

Mohammadreza Manaberi

Concept development of an AR user interface for flight inspection and airborne surveillance

Master's thesis in Industrial Design Engineering

Supervisor: Trond Are Øritsland

January 2021

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Norwegian University of Science and Technology
Faculty of Architecture and Design
Department of Design

Preface

This master's thesis has been written at the Department of Design at Norwegian University of Science and Technology, during the fall of 2020. The project has been in collaboration with Norwegian Special Mission AS (NSM).

The thesis describes and documents an exploration of use cases of augmented reality for flight inspection and airborne surveillance industry. It includes the insights I gained from studying the company, review of available AR solutions, ideation for use cases of AR for their different departments, and concept design of an AR user interface for flight inspection and airborne surveillance systems.

January 19th, 2021
Trondheim, Norway

Acknowledgments

I am truly grateful for all the guidance and support I have received from my supervisor Trond Are Øritsland, without whom this project would not have succeeded. I would also like to thank my co-supervisor Thomas Porathe for his support throughout the project.

As well, I appreciate NSM's team and Frank Robin Danielsen's trust in my abilities and the opportunity they gave me.

Last but not least, I would like to thank my family in Iran who supported me full-heartedly and push me to move forward even in difficult moments.

Abstract

Norwegian Special Mission, as one of the market leaders in the flight inspection and airborne surveillance industry, wants to prepare itself for the coming years. According to the strategic plans proposed to the company in our last collaboration, they are working on a new human-computer interaction as well as a drone-based mission system. This master's thesis proposes a concept of an AR user interface that provides advantages not only for their current mission platform, but also for their drone-based solution. The design brief was defined through the Delft innovation model, then, the concept was developed with a user-centered approach combined with the theoretical knowledge in information visualization. The AR concept was prototyped and presented to the users using HoloLens and Unity3D and improved through an iterative process. Finally, three ideas for communication, menus, and an input device are proposed for further development.

Sammendrag

Norwegian Special Mission, som en av markedslederne i flyinspeksjons- og luftovervåkingsindustrien, ønsker å forberede seg på de kommende årene. I henhold til de strategiske planene som ble foreslått for selskapet i vårt siste samarbeid, jobber de med en ny menneske-maskin interaksjon samt et dronebasert oppdragssystem. Denne masteroppgaven foreslår et konsept med et AR-brukergrensesnitt som gir fordeler ikke bare for deres nåværende oppdragsplattform, men også for deres dronebaserte løsning. Design prosjektet ble styrt ved hjelp av Delft-innovasjonsmodellen, og deretter ble konseptet utviklet med en brukersentrert tilnærming kombinert med teoretisk kunnskap i informasjonsvisualisering. AR-konseptet ble prototypet og presentert for brukerne ved hjelp av HoloLens og Unity3D og ble forbedret gjennom en iterativ prosess. Til slutt foreslås tre ideer for kommunikasjonen, menyene og inngangsenheten for videre utvikling.

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CHAPTER ONE

Introduction



1.1 Thesis background

Being a tech-savvy designer, I started learning AR in 2015. At the time, I used this technology to present my product concepts at university not only for showing the details but also for creating more attractions for the audiences. Throughout my education, I have always been looking for an opportunity to explore the AR field and learn more about how to design AR solutions.

In the spring of 2020, I found an online course by the Interactive Design Foundation dedicated for UX design of AR and VR. So, I participated in the course. That was when I decided on the topic for my thesis.

I was working for Norwegian Special Mission then. In a project, they tasked me with creating some renders of their new console to be shown to clients. In addition to the renders, I created an interactive AR model of the product. After showing them my idea, they expressed interest and were enthusiastic about my proposal for designing an AR solution for their business. In fact, this topic was something they had been eager to explore and had already procured some equipment.

So, I seized the occasion and found the thesis a great opportunity for me to dive into this field.

Master's thesis for Mohammadreza Manaberi

Design of an augmented reality user interface for flight inspection and airborne surveillance systems

Design av et augmented reality brukergrensesnitt for flyinspeksjon og luftbårne overvåkingssystemer

Augmented reality, as an emerging technology, is drawing more attention of various industries, other than entertainment and gaming that have been using them for a while. Being relatively new in comparison to other interactive media, there are a lot to explore regarding user experience and interface design for AR.

Norwegian Special Mission (NSM) is a producer of flight inspection (FI) and airborne surveillance (AS) systems. The company seeks to use AR at different stages of design process, production, and after-sale services. As well, NSM is working on the next generation of FI and AS systems in which airplanes are replaced with UAVs and drones. In this scenario, there are several potential usages of AR, for example, in form of an immersive control space for the mission operators.

