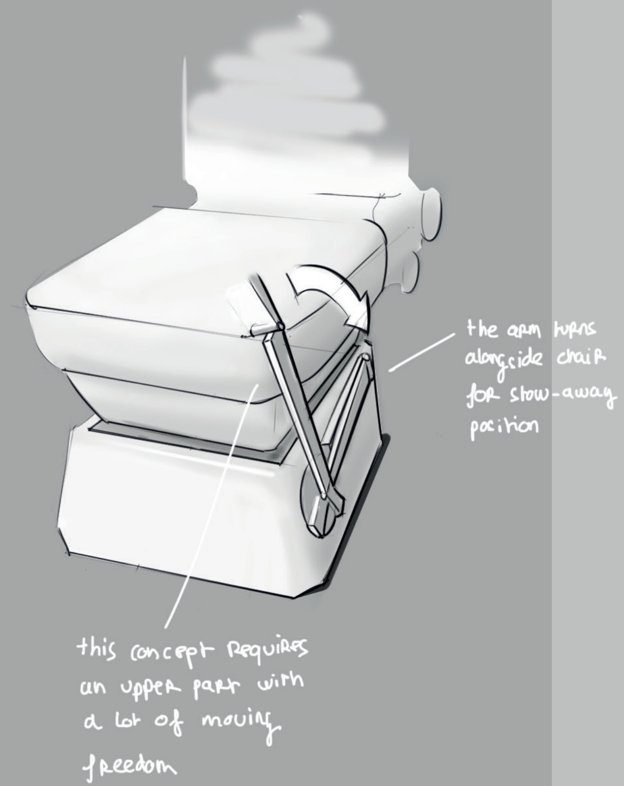
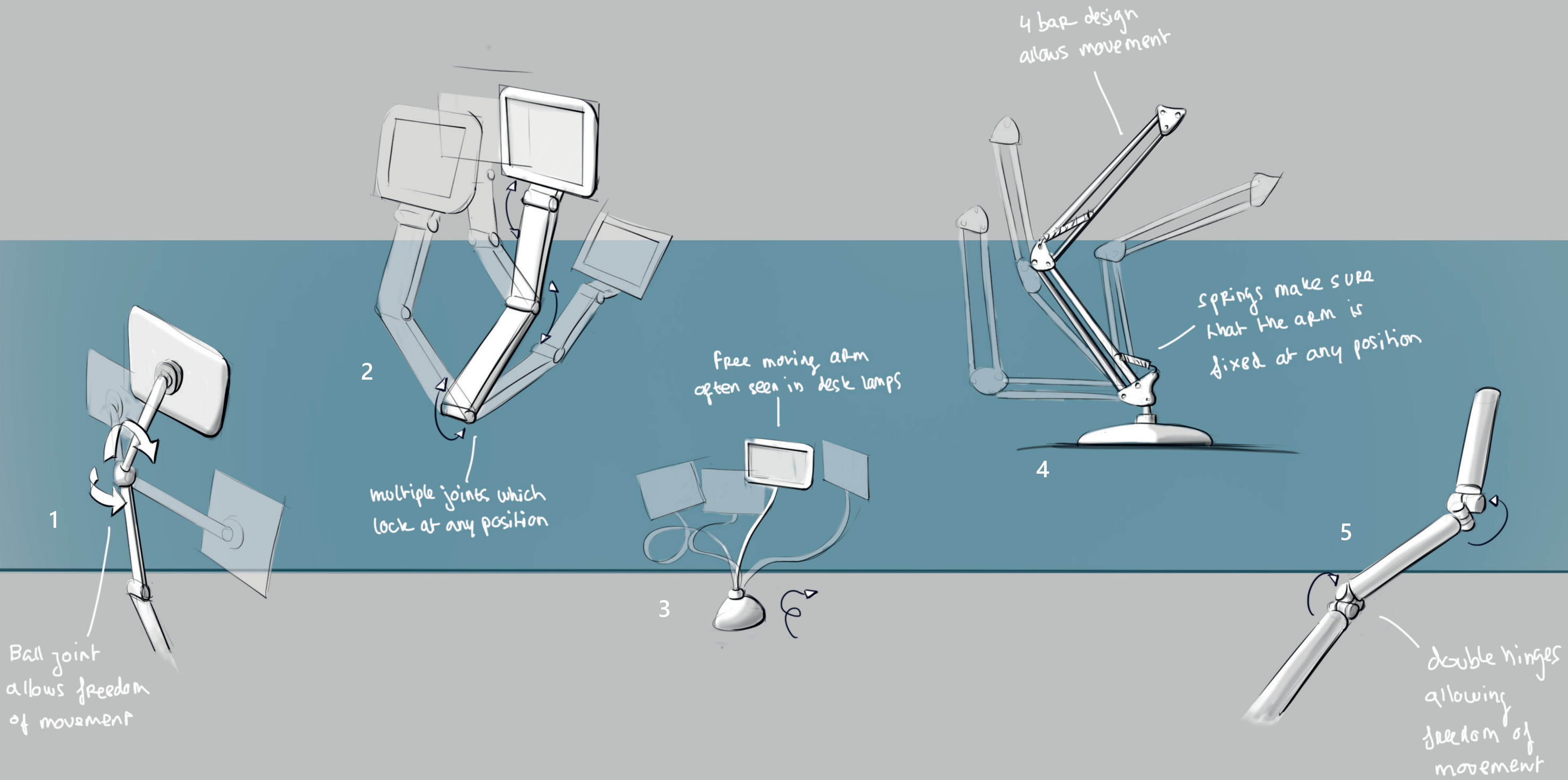


figure 27 : Concept ideation of the bottom part of the tablet holder

2. Conceptualization

2.2 Concepts middle part



Concept 1,2 and 3 are all promising concepts. They all feature a lot of freedom of movement. The third concept is also very lightweight.

For the final concept a hybrid concept between concept 1 and 2 was chosen. A double hinge at the base with a double hinge near the tablet. Concept 3 was not chosen at it has more chance to break down after extensive use.

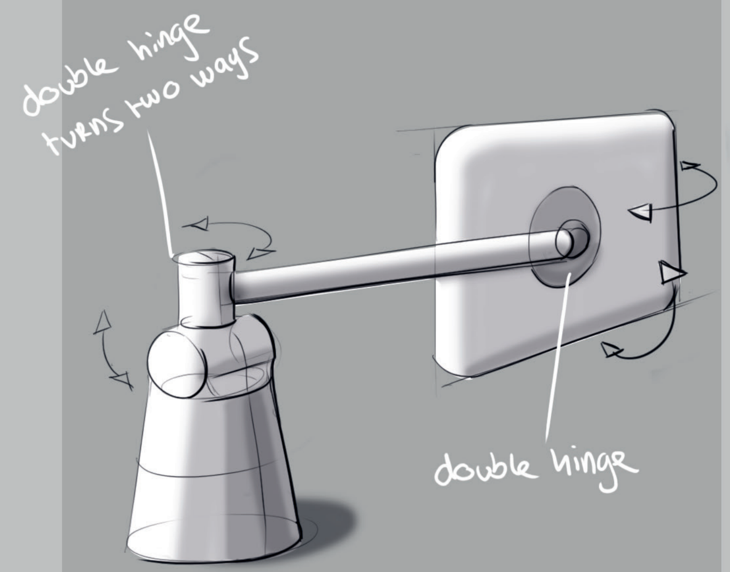
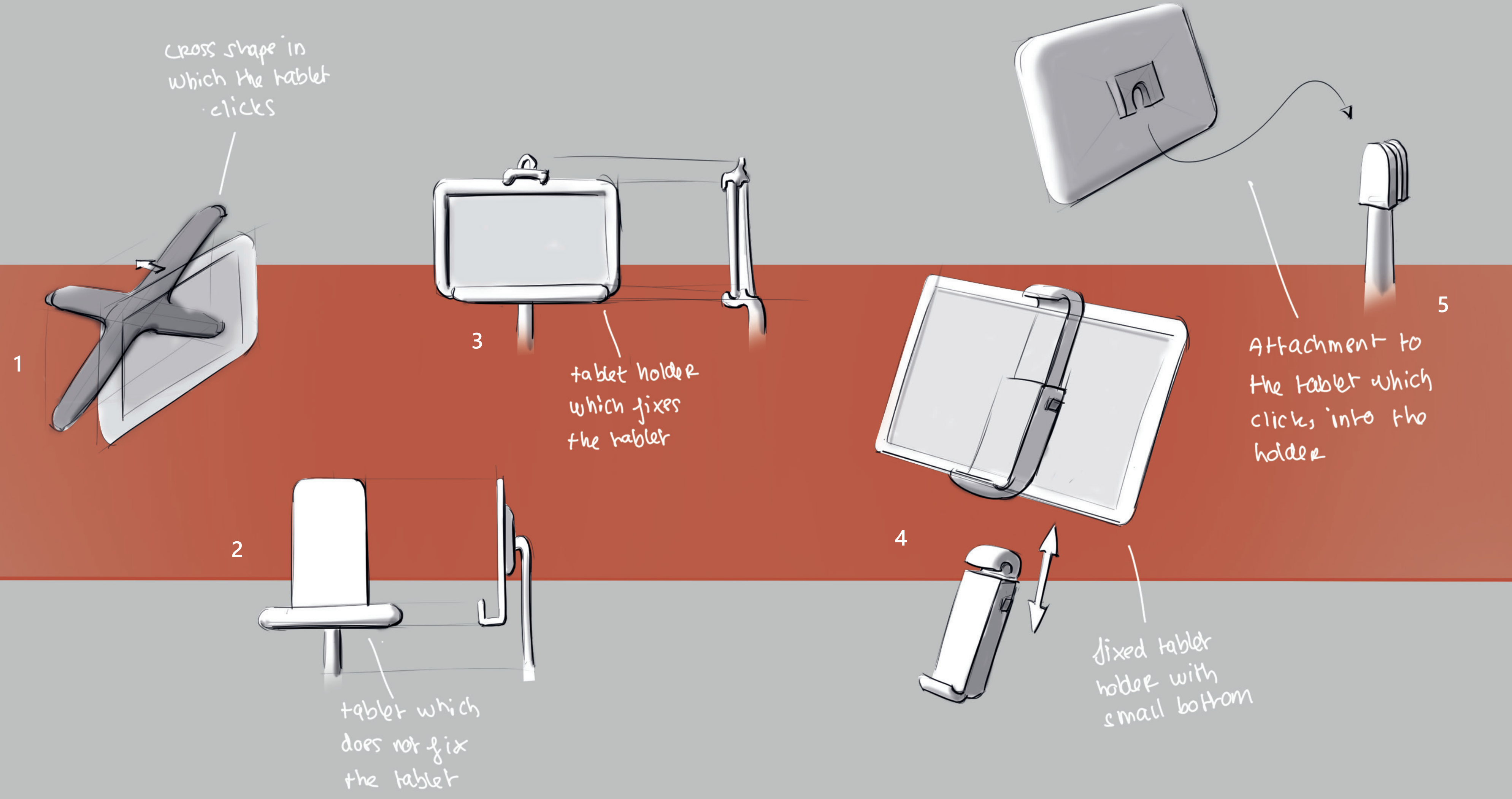


figure 28 : Concept ideation of the middle part of the tablet holder

2.3 Concepts top part



Concept 3, 4 and 5 look promising here. These are all concepts which fix the tablet and are compatible with any tablet size. Additionally, with concept 5 it is easy to attach the tablet to the arm.

Finally, concept 3 was chosen as a final concept. The wide bottom gives more stability compared to concept 4. Furthermore, concept 5 could be impractical as the attachment on the back can be annoying when using the tablet if not attached.

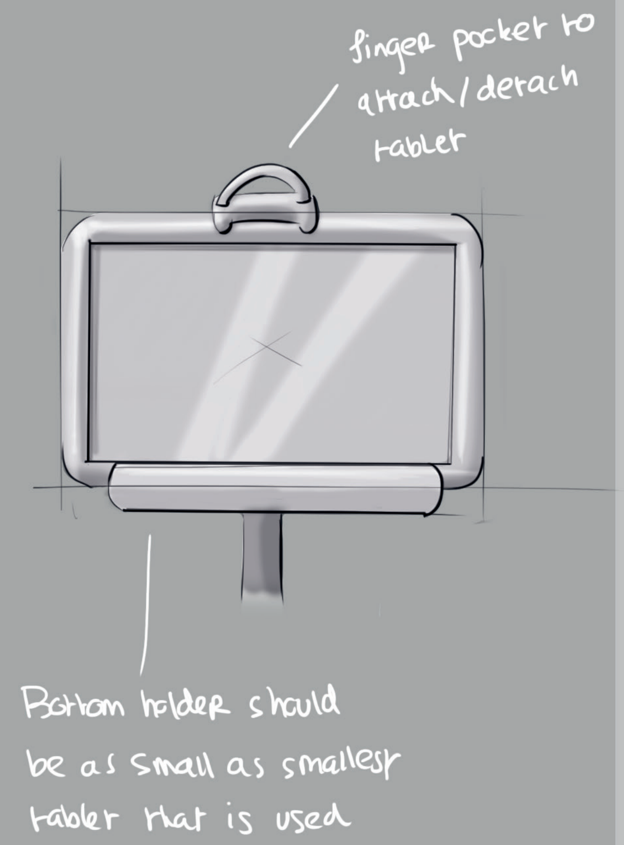


figure 29 : Concept ideation of the top part of the tablet holder

2.4 Combining concepts

This chapter further explains the process towards choosing the final concept. Additionally, it covers the name of the concept and the logo.

Aside of the final chosen concepts shown on the previous pages, other concept combinations were considered as well. These concept are shown in figure 30. The final concept combination, is highlighted in red.

The form which was created by linking different concepts, formed the inspiration for the logo of the design (figure 31). With its multiple directions the logo stands for the value it can bring to multiple stakeholders, including the seat manufacturing company, the pilot, the airliner and the aircraft manufacturer.

The design is named "Breach". Refering to the design making a breach towards a new era of aviation which should strive towards use-centered design. Making flying the airplane easier and more comfortable for the pilot.

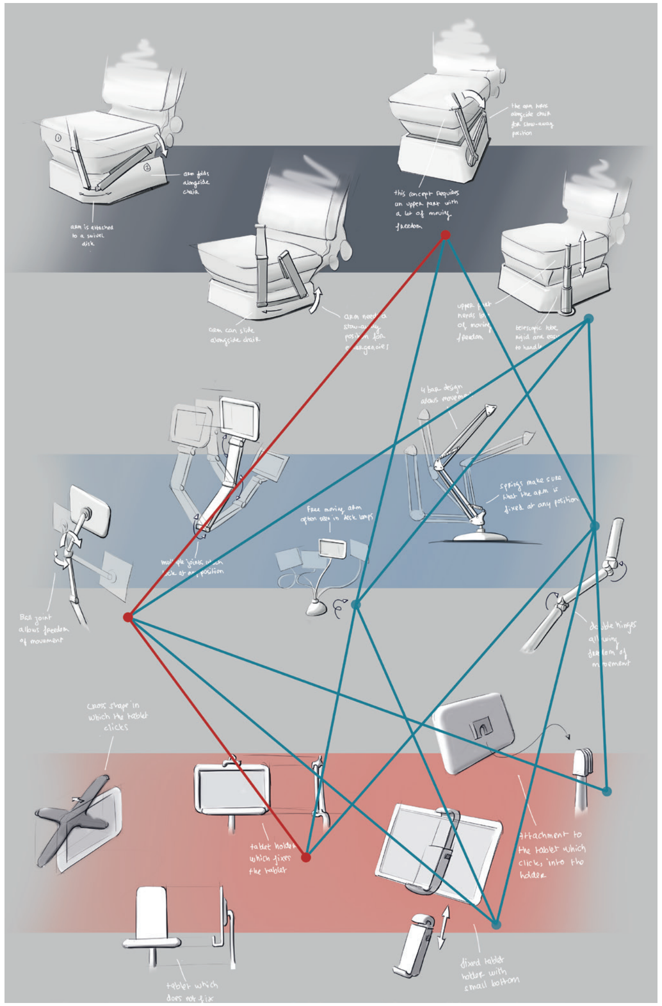


figure 30 : Concept combinations, leading to the logo design

Breach

figure 31 : The breach logo

Recap & continuation

The final concepts for each part of the tablet holder have been chosen and a logo has been designed. This forms the input for making the final combined concept of the complete tablet holder.