This thesis will be conducted as a design project in collaboration with NSM to explore different opportunities where AR can be beneficial, to shape a better understanding of UX design for AR, and to design a new human-computer interaction in AR for FI/AS systems.


The work may include:

- Exploration of current use cases of AR in various industries
- Ideation and Sorting the ideas based on company's values and framing a design brief
- Conceptualization of the selected solution and development of simple AR prototypes
- Presentation of the solution to the users and gathering feedback


The project should be executed according to "Guidelines for master's thesis in Industrial Design".

Supervisor: Associate Prof. Trond Are Øritsland
Co-supervisor: Prof. Thomas Porathe
Contact person at the company: Frank Robin Danielsen (CTO, Director R&D)

Starting date: 26.08.2020
Submission date: 19.01.2021


Trond Are Øritsland
Supervisor

Trondheim, NTNU, August 19, 2020


Ole Andreas Alsos
Head of the department

1.2 Who am I?

My name is Mohammadreza Manaberi and I am from Iran. I started a master's program in Industrial Design at NTNU in 2018. My background is in both product and interaction design. Now, I am about to finish this program in Industrial Design at NTNU.

Being a tech-savvy designer, I am going to explore the field of augmented reality and would like to learn more about the design of AR-based solutions.



Mohammadreza
Interactive Product Designer
Shiraz, Iran

1.3 Norwegian Special Mission

Norwegian special mission (NSM) is a company owned by Sundt AS specializing in designing and providing airborne surveillance and flight inspection equipment. Since 2003 they have been striving to provide the best solutions for airborne special missions. They are a small company with about 50 employees and located at Gardermoen approximate to Oslo airport along with their sister companies; Sundt Air AS, Pegasus Helicopter and Aviation Engineering.

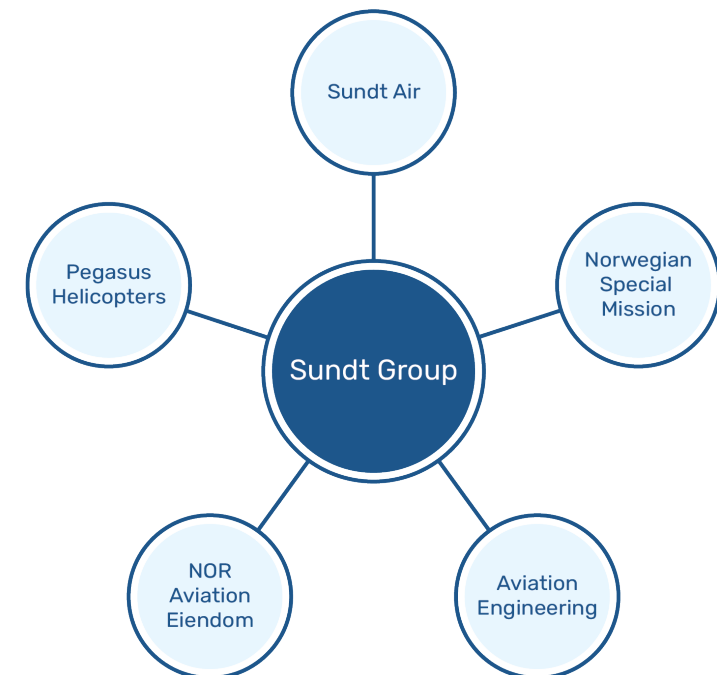


Figure 1.1. Sundt group and its subsidiaries.

NSM consider themselves as a leader in their field and provide equipment worldwide. They started out by making flight inspection and flight validation equipment, in 2010 they extended into the airborne surveillance and remote sensing business, and recently in 2020, NSM has taken an active role in the feasibility studies and experimental design of special mission systems adopted to remotely piloted aircraft systems (RPAS), unmanned aerial vehicles (UAV), and drones platforms. (NSM.aero, 2020).

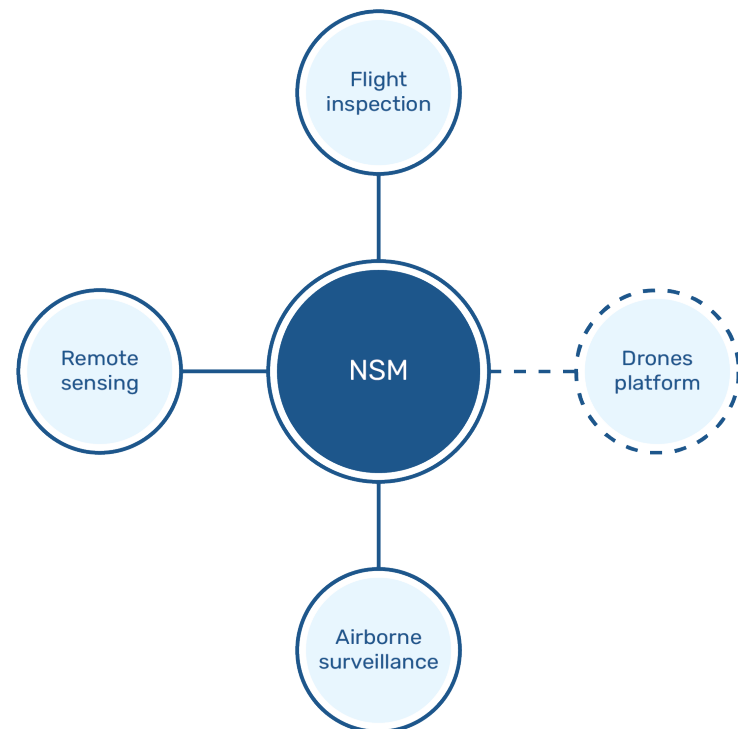


Figure 1.2. NSM's fields of business.

1.3.1 Current solutions

Flight inspection (FI) refers to the periodic evaluation of navigational aids used in aviation, such as flight procedures and electronic signals, to ensure they are safe and accurate. Flight inspection comprises reviewing flight procedures, such as routes, approaches, and departures, to ensure navigational support is sufficient, there are no obstacles, and the procedure is reliable. Flight inspection is a special type of mission where the antennas and equipment attached to the instrument landing system (ILS) get tested and maintained (Wikipedia, 2020).

Airborne surveillance (AS) is about surveilling the sea and other remote areas. The requirements for this type of mission are good cameras, radars, and other tools that let the operator get the information needed. Today, Norwegian coastal administration "Kystverket" uses airborne surveillance to surveil the seas and look for illegal fishing, oil spill, or to gather information about marine accidents. Seahunter 8000 is NSM's solution for this type of mission.



Figure 1.3. Unifis 3000.



Figure 1.4. Seahunter 8000.

1.3.2 Project ADA and G2

NSM wants to move away from different products to one modular console platform. They want to deliver one flight management system handling everything from brief to report. ADA, which stands for Adaptive Decisive Awareness, is the name of NSM's recent project in which they have defined a new design system for their future products. This system is thought to be more adaptive in configuration (one program structure for all products), responds adaptively to the user's needs, and can be adapted to new technology. Adaptation marks the company's new attitude.

With this mindset, the second generation of their product (G2) is under development. It contains a new hardware design, as well as a new software. Both components are designed in a modular way to be adaptable for different types of missions. Namely, instead of having different consoles and software for FI, AS, and remote sensing, NSM is going to deliver an identical console and software for the three types of missions, but with different internal components and software modules.



Figure 1.5. Unifis 3000.

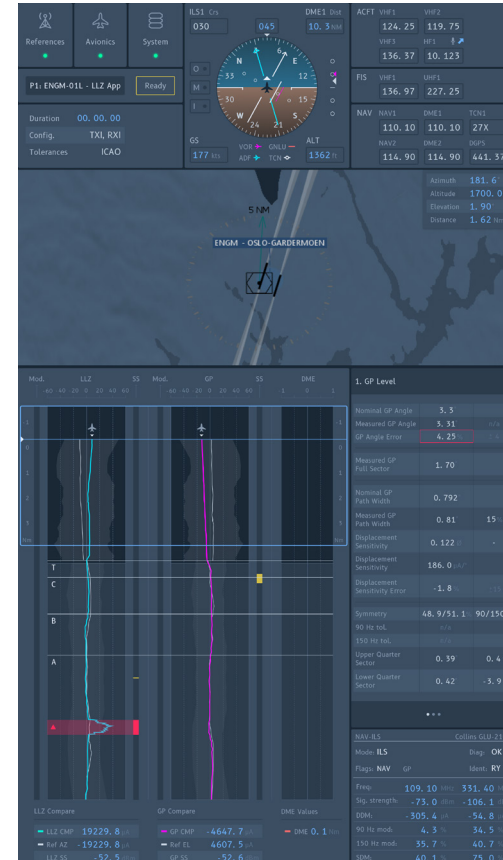


Figure 1.6. Concept of G2 software for flight inspection.