The final concept is shown on the next page. The design of the final concept concluded in a lot of improvements on the design. These are covered in the next chapter on page 46

Breach

Supporting the pilot during cruise altitude

Breach is a tablet holder for pilots. The tablet holder assists the pilot during cruise altitude. With the tablet holder the pilot can sit in a comfortable/ergonomic position while controlling the tablet. The tablet has two positions, one in which the pilot is able to easily touch the screen and one which gives the pilot overview over the controls as wel as the tablet. With this tablet holder aircraft manufacturers will also be able to work towards adding airplane control functions to the tablet, futher enhancing the comfortability of the pilot.

figure 32 : The final concept drawing

2.5 Iteration

This chapter covers an iteration step in which important design decisions were made after the conceptualization phase.

These design decisions had to create clear focus for the embodiment phase. It is an addition to the design brief and does not change the requirements and values identified in the design brief.

Physical design changes

A major change in the actual design, was replacing the tablet holder to the outer side of the seat. As can be seen in the final concept drawing (page 45), the tablet holder was placed near the center of the flight-deck. This final concept therefore also featured a design to quickly stow-away the tablet holder, as the pilot needs to be able to reach the mid-panel when flying the airplane (see appendix 12 for the concept drawing of the stow-away system). A stow-away system is not necessary when placing the tablet holder to the outer side of the seat. The pilot can then turn the tablet with the holder towards the outer side of the flight-deck, he is then still able to use all controls. This enables the design to completely take over the function of the EFB as pilots need to be able to access protocols at all times, especially when flying the airplane. Furthermore, it enhances the simplicity of the design. The lower tablet arm which is attached to the seat does not have to fold alongside the seat, but can be fixed.

During the conceptualization phase it was decided that the tablet holder should provide three positions to be able to fully support the pilot in his activities:

1. **position for intensive touch/type use of the tablet**
   This position allows the pilot to easily type on the tablet for documentation purposes, such as filling in checklists.
2. **An overview position**
   This position should be positioned further away of the pilot to be able to keep an overview of all systems. The pilot should still be able to easily touch the tablet.
3. **Flying position**
   A position to the side of the seat. This position is used when the pilot is flying the airplane. It allows the pilot to still use the tablet for accessing protocols, however it should not obstruct the pilot when flying the airplane.

In each position, especially the first and second position, the pilots would have to be able to make minor adjustments to the orientation of the tablet. This in order to accomodate a perfect position for all sizes of pilots. These adjustment systems would have to be fixed at any position, as the tablet should not move unexpectedly, for instance during turbulence. Preferably, these adjustment systems are incorporated in the top part of the tablet holder.

Incorporating the tablet in an airliner

The different values that the design can bring are important (see the design brief on page 36). The values can be beneficial in the near and far future. It is important that these values are represented in the design to introduce the design to the airline market.

However, if the design is incorporated in current airliners (of Boeing), it might be difficult to incorporate all the value in the design. As an example, we will take a look at the design of the flight-deck of a Boeing 787 dreamliner, the newest airliner of Boeing.

figure 33 : The flight-deck seat in the Boeing 787 in the most frontal position

Figure 33 shows a flight-deck seat in a Boeing 787 in the most frontal position. It shows the small amount of space between the seat and the steering column. By regulation, anything in the flight-deck should not touch any other components. In other words, the tablet holder would have to be placed very close to the pilot. So close, that using the tablet would become unhandy. It would also enclose the pilot in a small space, which would make other tasks difficult. Additionally, the steering column would most likely prevent the tablet holder to feature an overview position further away from the pilot.

These limitations would make it risky to introduce a tablet holder in current Boeing airliners, which all feature a similar steering column. It limits the design in such a way that a tablet holder would be impractical. A different approach is therefore needed.

Focus in the embodiment phase

Conclusively, designing the tablet holder for current Boeing airliners, would not be worthwhile. **Therefore, the idea is to develop a design that can be implemented in any flight-deck. The design will be complemented by an implementation plan.** This plan shows how the design could be introduced to the aviation market while exploiting the value in the design. The implementation plan can be found on page 68.

As a consequence the focus in the embodiment phase will be on the top part of the tablet as this part does not depend on specific flight-deck measurements. This part provides a click-mechanism that attaches the tablet to the holder, but also, the adjustment systems that allows the pilot to make small changes to the orientation of the tablet. **The specific requirements of the top-part of the tablet are covered in the embodiment chapter on page 56.** In theory the graduation company could introduce the design to any flight-deck, but the company would need to design an additional tablet arm which connects this top part of the tablet holder to the flight-deck seat. This tablet arm, would be unique for any flight-deck as it depends on specific flight-deck measurements.

However, to be able to communicate the overall idea of the whole design, the tablet arm, which connects the top part to the seat, will be featured in the embodied design, but only as a visual model. The design will apply to the flight-deck seat of the Boeing 787, one of their latest designs. This to showcase how it would look on a flight-deck seat and to show where and how it could be attached to the seat.

3. Embodiment

This chapter is focused on turning the concept into an actual embodied design. First, the ‘writing’ position of the tablet holder will be determined concerning ergonomics. Then, the design will be explained, beginning with the overall design of the tablet holder and ending with detailed explanation of the top part of the tablet and its features. The chapter also incorporates an implementation plan, explaining how the design could be introduced onto the market.

In the picture:
Features of the final embodied design

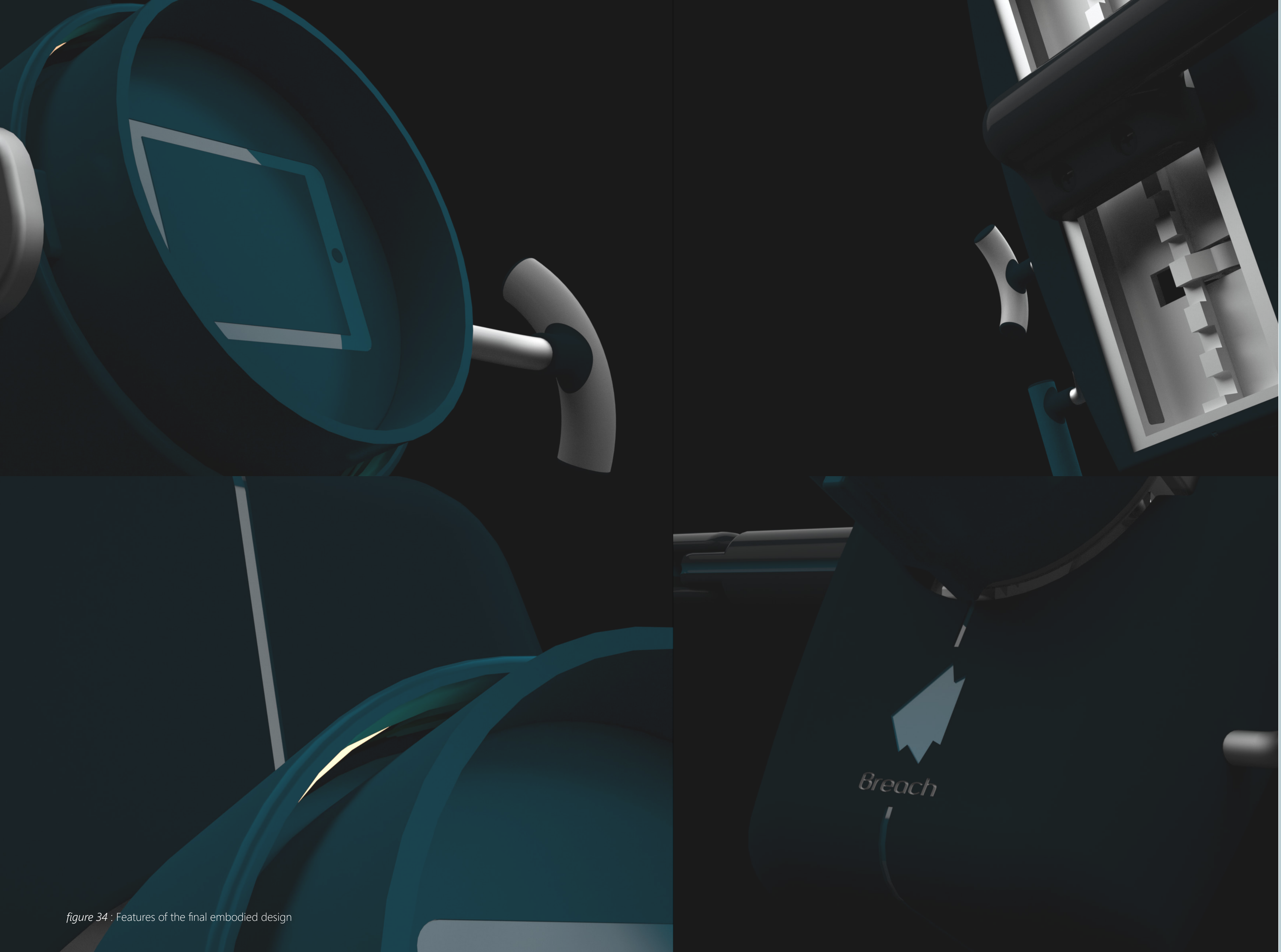


figure 34 : Features of the final embodied design

3. Embodiment

3.1 Ergonomic design

This chapter covers the process in which the ergonomic placement for the "writing" and overview position is defined.

The tablet arm should provide tablet positions that allow the pilot to use the tablet in an ergonomic manner. As mentioned before, the tablet arm will not be fully designed since this part is dependent on flight-desk specific design.. Nonetheless, the 'writing' and 'overview' positions will be ergonomically determined. These positions can be seen as a recommendation and guideline for designing the tablet arm. The position in which the tablet is placed to the side of the flight-deck is not addressed. This position, is very dependent on specific flight-deck measurements and will only be used when the pilots are controlling the yoke. Further addressing would therefore not be valuable.

For the 'writing' position, the actual position relative to the seat will be determined based on ergonomic data. For the overview position the minimal horizontal distance from the seat will be determined. Further recommendations on the height of this position will be included. Specifically, determining the height is not necessary, it depends on the distances of the panel boards and location of screens and buttons, measurements which are not at our disposal.

The 'writing' position

For determining the position of the tablet, the model of Young (2011) is used (see figure 35). **Data necessary to determine the actual position were put on a technical drawing of the Boeing 787 seat (see figure 36).** After all the input was placed on the technical drawing, the actual position of the tablet relative to the seat could be determined. In the model of Young (2011), all distances are measured relative to the C7-spine. Therefore the location of the C-7 spine for P-5 and P-95 users had to be determined. These locations were added to the technical drawing (figure 36) and were based on measurements from the case study as well as measurments from DINED (Molenbroek, 2018). The DINED-data was based on adults measured in 2004 between the age of 18 and 65. See appendix 13 for all the calculations concerning this sub-chapter.

The case study of Young (2011) shows differences in head- and neck flexion angles of participants using tablets in different configurations. In all configurations, the participants were sitting in a chair. In one of the configurations, the participants were asked to type on a tablet placed on a table in front of them. Participants could determine the distance of the tablet themselves. This resulted in an average preferred distance among all participants. This average preferred distance was added to the technical drawing by adding a circle with the center at the C-7 spine points.

The vertical positioning of the tablet is more difficult. For typing activity it is preferable to have the lower arms supported. A study showed that the use of forearm support has a number of advantages over a traditional floating posture and should be considered as an alternate working posture for keyboard users (Cook & Burgegss-Limerick, 2004). The forearms should be supported where

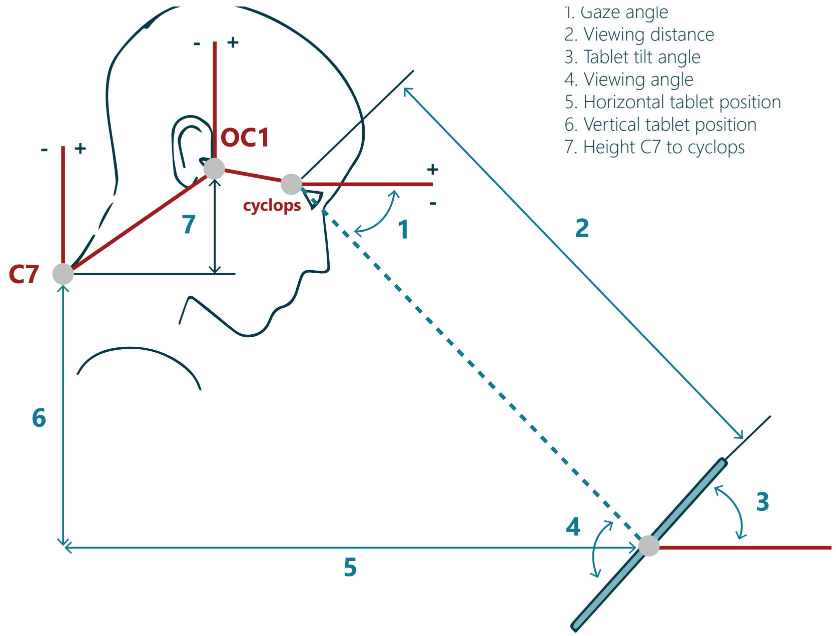


figure 35 : The model of Young (2011) showing the angles which were used for the calculations

the upper arm ends, so that the user can sit straight while leaning on the armrest. The height will therefore be determined based on the upper arm length of P5 and P95 pilots. This height was added to the technical drawing.

In the technical drawing the forearm length was added from the elbow height. Ten centimetres were added to the forearm length as the arm is often moved forwards during typing. Between these two positions for the P5 and P95 pilot and between the preffered tablet distances the 'typing' position was determined. Note that in this position the pilot is still able to make minor adjustments to the tablet.

During embodiment the position of the tablet will be measured from the adjustment lever shown in the technical drawing. However, actual distance for the P5 and P95 pilots measured from the C7 spine are:

P5 horizontal distance = 457 mm
P5 vertical distance = 323 mm

P95 horizontal distance = 477mm
P95 vertical distance = 391 mm

The 'overview' position

An important factor for this position is to get to know the preferred tablet distance of pilots. It could be that this differs from the preferred tablet distance which came from the study of young (2011) as the situation in the flight-deck differs from the situation of the study. It might be so that pilots prefer a distance further away as the pilots are in a confined space. Additional research could show what the preferred distance would be. The only thing that can be determined at the moment is that this distance should not be further than the maximum reach distance of a P5 pilot, also see the technical drawing.

Furthermore, this position preferably is positioned as high as possible to assure that the head of the pilot is in a neutral position. However, it should not obstruct the pilot's vision. The pilot should have a good overview of all controls and systems.

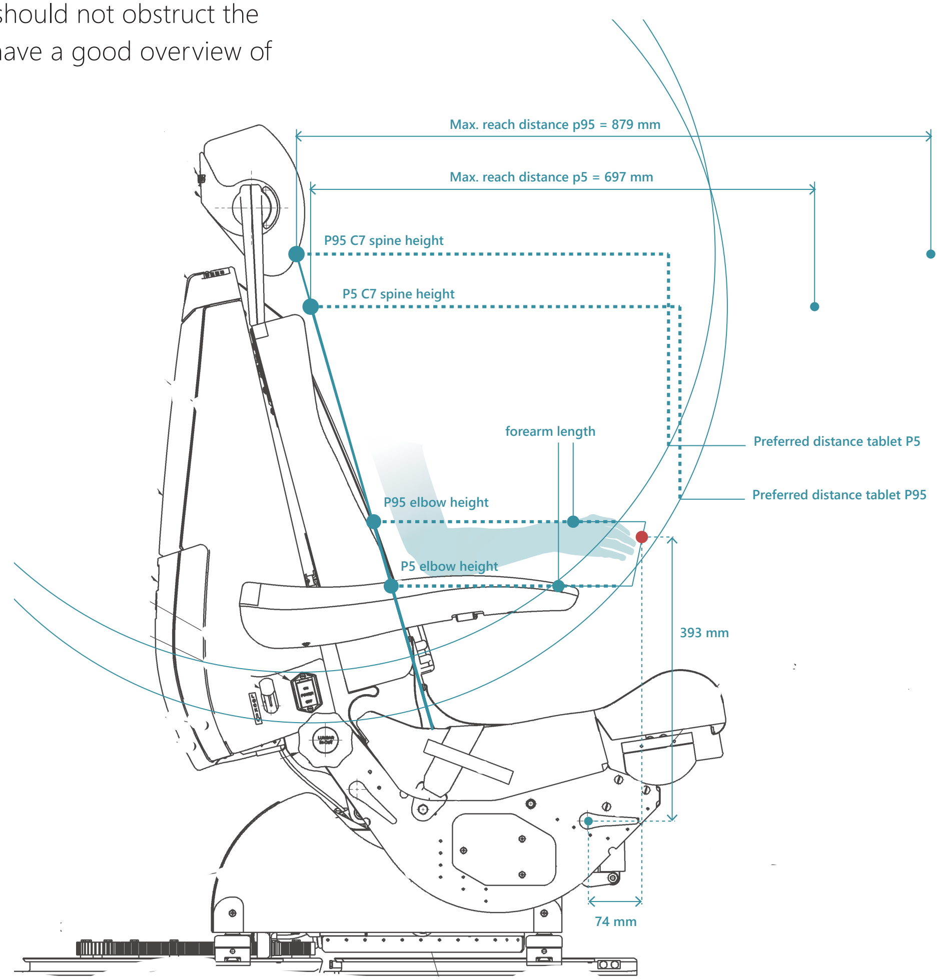


figure 36 : The technical drawing on which the position of the writing position and distance of the overview position was determined

3.2 Final design

This chapter shows the complete embodied design. Additionally, it explains how the pilot interacts with the product and how it can be used in different situations.

The tablet holder consists of two parts. The top part of the tablet holder; which is designed in detail and the tablet arm, which connects the top part of the tablet holder to the seat (see figure 37).

The tablet holder is bolted to the side of the seat. No additional changes are necessary to get the tablet holder attached to the current flight-deck seat design of the Boeing 787. Depending on the flight-deck layout the arm should feature multiple hinges to provide the three positions. The tablet arm and systems that provide these three positions are not further addressed in the design. Even though the tablet arm is only designed visually, a study was done to figure out how much space there is for such a tablet arm onboard a Boeing 787. See appendix 14 for this study.

The tablet arm is attached to the back of the top part of the tablet holder. As the tablet is always positioned lower than the pilot's head, the top part of the tablet is attached to the tablet arm in an upward angle.

The cover of the actual tablet features an integrated part, which allows the tablet to be clicked into the tablet holder. In this design an apple Ipad pro (10.2 inch) is incorporated. However, it is suitable for other sizes as well, although the levers might not perfectly align with the sides of the tablet. More information on the actual design of the top part and the connection system is featured in chapter 3.3.

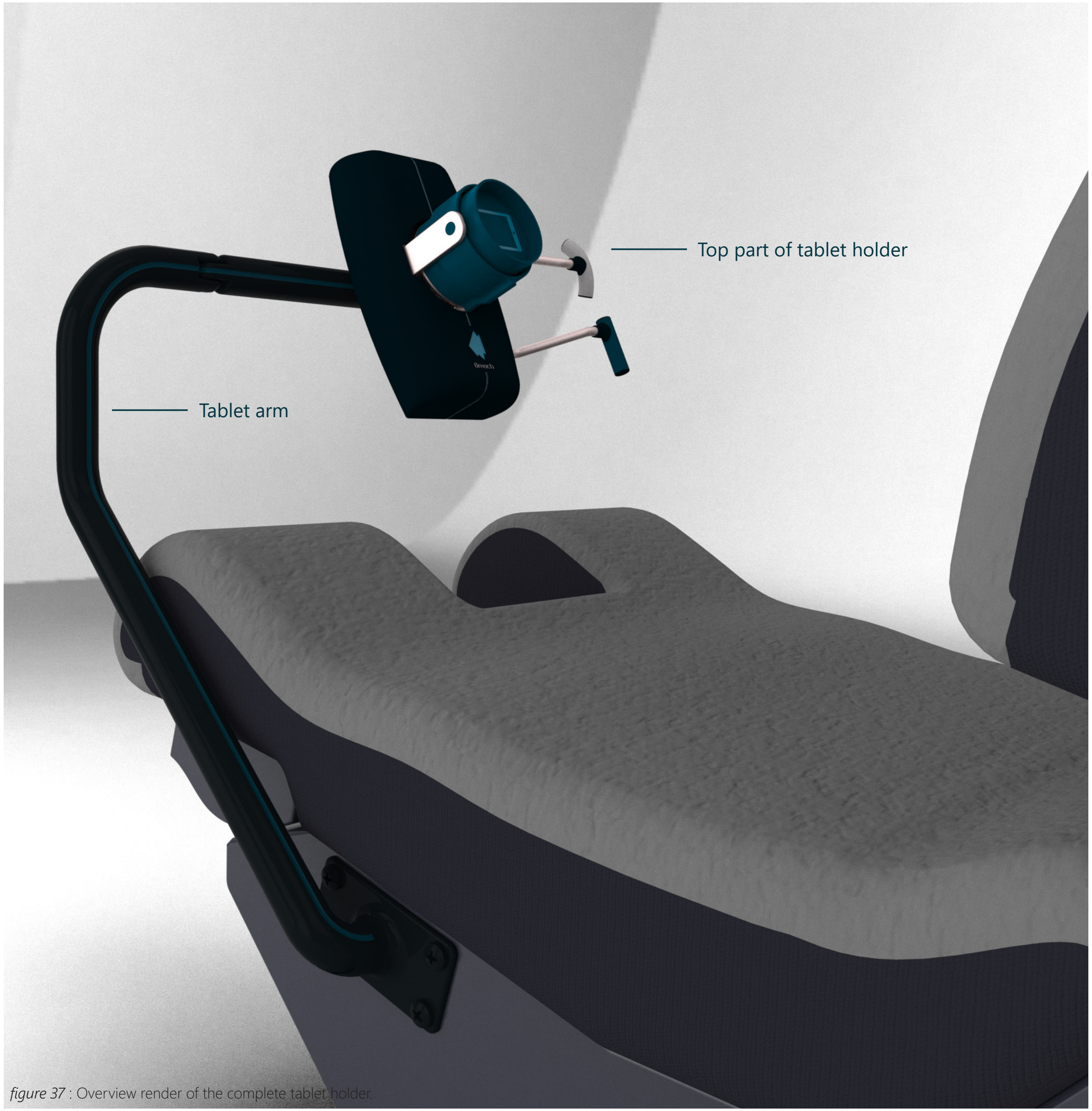


figure 37 : Overview render of the complete tablet holder.

1

figure 38 : The tablet stowed to the side

2

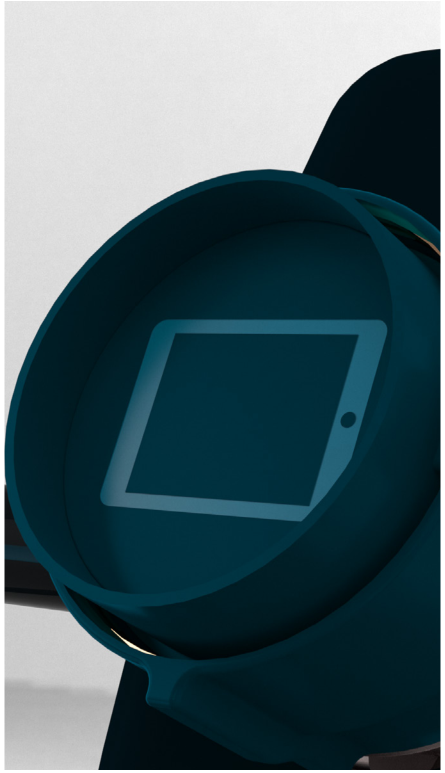


figure 39 : Orientation of the tablet when attaching

3

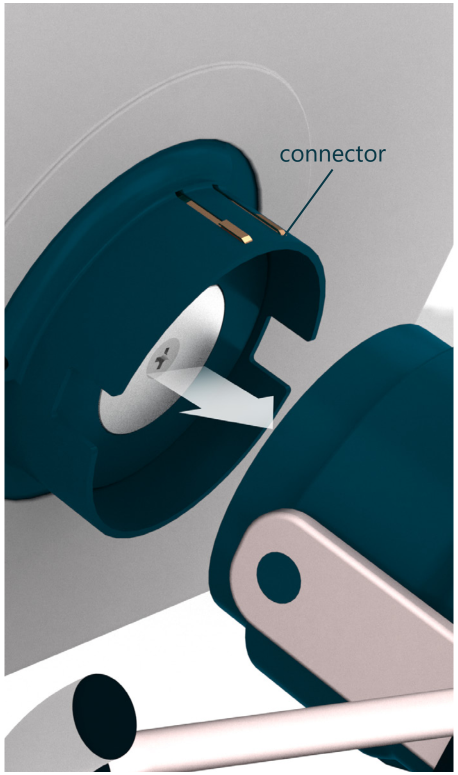


figure 40 : The part attached to the tablet

3.2.1 Clicking in the tablet

1. When the pilot arrives in the flight-deck the tablet holder is stowed to the side of the flight-deck. This makes it easy for the pilot to get in and out of the seat. Additionally, this is the position which is used when the pilot is flying the airplane by himself.

2. When the pilot is seated, he pulls the tablet holder towards him. On the tablet holder it is portrayed how the tablet should be positioned to click it on the holder. It is possible that the previous pilot had his tablet in portrait mode. In that case the figure of the tablet would be in an upright (portrait) position.

3. The pilot clicks the tablet in the holder. The tablet stays fixed to the holder through magnets incorporated in the tablet case as well as the tablet holder. Connectors in the casing make sure that the tablet is electrically connected, preventing it from shutting down during flight.

4. By connecting the tablet to the flight-deck the pilots are able to access their seat settings through an app. In this way they can quickly adjust their seat to personally pre-set adjustment settings in the app. In the future, pilots might be able to also access flight-deck control systems through the tablet. See appendix 15 for a basic design of the seat adjustment application.

4

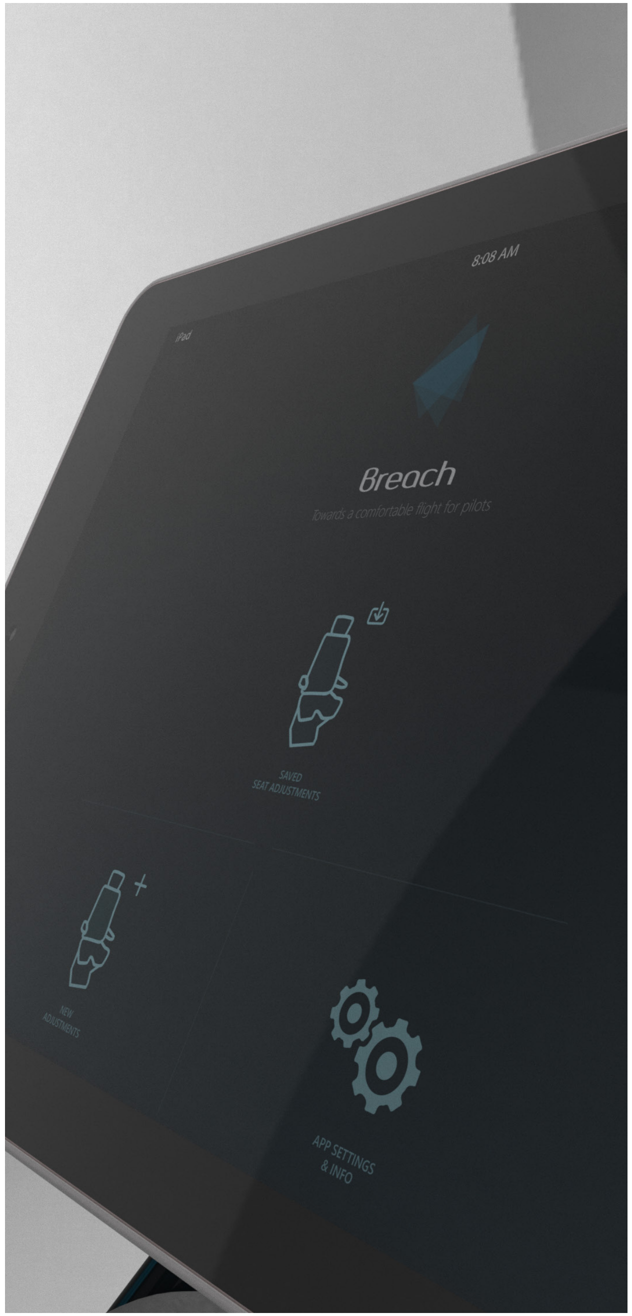


figure 41 : The seat adjustments app home screen

figure 42 : Turning into portrait/landscape mode

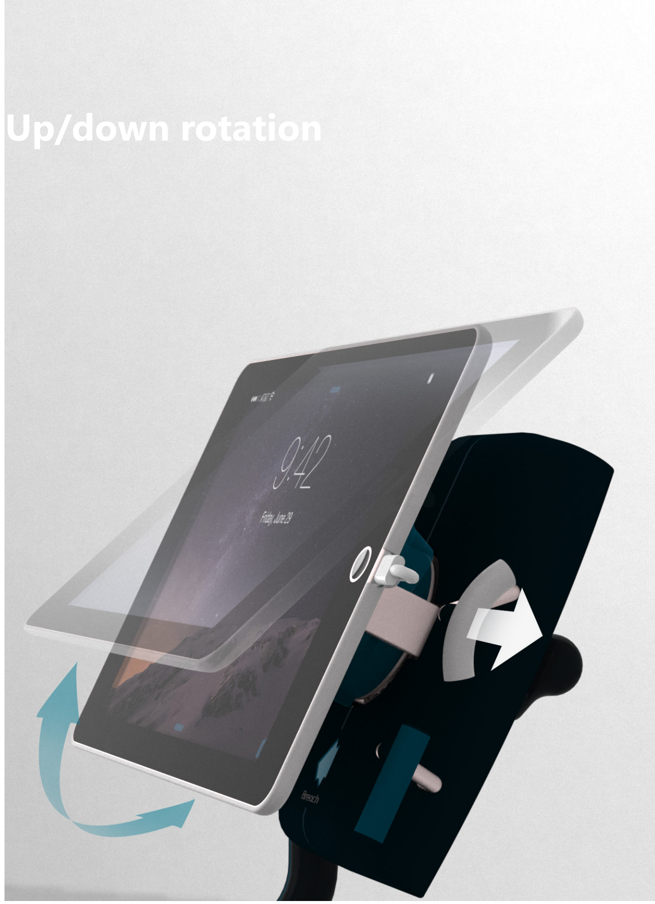


figure 43 : Up/down tilt adjustment

3.2.2 Orientation adjustments

In each tablet position the pilot is able to adjust the tablet orientation. This is necessary to provide an optimal position for pilots of different lengths.

Portrait/landscape mode

The pilot can turn the tablet into a portrait or landscape mode by grabbing the tablet and simply turning it. The systems consists of two magnets that interlock each 90 degrees.

Up/down tilt

The pilot can tilt the tablet up and downwards by pulling the lever with the white handle to the side. The pilot can pull the lever to the side while pushing off the tablet with his thumb. While pulling the lever the tablet will be able to tilt. Once it is released the tablet will lock into position.

Vertical movement

The pilot pulls the lower lever by pushing of with the tumb of his right hand. The whole top part of the tablet will move up and down along with the tablet over the point where it is fixed to the tablet arm. Once the lever is released the tablet will lock in place.

figure 44 : Up/down vertical adjustment

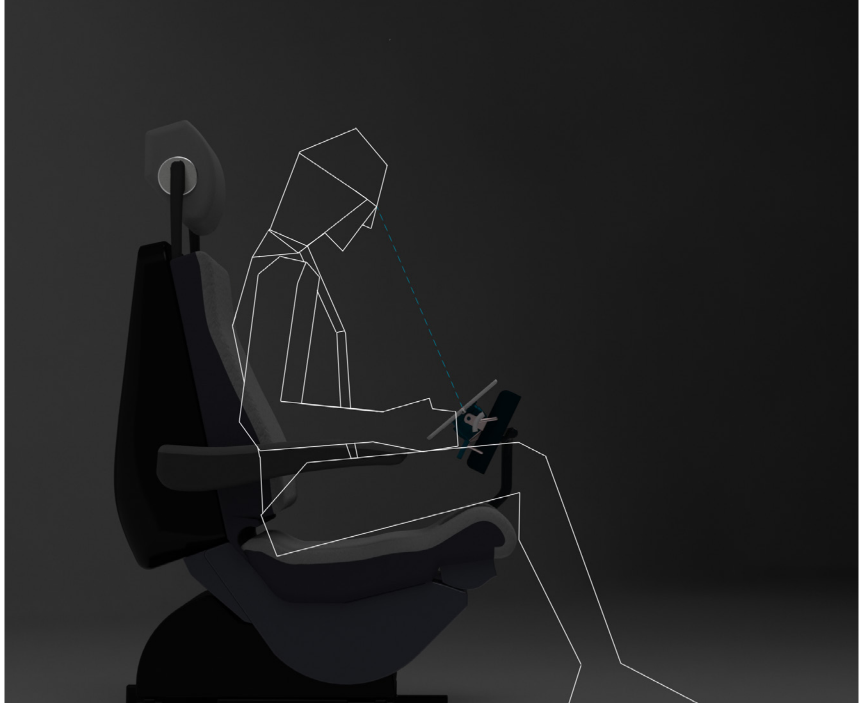


figure 45 : Adaps figure in a render showing the posture with the tablet in the 'writing position from the side

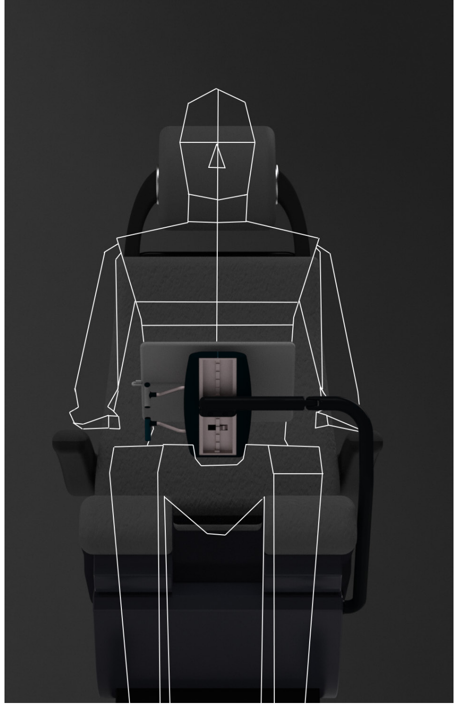


figure 46 : Adaps figure "writing" position from the front

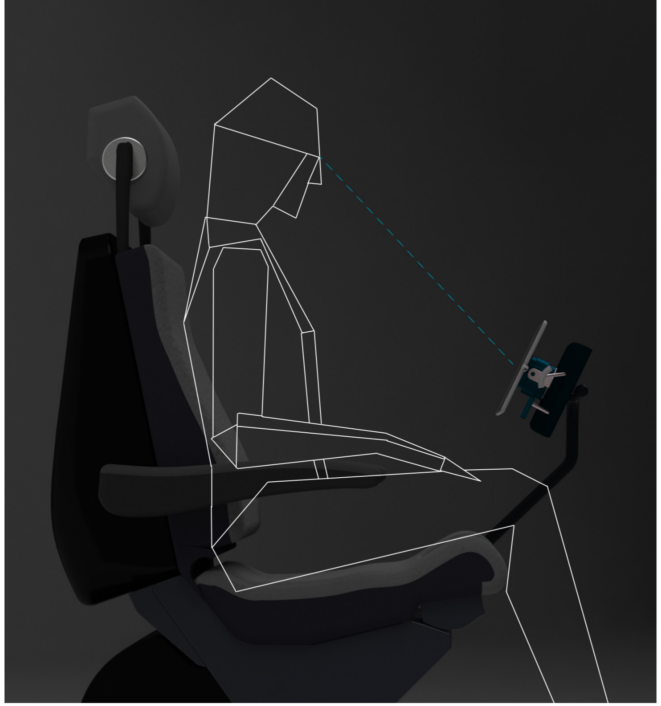


figure 47 : Adaps figure "overview" position example

3.2.3 Tablet positions

The "writing" tablet position in the embodied design is evaluated by using "Adaps", a program to evaluate postures. The figure from "Adaps" is portrayed onto a render of the final design (figure 45 and 46). It shows a P5 pilot in the seat in the lowest position.

Writing position

In this position the pilot is able to fill in checklist and take notes on the tablet. When typing on the tablet, the arms are supported by the armrest.

With the use of "Adaps", the neck flexion angles and vertical distance between the tablet arm and legs were estimated for a P95 posture. The seat was adapted with all adjustments in their maximum setting, except for the inclination which stayed the same. See appendix 16 for the original adaps file showing the angles, distances and explanations on adjustment settings.

The neck flexion angels was estimated around 36 degrees. From literature, the following neutral neck flexion angles were derived: For an erect posture Raine & Twomey (1997) found an angle of 41,1 degrees and Johnson (1998) found 40,6 degrees. Ankrum (2000) found 43,7 degrees as perceived most comfortable. We can conclude that the neck does not over flex, however, pilots might find it more comfortable to flex the neck even further. Actual measurements with pilots could clarify how pilots would actually bend their neck in this situation.

The vertical distance between the legs and tablet arm of the P95 pilot, with the thigh support adjusted fully downwards is 17 mm. The P95 pilot will touch the tablet arm if the thigh support is adjusted upwards. Thus, more space should be created between the tablet arm and the upper leg.

Overview position

The exact "overview" position has not been determined and will not be evaluated. However, figure 47, shows a possible "overview" position for the tablet. This figure shows that the neck will flex less when the tablet is positioned higher. The expectation is that this position will be used most often. It is therefore imporant that the neck does not over-flex. Further research could reveal how often the tablet would be used in this position and which appropriate neck-flexion angles suit this kind of use.

3. Embodiment

3.3 Top part

This chapter shows the top part of the tablet holder in detail. It shows how the systems are designed and how they adhere to the specific requirements of the part.

The top part should feature multiple adjustment systems. With these systems the pilot can make small adjustments to the tablet position within each of the three positions that the tablet holder should provide. These adjustment systems will make sure that pilots of all sizes are able to adjust the tablet to their preferred position. The top part of the tablet holder should feature the following:

1. Attachment fixing the tablet to the holder
2. Portrait-landscape adjustment
3. Up and down tilt adjustment
4. Vertical adjustment
5. The positions provided by these adjustment systems should be fixed to prevent unexpected movement
6. Electrical connection to power the tablet

These features are designed while considering optimal usability and while keeping the design as small as possible. The number of use cues are minimized to make the interaction intuïtive.

The overall size of the top part with the handles is:

Height = 172 mm, Width = 175 mm, Depth = 85 mm

The top part approximately weighs around 1.17 kg including an 10.5 inch ipad pro.

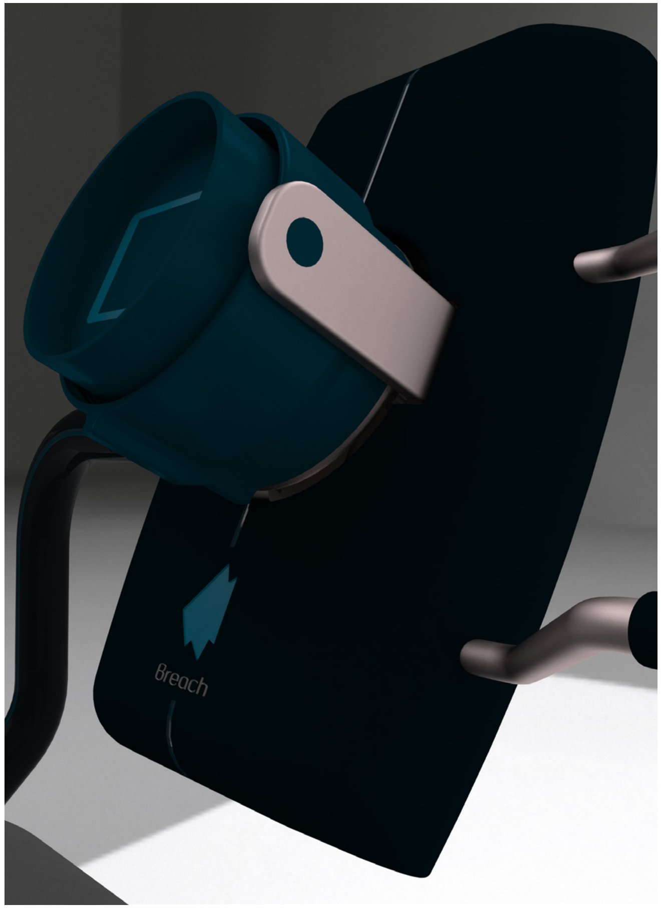


figure 48 : The top part of the tablet with cover

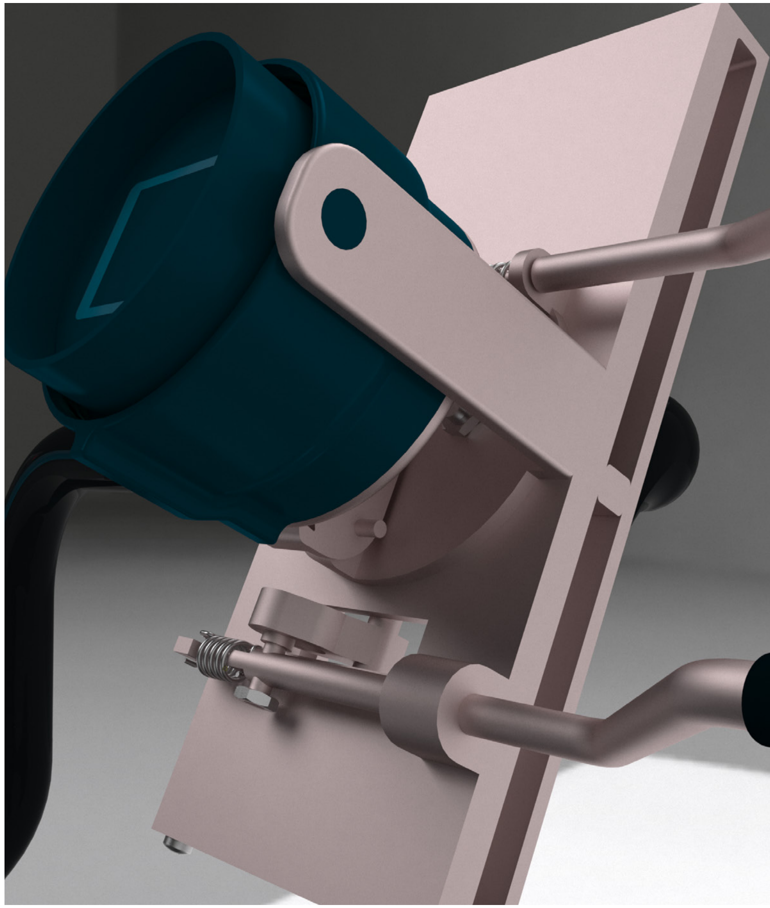


figure 49 : The top part of the tablet without cover

3.3.1 Portrait/landscape and click adjustment

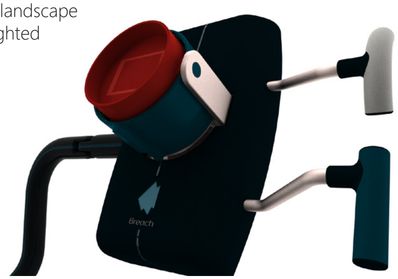


figure 50 portrait/landscape adjustment highlighted

Magnets make sure that the tablet attaches to the tablet holder and can be adjusted in portrait and landscape mode. The part in which these systems are incased is highlighted in the figure above.

Magnets are used to create a compact design and to enhance the usability. There is no additional levers or handles necessary to attach the tablet or to adjust it to landscape or portrait mode. When the tablet is connected to the holder, bulges in the holder fit in the slots of the part integrated in the tablet cover (figure 57). The tablet then clicks into the holder as the top magnet in the tablet holder attracts the magnet in the cover of the tablet (figure 52).

Once the tablet is fixed, the pilot can turn the tablet into portrait or landscape mode. The tablet turns 90 degrees together with the red parts higlighted in the cut-section (figure 52). This movement is possible because of the click-fingers which can rotate around the axis of the highlighted (red) parts. The two facing magnets make sure that it is only fixed in portrait or landscape mode as these magnets interlock every 90 degree turn. There is only one portrait and landscape position as the click fingers can only turn 90 degrees in one direction.

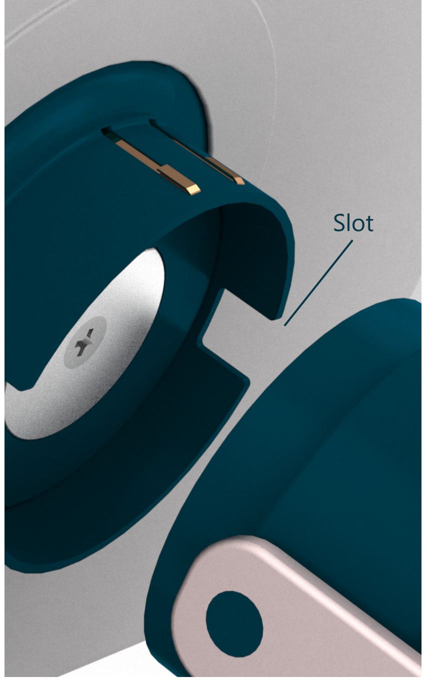


figure 51 Slot, tablet click-attachment

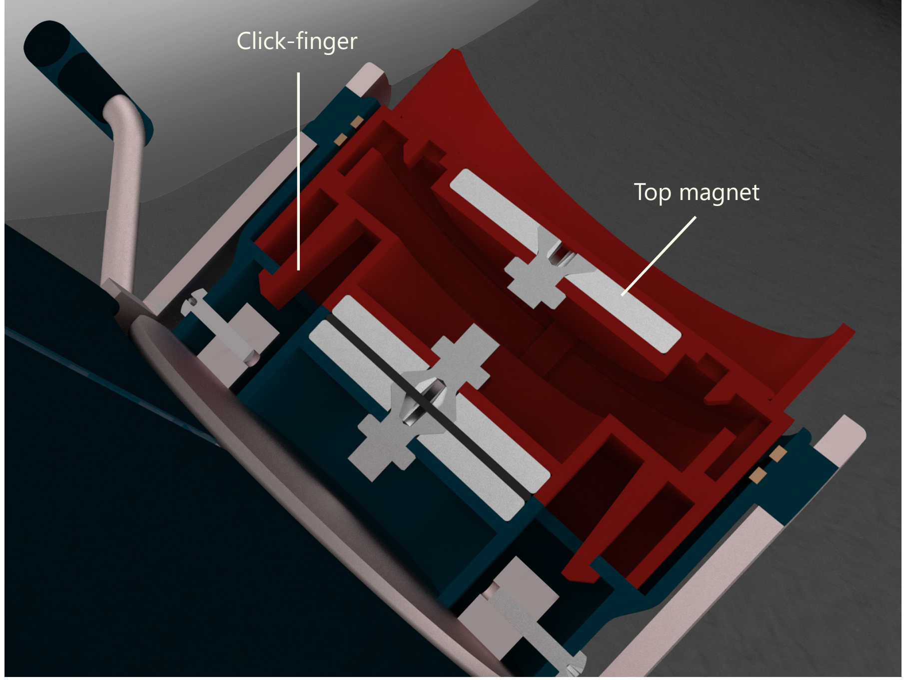


figure 52 Cut-section view showig the magnet systems inside the cylindrical part of the tablet holder

Polymagnets

The system makes use of polymagnets, produced by Polymagnets Correlated Magnetics. Polymagnets are magnets on which different magnetic field configurations are printed. This allows the company, to make sure that the magnets only interlock in certain positions. Additionally, they can make the magnet smaller without influencing the force of the magnetic field. This is possible because little magnetic fields are placed close together (see figure 54). To make sure that the magnets will not interfere with any flight-systems the casings around the magnets creates the right amount of distance between the magnets and any other objects to not cause any interference. It is assumed that the magnets do not interfere with the tablet as the company offers portrait. landscape mode solutions in which the magnet is placed diretly against the tablet. There is still room for improvement, in cooperation with this company, the design might be able to be more compact by printing specialized magnet designs for this tablet holder.

figure 53 The magnetic field boundaries of the portrait landscape mode magnet.

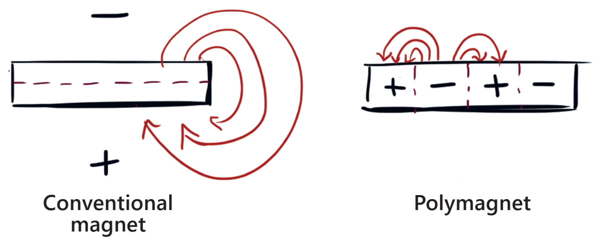
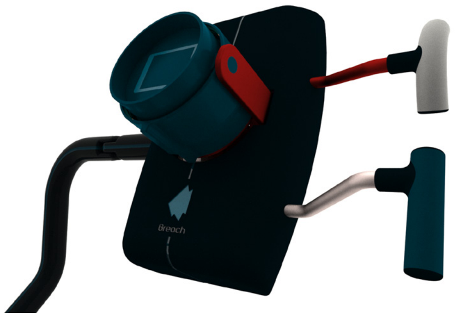


figure 54 Schematic view of the magnetic field of a conventional magnet and a polymagnet.

3.3.2 Up and down tilt

figure 55 Up/down tilt adjustment highlighted



The up and down tilt adjustment system makes the tablet rotate around an horizontal axis parallel to the tablet. The system that makes this adjustment possible is highlighted above.

The mechanism is situated behind the blue cylindrical part which holds the magnets. When the lever is pulled certain teeth are freed up by the moon shaped part (see figure 56), The whole blue cylindrical part can then rotate around the axis shown in figure 57. When the lever is released the spring will push the moon shaped part back in its original position locking the mechanism in place. At the end of this part there are two bulges that make sure that the tablet with the blue cylindrical part will not rotate further than the system allows. The tablet can be rotated 17.5 degrees downwards and 35 degrees upwards.

This system is very space efficient because the rotational axis is separated from the actual mechanism. Additionally, this makes sure that the tablet tilts in the right manner. If the rotational axis would be far away from the tablet the tablet would displace vertically with little rotation.

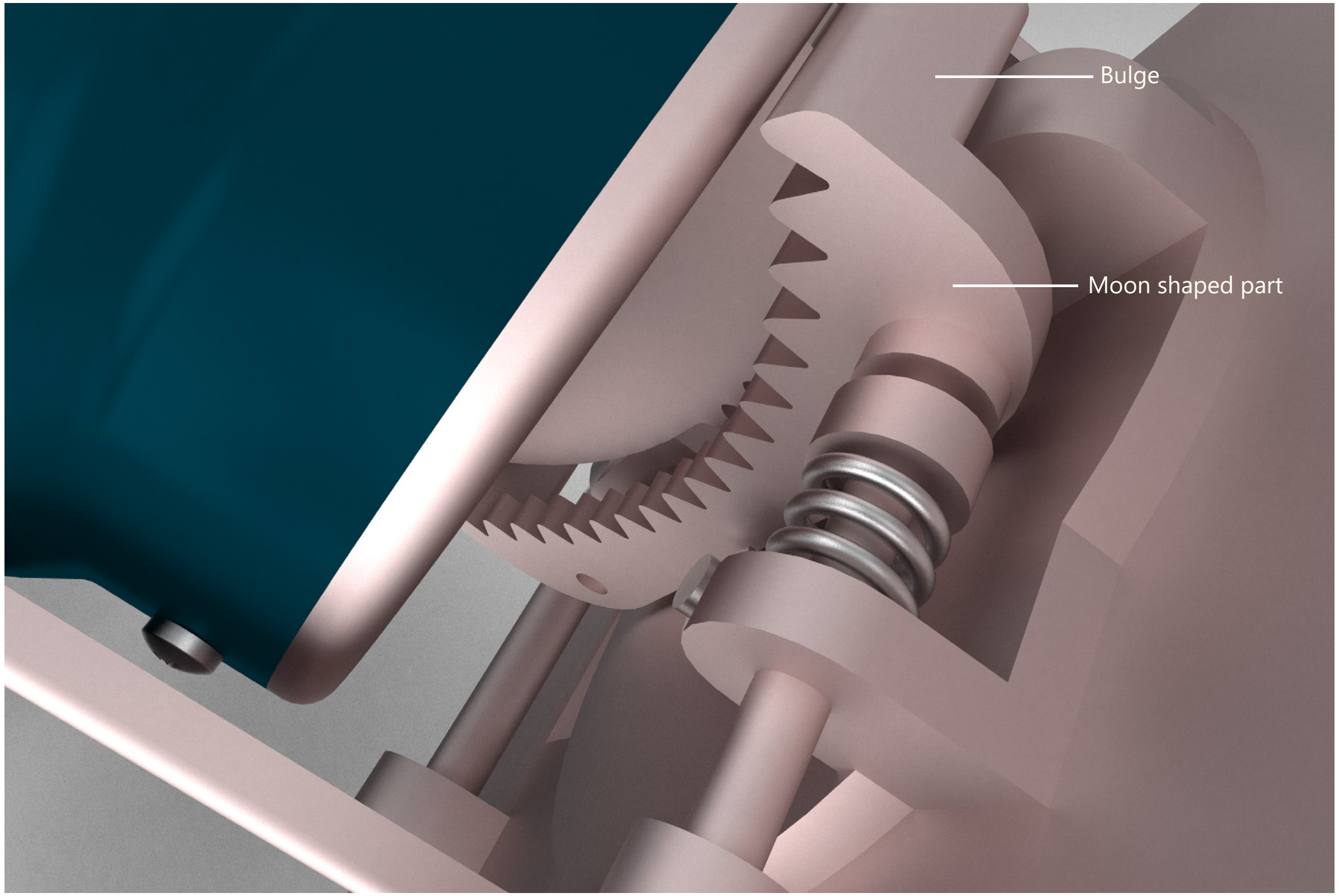


figure 56 : The moon shaped part of the up/down tilt adjustment system

The shape of the handles should guide the user in knowing which lever to use for which adjustment system. The shape of the handle of the tilt system is therefore curved.

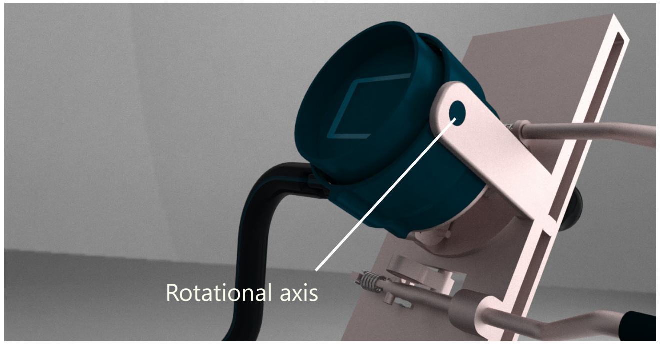


figure 57 : Showing the rotational axis of the up/down tilt adjustment

3.3.3 Vertical adjustment

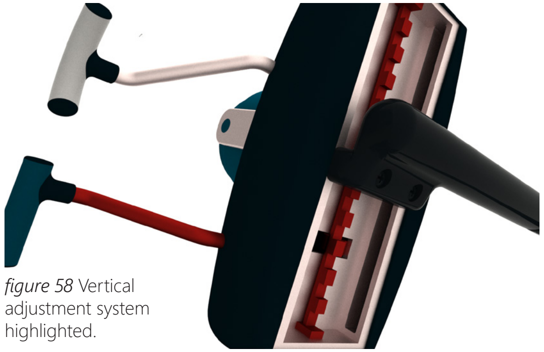


figure 58 Vertical adjustment system highlighted.

The vertical adjustment system makes to the top part of the tablet holder adjust vertically. This adjustment system consists of the bottom lever and the back part of the tablet holder and is highlighted in the figure above.

When the lever is pulled to the side, it rotates the rod at the back of the holder (see figure 59). This is possible as the rod is connected to the lever at the front side of the part (see figure 61). This connection makes sure that the rod will turn once the lever is pulled to the side. The bulges (see figure 61) on the rod fit into a slot in the part that is attached to the tablet arm (figure 60). The whole top part of the tablet, the casing with all the adjustment systems, is then able to slide over the part which features the slot. When the lever is released a spring pulls back the lever (figure 61) and the rod rotates back into place locking the system.

The benefit of this systems is that the whole casing with all the systems move up and down with the tablet. This makes sure that no parts of the tablet holder stick out when the table is adjusted up or downwards. Additionally, The levers will then move with the tablet which makes it easier to adjust the tablet. Furthermore, the system is very space efficient, without taking the levers in account this adjustment system only adds around 17mm to the depth of the top part of the tablet.

The maximum displacement of the vertical adjustment system is around 150 mm, so from the centered position showed in figure 58 on the top left it will move 75 mm downwards and upwards.

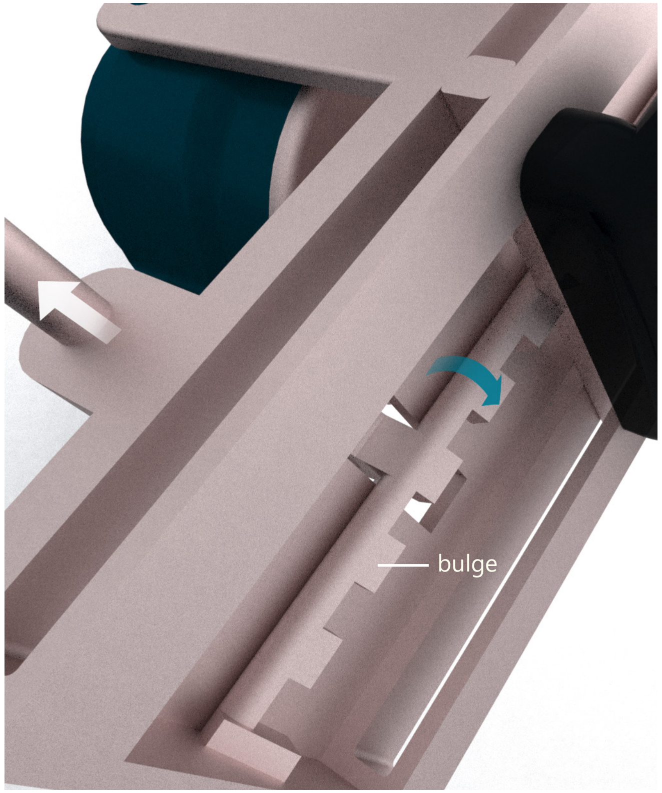


figure 59 : When the lever is pulled the rod will rotate.

figure 60 : When the rod rotates it free's up a slot in the part connected to the tablet arm. Note, the vertical adjustment rod is not shown in this figure.

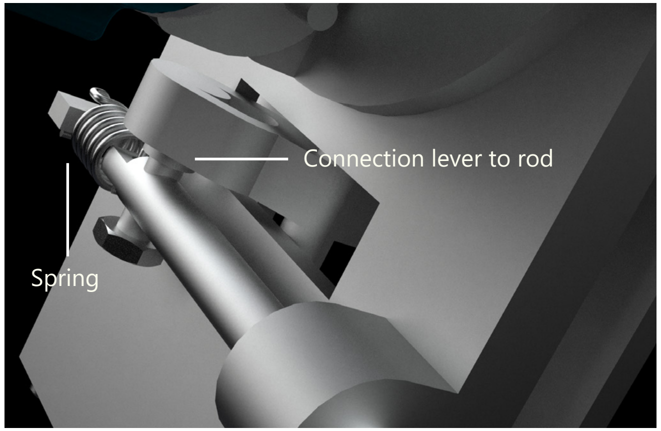


figure 61 : The connection from the lever to the rod. Additionally, this figure shows the springs which pulls on the lever and locks the mechanism once the lever is released

3.3.4 Electric connection

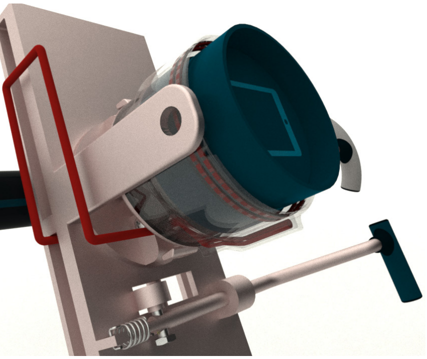


figure 62 The electrical connection highlighted

The electric connection makes sure that the tablet is powered and will not shut down during flight. Additionally, it creates the possibility to access seat settings from the tablet and, in the future, access flight controls through the tablet. The electric connection is highlighted in the figure above, part of the holder is made transparent to show the parts.

It is important to note that the electric connection has not been designed in detail. It is more a showcase of a possible solution to get the tablet connected. This feature was added late in the design proces at the request of the company.

When the pilot clicks the tablet in the holder, two copper connections (figure 63) slide into a slot of the tablet holder (figure 64). In the slot there are two circular copper parts (figure 65). The copper parts of the tablet holder, touch the circular parts making sure that the tablet is powered. Power is guided through a wire integrated in the tablet cover (figure 63)

The power comes somewhere from the seat and is guided all the way through the tablet arm. It enters the top part of the tablet at the back and is fixed to the part

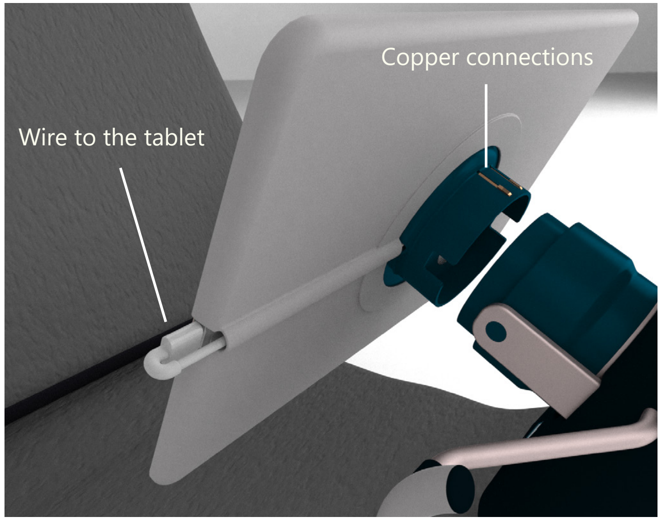


figure 63 : Showing the wire in the tablet cover and the copper connectiosn

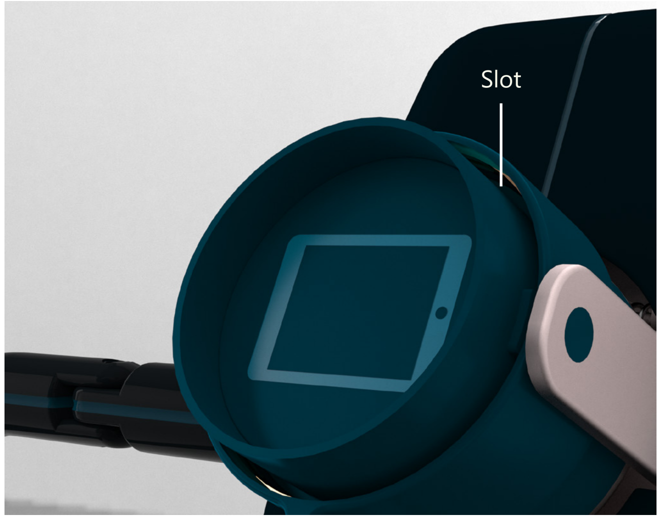


figure 64 : Showing the slot in which the tablet attachment fits

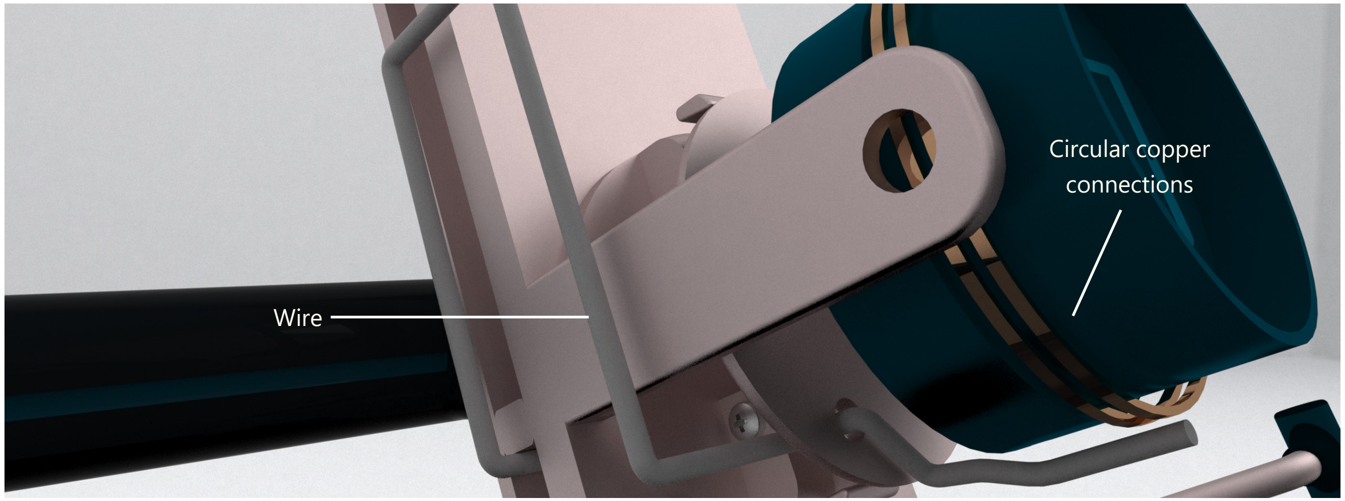


figure 65 : Showing the circular copper connections and the wire through the tablet holder

over which the hole casing with the adjustment systems slide (part with the slot, see figure 60 on page 59). There is enough room inside the casing to make sure that the wire can move up and down without breaking the wire. Additionally, the wire runs through the part that does not rotate when adjusting to a portrait or landscape mode, so the wire can stay fixed in the blue circular part of the tablet holder.

As the system has not been designed in detail, it still needs adaptions to make sure that it works properly. This will be adressed in the implementation part.

3.4 Exploded view and basic materials

This render shows an exploded view of the top part of the tablet. It gives a clear overview of all the parts. Additionally, it shows from which materials the most important parts are made. Parts that should be strong enough to withstand certain forces and stresses will be validated in the strength analysis on page 64. These parts are assigned with a '*' in the exploded view. In the strength analysis specific materials are selected to make sure that the parts can withstand the stresses and forces.

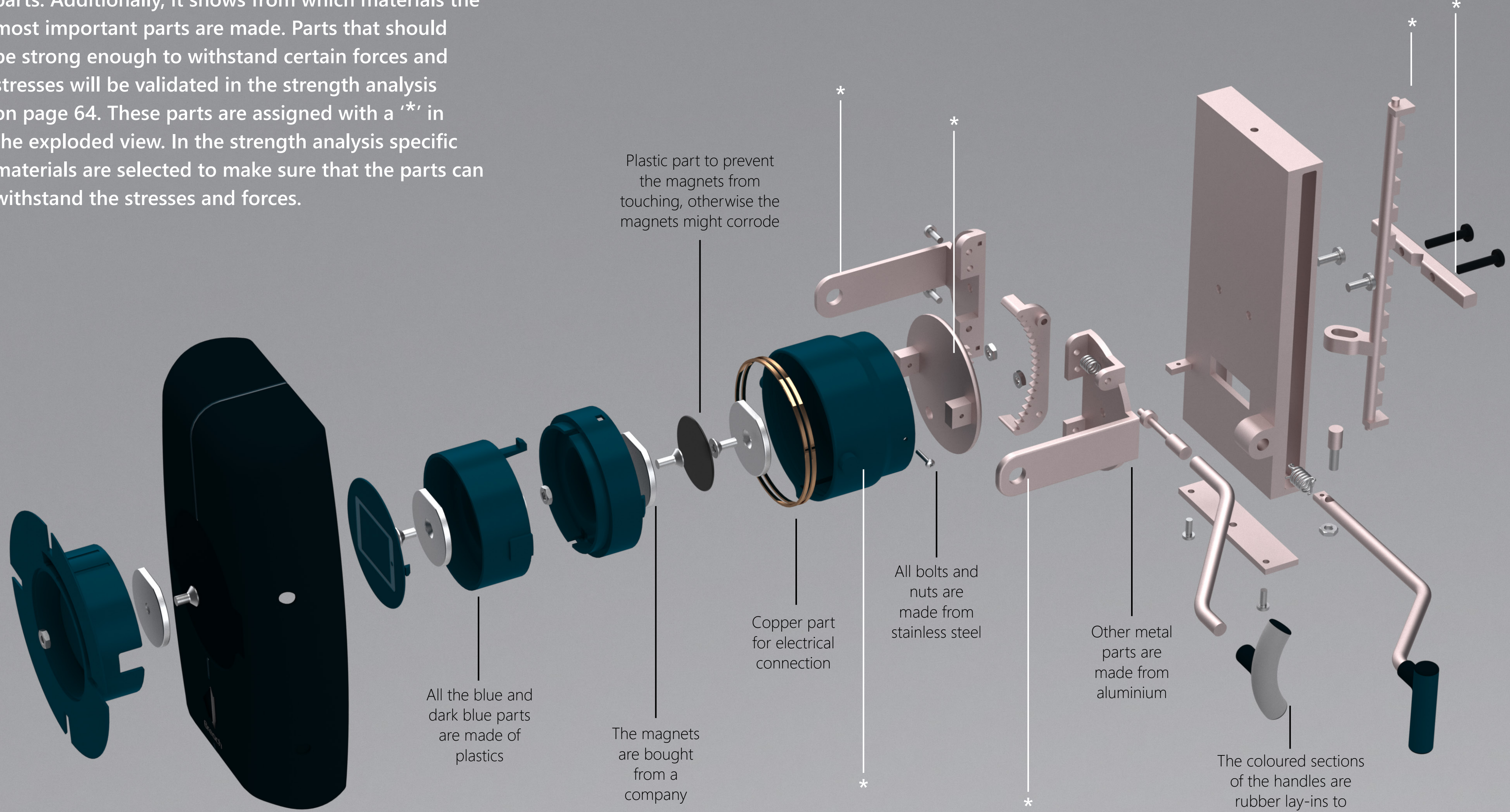


figure 66 : Exploded view of the model

4. Validation & implementation

The design of the top part of the tablet is validated through a strength analysis and a proof of concept. The strength analysis clarifies if parts are strong enough to withstand certain forces. The proof of concept, is a prototype showing that the actual systems of the top part of the holder work. Additionally, this chapter includes an implementation plan showing how to best introduce the tablet holder to the market.

In the picture:
The back of the prototype, showing a part of the vertical adjustment system.

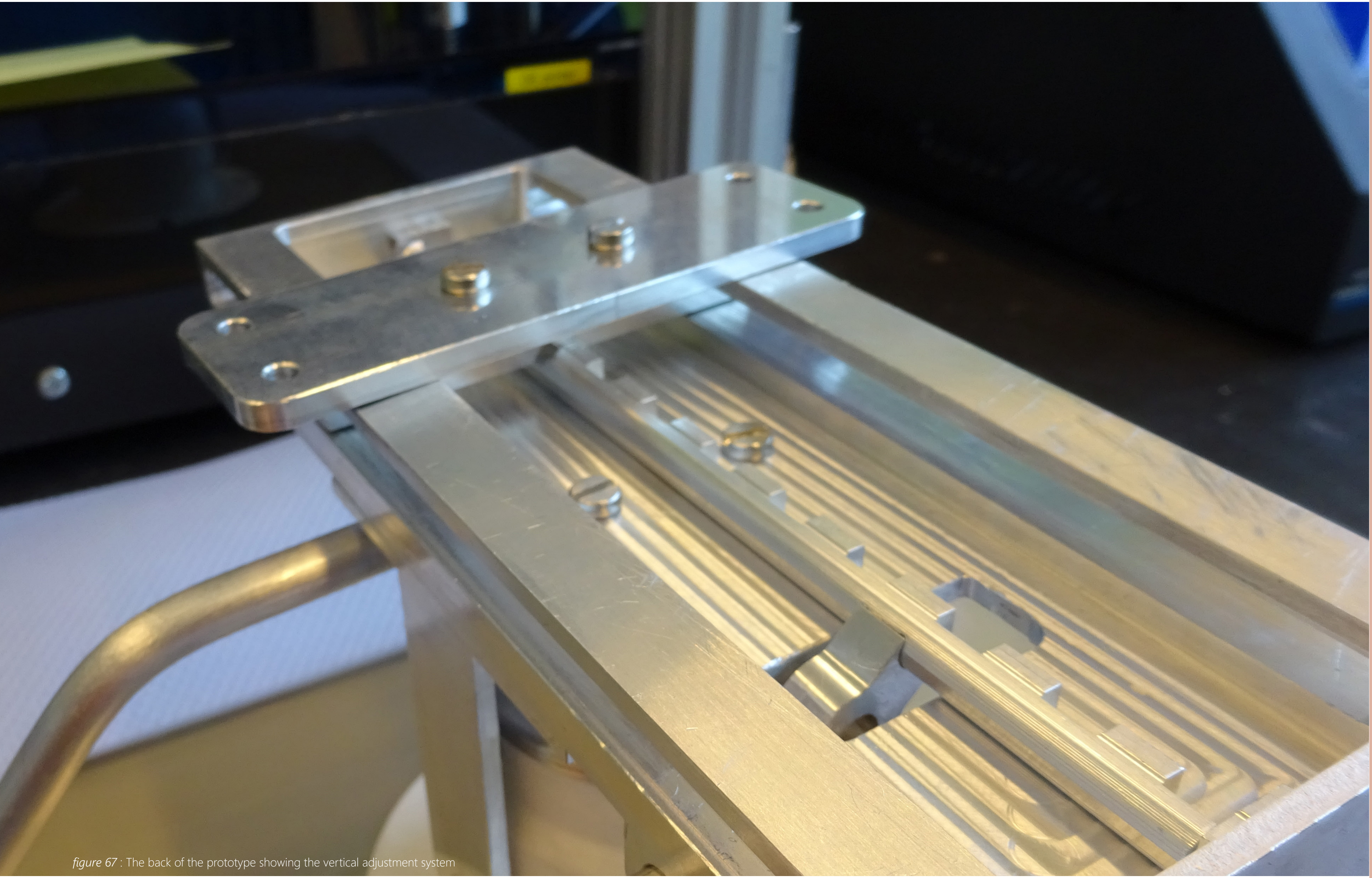


figure 67 : The back of the prototype showing the vertical adjustment system

4. Validation & implementation

4.1 Strength analysis

This chapter covers a strength analysis on critical parts of the top part of the tablet holder.

The list of requirements states that the tablet arm should be able to withstand a force of 0.65 kN sideways and downwards. This load is applied on five critical parts of the top part of the tablet arm design, these are highlighted in the exploded view on page 61. This chapter covers the strength analysis of two parts in detail. For the complete strenght analysis of all the parts see appendix 17. The strength analysis was conducted with Solidwork Simulation.

The top part of the tablet arm consists of aluminium and plastic parts. Only one plastic part is critical for the strength analysis, this is the part which forms the rotational point of the up/down tilt mechanism. Static loads will be applied on the parts after which the Von Mises and shear stresses will be analysed. The von Mises stress will be compared with the yield strength of the material and the shear stress with the shear strength of the material. The yield and shear strength of the material should preferably be 1.5 to 2 times higher than the stresses occurring in the part, this factor is called the reserve factor. The reserve factor preferably is not higher than 2, as an over engineered part is undesirable. A reserve factor lower than 1.5 is considered unsafe.

There is one alloy which is most often used in flight-deck seating; the one with designation 2014. In some cases alloys with the 7075 designation is used, this alloy has a higher tensile strength but is more brittle. For this strength analysis we will use a 2014 alloy. There are multiple 2014 alloys available in Solidworks Simulation, one with a medium strength is chosen:

Alloy 2014-T4

Yield strength: $2.9*10^8$ N/m^2

Tensile strength: $4.25*10^8$ N/m^2

Shear strength=0.50*tensile strength=$2.125*10^8$ N/m^2

Pin of the vertical adjustment system

During vertical adjustment the whole system slides over this pin. The pin is fixed to the rest of the tablet arm and stays in the same position, unless the whole tablet arm is moved. The pin makes contact with the vertical adjustment rod, the whole upper part of the tablet holder together with the tablet rests on this point. Thus, this is where the load is applied. Figure 68. shows the vertical adjustment rod, the pin lies in this rod between two bulges and makes contact at the highlighted area's.

Figures 69 and 70 show the von Mises and shear stresses in the pin when the 0.65 kN is applied. The highest stresses that occur within the pin are:

Max. Von Mises stress= $1.529*10^8$ N/m^2

Max. shear stress= $2.763*10^7$ N/m^2

The reserve factor in this part for the von Mises stress is 1.89 and for the shear stress it is 7.69. The part will be able to withstand the force of 0.65 kN.

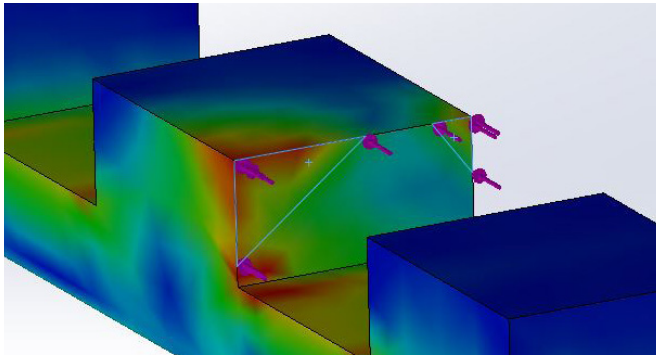


figure 68 : Contact surface adjustment rod and pin (shown in figure below)

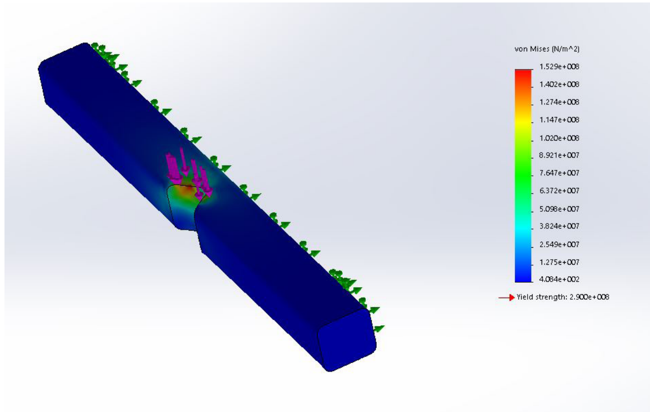


figure 69 : Von mises stresses vertical adjustment pin

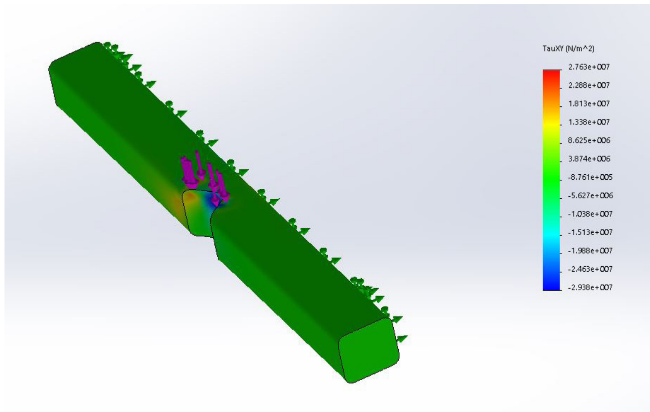


figure 70 : Shear stresses vertical adjustment pin

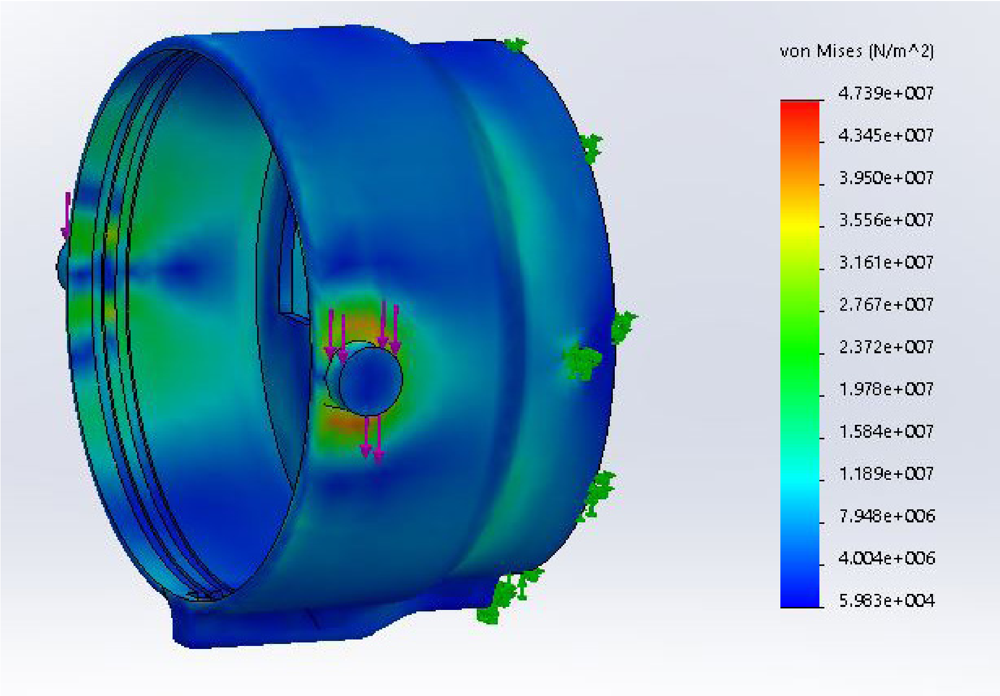


figure 71 : Von Mises stresses plastic component with rotational axis for up/down tilt adjustment

Plastic component with rotational axis for the up/down tilt adjustment

This plastic component forms the rotational axis for the up/down tilt adjustment system. It makes contact with the aluminium parts which hold the axis. During the strength analysis, it appeared that most plastics are not strong enough to withstand the force (such as ABS and ABSPC plastics). Finally, PEI (polyetherimide) was chosen. PEI combines inherent flame resistance, outstanding electrical properties, high heat resistance, and mechanical strength in a material that is easier to process than other high-performance plastics (Beall, 2010). Additionally this plastic is often used in aviation. However, a problem is that the shear strength of the material is unknown. For plastics, shear strength is often unique for each plastic. Thus, the part will only be analysed by looking at the Von Mises stresses. These act on the part which forms the rotational axis for the up/down tilt adjustment system (see figure 71).

The material has the following relevant mechanical properties:
Yield strength: $7.35*10^7$ N/m^2

The actual maximum stresses occurring in the material are:
Max. Von Mises stress= $4.739*10^7$ N/m^2

The reserve factor for the von Mises stress is 1.55. So the part can just withstand the stresses.

Recommendations

It can be concluded that all the tested parts will very likely withstand the forces of 0.65 kN. However, the product will be certified on real-life static and dynamic testing. These tests could show other results. Additionally, the shear stresses in the plastic component should still be analysed.

The moon-shaped part which is explained on page 58 , should still be analysed.

Further testing could also clarify if other more suitable materials can be used, so that an optimal balance between lightweight design and strength can be found. To give an example, a lighter and weaker aluminium alloy might be more suitable for the teeth and holder for up/down tilt adjustment as the reserve factor of these parts are relatively high. The same goes for the plastic parts, preferably other more lightweight and cheaper plastics are used for the parts that do not have to withstand high forces.

4.2 Proof of concept

This chapter describes the proof of concept which consists of a prototype made from cnc milled aluminium parts and 3d printed PLA parts.

The purpose of the prototype is to show that the systems work in real-life. The proof of concept will be explained by adressing the prototyping process, assemblying the prototype and by showing how the adjustment systems work. The prototype gave some new insights on improving the design. These will be implemented in the recommendations. Additionally, it is important to note that some parts in the prototype are different compared to the original design. Some changes were made to make prototyping more efficient.

Prototyping

The cylindrical parts (figure 75) which hold the connection mechanism and portrait/landscape mode were 3d printed with PLA on an ultimaker 2+.

Most of the other parts are made by cnc milling aluminium blocks, see figure 73 and 74 for the milling machine and a cnc milled part. The part can be made by simply delivering a cad-file to the workshop. However, not all parts could be cnc-milled as a whole. Most parts had to be finished by hand. This was done by milling, turning, drilling holes and tapping screw wire (see figure 72). Some parts had to be split in two, after which they were glued together.

Assembly

The 3d printed cylindrical parts are stacked up to form the connection and portrait/landscape mode mechanisms, also see figure 75. In each of the parts a magnet is placed

figure 72 : Centre fix drilling for tapping screw wire

figure 73 : CNC-milling maching

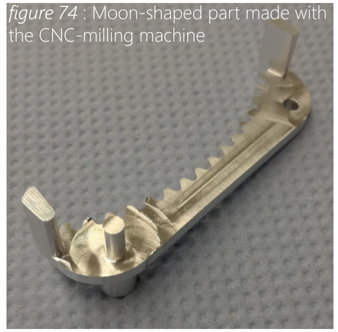


figure 74 : Moon-shaped part made with the CNC-milling machine

figure 75 : The 3d-printed parts. Forming the magnet adjustment systems

to make the systems work. The magnets will be bolted down in the actual model, but are fixed with glue in the prototype. Each system needs two magnets. A pair of magnets, which is used in the prototype is shown in figure 76, the magnets are kept separate by a spacer.

The assembly of the aluminium parts, which also holds the 3d printed parts is a bit more complicated. For the whole assembly process see appendix 18. For now we will highlight the most complicated parts to show how these are fixed. The vertical adjustment lever is connected by a bolt to the vertical adjustment system, see figure 77. The up/down tilt lever is connected to the rest of the system by glueing the srew wire into the moon shaped part, see figure 80. Both systems will lock itself in place by means of a spring connected to the levers.

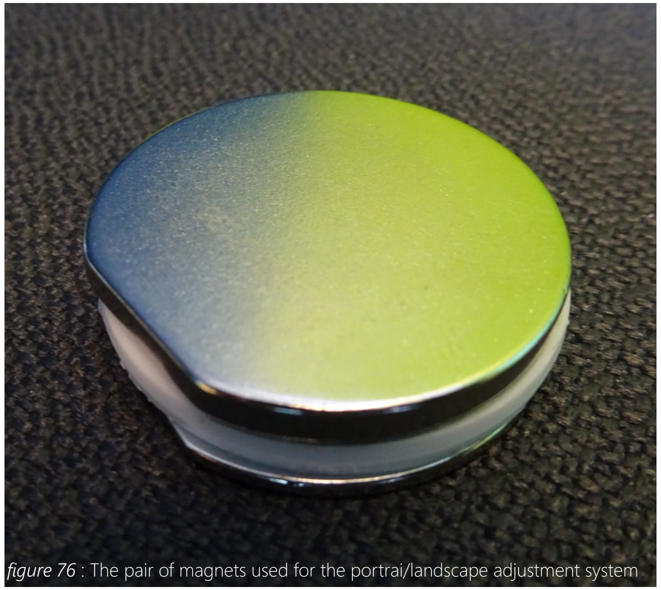


figure 76 : The pair of magnets used for the portrai/landscape adjustment system

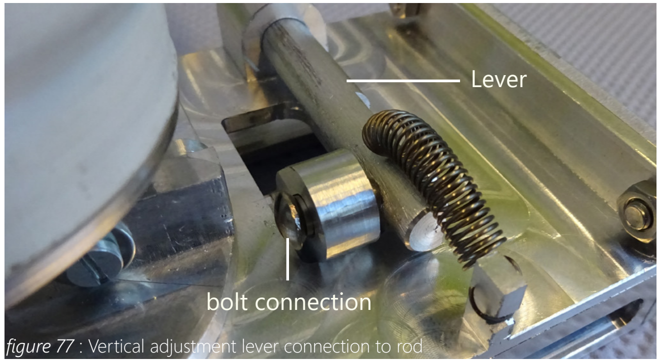


figure 77 : Vertical adjustment lever connection to rod

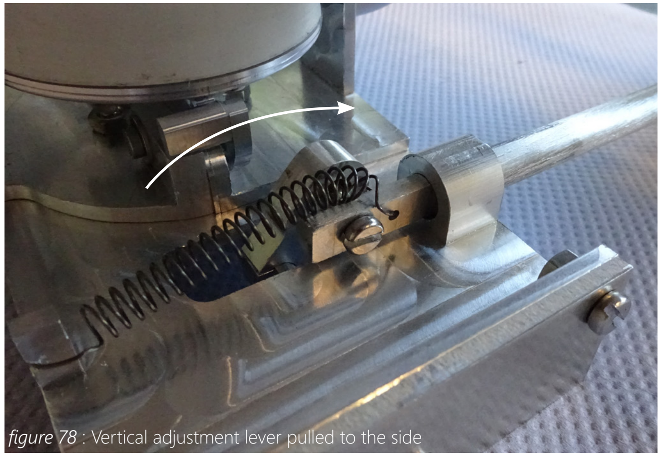


figure 78 : Vertical adjustment lever pulled to the side

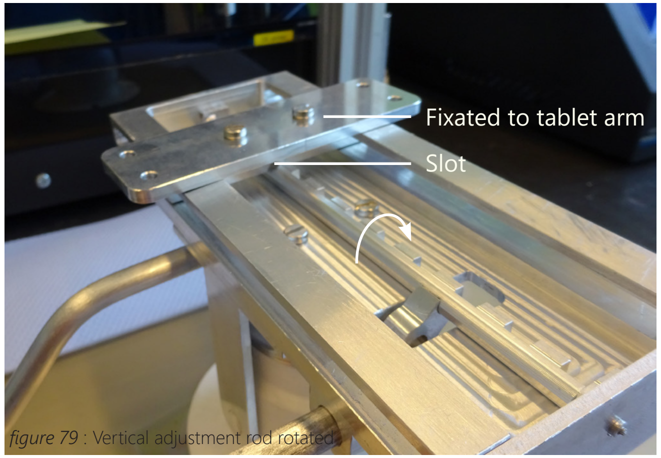


figure 79 : Vertical adjustment rod rotated

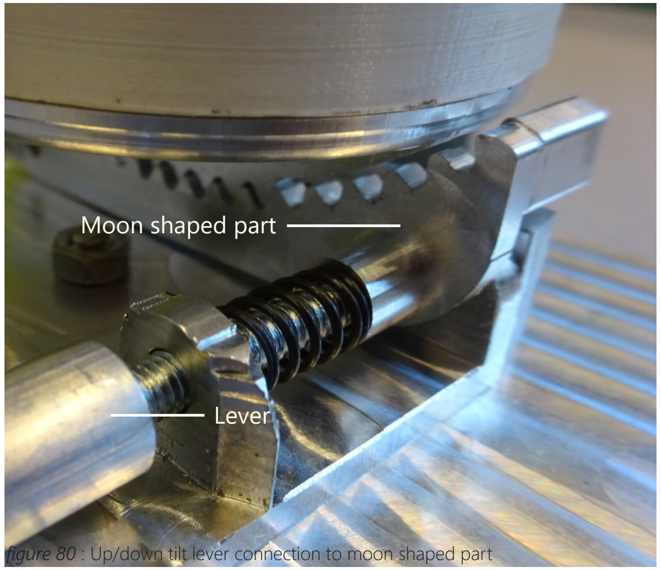


figure 80 : Up/down tilt lever connection to moon shaped part

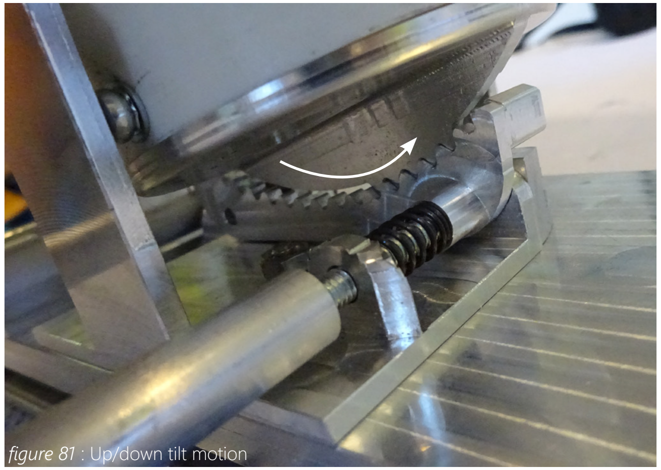


figure 81 : Up/down tilt motion


figure 82 : Portrait/landscape mode motion

Adjustment systems

The adjustment systems will be explained starting from the systems which are situated at the back of the prototype.

The tablet is vertically adjusted by pulling the bottom lever. The lever will pull on a part which is fixed to the rod (figure 78). The rod will turn and this will open up a slot in the part which is fixated to the tablet arm, also see figure 79. The whole prototype is then able to move over this part, which is fixated to the rest of the arm.

The tablet is tilted by pulling on the upper lever. The teeth are freed up after which the tablet, together with the cylindrical parts can be tilted, see figure 81 which shows the movement of the part. Do note, that in the prototype a smaller tablet is used, which make the levers stick out too much

The portrait/landscape mode can be used by simply grabbing the tablet and turning it (figure 82).

Recap

The systems of the prototype all work, although at time of writing, little adaptions were needed to make the systems work smoothly. The prototype will be showed and demonstrated during the graduation presentation. The prototype will then be fixated to a standard. Additionally, the 3d printed parts will be painted. Depending on the size of the tablet used, the size of the levers will be adjusted.

4.3 Implementation

This chapter covers the implementation plan. Which is a combination of a market introduction - and strategic business plan.

The plan shows how to introduce the product to the market while further developping the design and stimulate market and revenue growth for the graduation company.

The airline industry will be challenged to cope with the growing demand of pilots. One way of adressing this problem is by making it easier to select candidates for pilot training through technology advances which makes it easier to fly airliners. And, working towards single-pilot operated aircraft through a distributed, air/ground socio-technical system (also see trends analysis on page 18). **Anticipation of the airline industry to the growing demand of pilots might require major advances in technology, for example in flight-desk design. Therefore, it might be a good idea to make sure that the graduation company has a product (the tablet holder) ready for the airline industry that supports this change.**

A way to do this is by introducing the product to the business-jet industry. The business-jet industry is faster in adapting to new trends. Additionally, regulations concerning flight-deck design are not as strict as in the airline industry. Therefore, introducing to this market could be worthwhile. The introduction onto the business-jet market is divided in four phases; marketing, planning, development and production & implementation. Figure 84 gives an overview over the whole implementation plan. The main idea of each phase is explained by giving examples on what actions the company should take and what opportunities can arise during these phases.

figure 83 : G-500 Flight-deck design

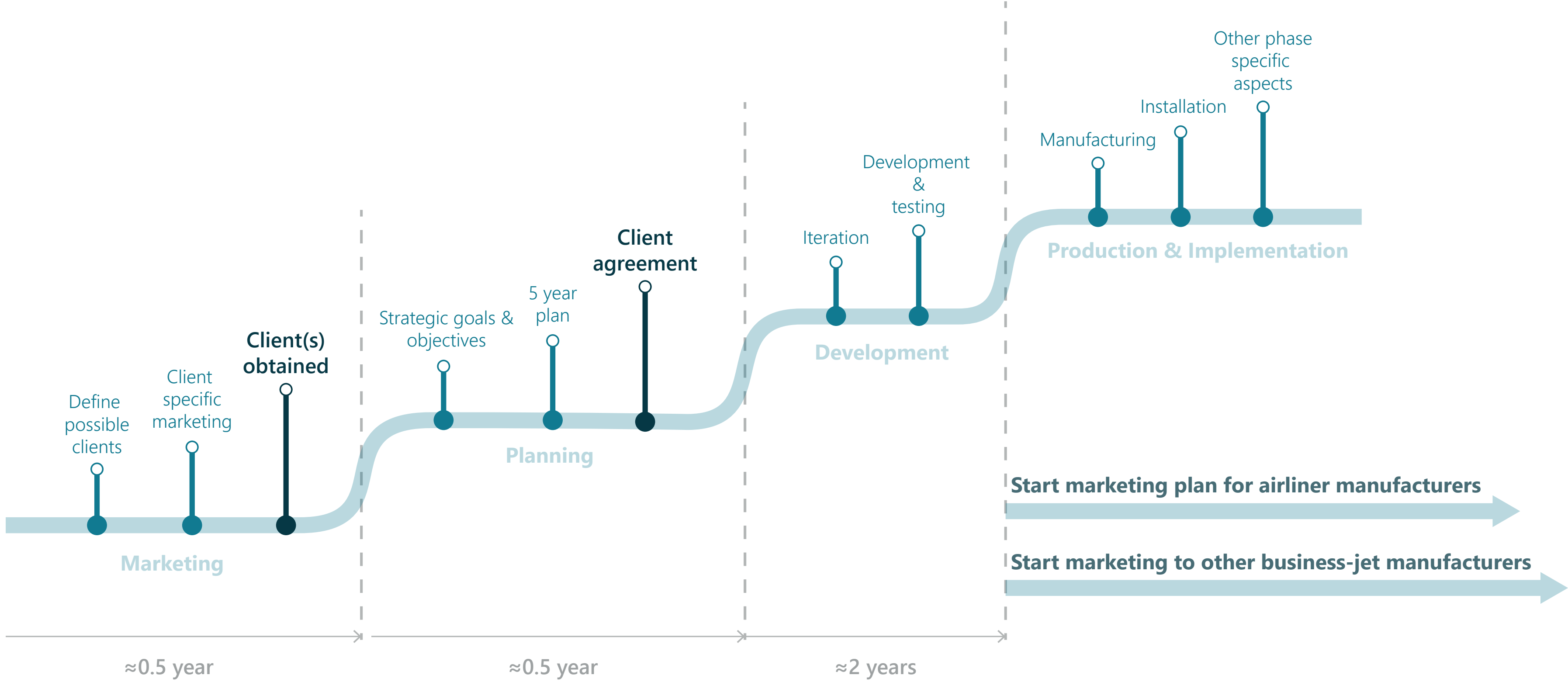


figure 84 : Implementation plan overview

Marketing

The goal of the marketing phase is to obtain one client in the business-jet market. Further developing and iterating the design at multiple clients at the same time would make the process too complex. A good potential client could be Gulfstream. The graduation company already delivers flight-deck and business-jet passenger seating to Gulfstream. Moreover, their new G-500 airplane features an innovative flight-deck design (see figure 83) which incorporates a flight-stick with linked force feedback and touch screens instead of the common button panels (Zhang, 2016). It shows that Gulfstream is progressively incorporating new technology. Additionally, the flight-stick design provides a lot of space in front of the pilot. Which makes it easier to incorporate a tablet holder.

After deciding on a potential client, the next step is to do client specific marketing. Marketing adapted for each specific client, preferably through meetings and presentations. The goal of this client specific marketing is to show that the company is aimed at adapting the tablet holder to perfectly match the clients flight-deck design.

Planning

After a client is obtained the company needs to discuss its goals with the client. We assume that the company is aiming to introduce the tablet holder to the airline industry in the future. This could then be considered when determining the strategic goals. The strategic goals are further detailed into objectives, which show how the strategic goals can be met.

Strategic goal: Assets for marketing to airline industry

- Have an optimized, manufactured and implemented product by 2023
- **By 2023 have results from user tests which show the success of the tablet design.**
- **A promotional video, made on board a flight-deck showing the added value of the tablet holder design.**

Strategic goal: Product innovation

- **The first design should be optimized based on tests onboard flight-simulators.**
- Have the first design implemented on flight-decks by the end of 2020.
- **Have a second optimized design based on actual use onboard flight-decks by 2023**
- Have a working app for seat adjustment controls connected to the seat by the end of 2019

It is important to note that the goals above are examples and are made to be able to explain the overall idea. In reality, the company would have more goals and in more detail.

The company will have to plan their strategic goals in negotiation with the client. To achieve the goals portrayed in bold, they would need help, as the graduation company does not own any aircraft or simulators. This is where negotiation starts. The graduation company delivers a tablet holder design perfectly adapted to the client's flight deck(s) if the client offers certain facilities to be able to realize this design. This is beneficial for the client, especially in the growing business-jet market where competition is high. Additional agreements will most likely be necessary to be able to meet all demands of both parties. These demands will be settled in an agreement.

Development

During development the design can be optimized through iterations after which further development makes sure that the product is ready for production.

A good way to improve the design is to do iterations based on tests on board flight-decks. The product could be tested inside simulators. Results of these tests could then be used as input for new design iterations.

Further development consists of finishing the design into detail. During this process, the design will have to be tested to adhere to certain regulations,after which adaptions often have to be made. This process will repeat itself until the design is ready to be produced.

Production & Implementation

During this phase the product is manufactured and implemented into the flight-decks of the client. Certain aspects will be important during this phase, such as:

- How often will the product need to be serviced?
- When the product breaks down, how is it repaired? Can the business-jet manufacturer repair the product themselves? Or is the complete tablet holder replaced by a new one and sent back to the graduation company?
- How will the company gather data on the use of the tablet holder? the tablet might be a good means to gather user experience data.
- How and when are improvements on the product going to be implemented?

These are aspects which are important to both parties and which should be settled in an agreement during the planning phase, as it can affect the design of the tablet holder.

During the production phase, the graduation company has obtained a finished product. At this moment, the graduation company could start to look at other clients to sell the tablet holder. Additionally, this is a good moment to present the design to an airliner manufacturer such as Boeing.

Introducing to the airline market

As stated in the iteration chapter (see page 46), incorporating a tablet holder in *current* flight-deck design of Boeing is not realistic. A combination of the current steering column design with a tablet holder would enclose the pilots in a small space and make other tasks difficult. The design of the steering column would have to be adapted so that more space is created in front of the pilot. The graduation company does not have the position to discuss changes to flight-deck design with Boeing. However, by showing the implemented design in business-jets, the company shows it has the experience and knowledge to successfully implement a tablet holder into the flight-deck. This gives the company leverage, which might lead to more direct communication with Boeing. The best way to convince Boeing is to show them a finished product which works. According to that product, the company can show how Boeing's flight-deck design limits the full potential of the tablet holder.

The company could also market the product to other aircraft manufacturers such as Bombardier, which is already a client of the company. Their new c-series (figure 85) airliners feature a flight-stick as well, which makes it suitable for the tablet holder design. However, the question is if Bombardier is interested as almost half of the project of the new c-series is owned by Airbus, which is not a client of the company and which have their own supplier of flight-deck seats.

figure 85 : Flight-deck design of the Bombardier c-series

Recap

It is recommended to first introduce the tablet onto the business-jet market as it allows the graduation company to further expand. Additionally, the business-jet market can be seen as a gateway to the airline market as it adapts faster to technology advances. New products most likely can be implemented successfully onto the business-jet market at an early stage. Subsequently, the developed product can be adapted and be fluently introduced onto the airline market. **Conclusively, expanding into the business-jet market could help in sustaining the market position in the airline industry.**

5. Finalization

The final chapter features an evaluation part, recommendations and a conclusion

In the picture: A Boeing 787 Dreamliner touching down

figure 86 : A KLM Boeing 787 Dreamliner during landing

5. Finalization

5.1 Evaluation

The master thesis project is evaluated by looking at the research part and the design part of the project. The research part focuses on the analysis chapter, the design part on the conceptualization and embodiment chapter.

Research

As the initial problem statements shows, the thesis started with a broad scope:

"How can a flight-deck seat be improved to reduce discomfort among airline pilots?"

This problem statement was answered by composing a list of improvements, based on the user research. The TU Delft initiated this user research and it was conducted during the master thesis project. As the research was still being conducted, only the data of the first six participants could be analysed for this thesis. A statistical analysis was not conducted. However, the research resulted in some interesting findings and could direct further research towards doing specific statistical analysis with data from all (twelve) participants (see appendix 9 for the complete research document made during the thesis). It is important to note that the research was conducted with an airline that only owns Boeing 737 aircraft. This could influence the results as the airline pilots switch to the captain seat just once during their career.

The user research data together with personal findings during the analysis phase was translated into the list of improvements. The list of improvements is valuable as it also shows according complaints and injuries (see appendix 10 for the complete list). It gives the graduation company the opportunity to directly address certain flaws in the design of the seat. Additionally, the relating complaints and injuries enables them to see how certain complaints relate to each other, and if these might be eliminated by adapting one certain design feature. Furthermore, improvements, complaints and relating injuries on flight-deck design are also listed. This could be valuable information for Boeing and might also be addressed through flight-deck seat design.

Design solution

As opposed to improving already existing features of the flight-deck seat design, adding a tablet holder seemed to bring along certain advantages. This is where the scope of the project changed to:

"Designing a tablet holder to reduce discomfort among airline pilots."

The tablet holder design is able to address multiple causes of discomfort, can evolve considering certain upcoming trends in the market and gives the company the opportunity to grow. The following values were identified:

1. **Create an ergonomically responsible way of using the tablet.**
2. **Minimizing the area of visual attention by replacing the EFB.**
3. **Incorporating flight control systems.**
4. **Limit the added weight by replacing the EFB.**
5. **Working towards a paperless flight-deck.**
6. **Showing the benefits of a use-centred design**
7. **Provide the ability to access seat adjustment**

With the embodied design of this project, the company should be able to incorporate the product in a flight-deck design within 3 to 5 years. It will not be possible to incorporate all the value mentioned above from the start. All values except for the third can be realized from the beginning. The third value is considered to be a far-future value. Incorporating flight control systems in the tablet needs new regulations and lots of testing. Nonetheless, its an important value as it shows the future potential of the design.

Only the top part of the tablet holder has been designed. Specific requirements were identified for the top part of the tablet:

1. Attachment fixing the tablet to the holder.
2. Portrait-landscape adjustment
3. Up and down tilt adjustment
4. Vertical adjustment
5. The positions provided by these adjustment systems should be fixed to prevent unexpected movement
6. Electrical connection to power the tablet

All requirements, except for the sixth requirement, have been fully met. The sixth requirement was added late in the project. The electrical connection needs to be further detailed. This will be adressed in the recommendations on page 76. The rest of the requirements have been validated through a strength analysis and a proof of concept. It is safe to say that the systems will work and are strong enough. Specific material selection should still be done and certain detailing of the top part is necessary.

This will be featured in the next chapter along with other recommendations.

It is important to emphasize that the opportunity of designing a tablet holder derived from research conducted on the airline market and flights along Boeing 737 aircraft. The tablet holder is still aimed at reducing discomfort among airline pilots. However, for this company, introducing it to current Boeing airliners, might not be the best option as the flight-deck layout limits the the tablet holder design.

5. Finalization

5.2 Recommendations

The following main results of the master thesis are useful for the graduation company:

- The user research results, under which the list of improvements based on the 737 flight-deck seat design
- The tablet holder design
- The implementation plan

Recommendations are covered concerning each part.

User research results

By the end of the master thesis, the complete user research, in which twelve pilots participated was completed. The TU Delft, is analysing the data for further findings. The company should consider if there are specific relationships between the qualitative (posture analysis) and quantitative data that can be valuable for them. Additionally, further analysing data that might lead to flight-deck improvements could be worthwhile, as this is valuable to Boeing.

The list of improvements is based on the seat design of the Boeing 737, certain improvements might be applicable to other seat designs as well. For instance, most adjustment systems of the different flight-deck seat designs are similar. It would be worthwhile to improve the adjustment systems design and make it possible for the pilots to adjust the seat to a specific setting. Pilots do not get any feedback from the adjustment systems and have to guess how they have adjusted the seat. This could be provided through an adjustment app in the tablet, however, that would only be achievable if the seat features electronic adjustment systems.

Tablet holder design

In terms of the actual design of the tablet holder, the company should consider the following recommendations:

- As stated in the list of improvements, the armrests should feature a vertical up/down adjustment system. While designing these systems, the company should consider the use of the tablet. During typing activity on the tablet, the pilots need to be able to lean the forearms on the armrests.
- The magnets should be optimized for the tablet design in cooperation with correlated magnetics, the company that manufactures the magnets. The prototype has shown, that the portrait/landscape mode magnets should be stronger, it requires too little force to turn the tablet. Additionally, the magnets might be made thinner to allow for a smaller design. Furthermore, correlated magnetics could provide the graduation company with more specific information about the distance at which the magnets might interfere with other systems. The encasings around the magnets are quite large, possibly, these encasings can be made smaller.
- Although the tablet arm has only be designed visually during this thesis, the clearance between the legs and the tablet arm was too small. According to the visual design the form of the tablet arm should be adapted to allow for a bigger clearance.
- The handles for the adjustment systems will have to be tested. It is important to make sure that the positioning of the levers and the distance from the tablet is good. Additionally, further testing could show what kind of use cues are the best to communicate how to use the levers.
- The portrait/landscape mode adjustment should be able to rotate 360 degrees. At the moment, the adjustment system can only rotate 90 degrees. However, this means that the pilot can break the system if he tries to rotate the wrong way around.
- The moon shaped part of the up/down tilt system should be analysed on its strength. This part should be able to withstand a considerable amount of force and was not covered in the strength analysis.
- After testing the prototype it became clear that the lever for the vertical adjustment system can rotate around its axis. By adjusting the shape of the lever, for example by making a certain side rectangular, the lever will not be able to rotate around its own axis.
- The electrical connections should be designed in detail. An additional, tablet cover design should hold the connection from the tablet to the tablet holder and cover any wires and plug connections.
- Very specific detailing such as optimizing the plastic parts for injection moulding still has to be done.
- As already stated the tablet arm should be designed specifically for each flight-deck. Additionally, it might be valuable to test certain tablet configurations to find the optimal positions of the tablet in different configurations.

The implementation plan

One of the underlying ideas of the implementation plan is to prepare on upcoming technology advances, mostly caused by the major growth of the aviation industry. The business-jet market is a technology progressive market, which enables the company to grow with these changes. Additionally, a product that has been introduced to this market can later be fluently introduced to the airline market. This can strengthen their relationship with Boeing while at the same time making the company more independent. This is important as the company does not know how Boeing will prepare for the probable upcoming technology advances in the market. It is a form of risk management by diversifying in the aviation industry. It is recommended to take a look at how the aviation industry might change in the future and consider this in long-term plans.

figure 87 : The future flight-deck design by Thales

5.3 Conclusion

The user research resulted in a list of improvements on the current Boeing 737 seat design of the graduation company. Based on this list and other findings from the analysis phase, a tablet holder proved to be beneficial for the graduation company and multiple stakeholders.

The tablet holder design can reduce discomfort among airline pilots while enhancing their work environment and supporting growth towards future technology advances in the flight-deck. The product can be beneficial for the aircraft manufacturer and the airline. It enables the aircraft manufacturer to work towards making airplanes easier to control. Additionally, a platform to incorporate flight-control systems into the tablet could act as the instigator for a distributed, air/ground, socio-technical system. Both aspects that adhere to the growing demand of pilots and which supports the change towards single-pilot operated aircraft. Additionally, the tablet allows the aircraft manufacturer to get rid of a fixed EFB and allows the airline to work towards a digitalized documentation system, which can be accessed through the tablet.

Introducing the tablet holder to current Boeing aircraft will be difficult. The steering column in current aircraft of Boeing would limit the design and make a tablet holder impractical. Introducing the tablet to the technology progressive business-jet market could be worthwhile. It allows the company to diversify in the aviation industry and grow along with technology advances.

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