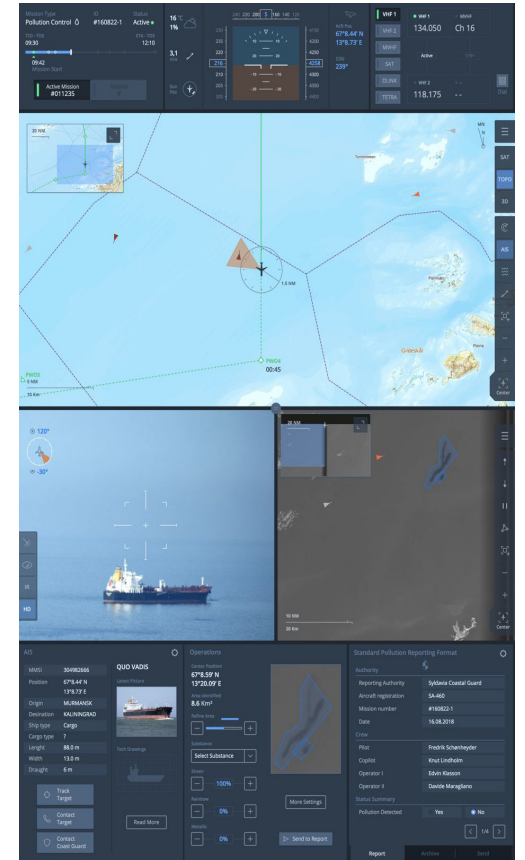


Figure 1.7. Concept of G2 software for airborne surveillance.

1.4 Collaboration with NSM

The beginning of collaboration with NSM dates to spring 2019 when I along with two other teammates worked with them in our Strategic Design course. In that project, we analyzed NSM internally and externally and developed three strategic plans for them based on their strengths and weaknesses, as well as mega trends. This will be explained more later in this chapter.

At that time, they were working on the development of the second generation of their products (G2). Also, it was the beginning phase of ADA concept development.

Our team got the opportunity to work at NSM during summer 2019 to develop and prototypes one of our ideas: a new HCI, including a hand-held control device and a new display layout, for the second generation of their software and system as a part of ADA concept development project.

During last year, I have been in touch with NSM and worked for them remotely. In one of the tasks, they wanted to present their new console to a potential customer. They used to have low quality renders and photos of the previously delivered systems in their presentation. In ADA project, however, the final product was not ready yet and there was no photo of it. Therefore, I made a realistic representation of the new console in AR that the customer could see in one by one scale in the real world using an Android tablet.

After presenting my idea to NSM, they showed great interest and offered me to develop the solution with more details during an internship in summer 2020. So, I worked there again and developed a software for tablets and Microsoft HoloLens in which NSM's new system is presented and the user can interact with it in order to, for example, place the model in a specific location, see and disassemble the internal components, and get access to the datasheet of each part.

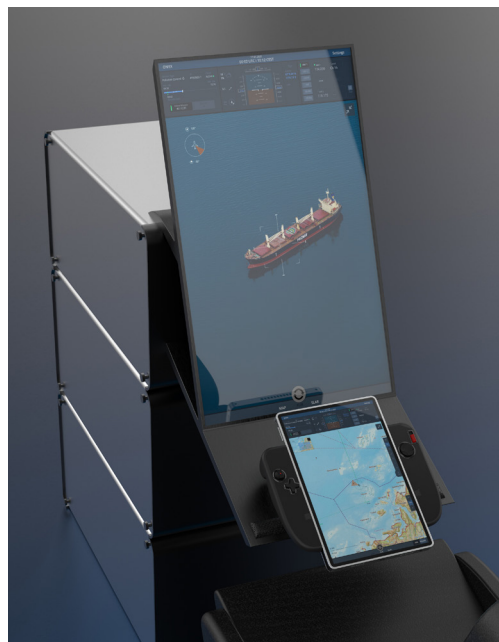


Figure 1.8. Concept of a new HCI for G2.



Figure 1.9. Concept of a hand-held controller for G2.



Figure 1.10. AR prototype for tablet.

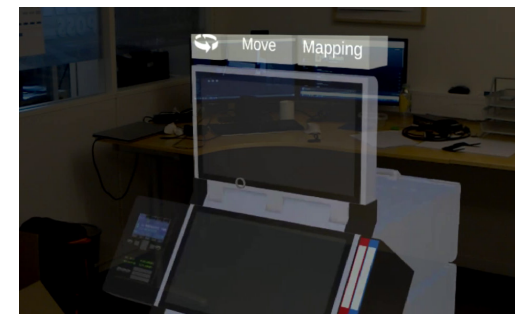


Figure 1.11. AR prototype for HoloLens.

Being interested in AR and having a little experience in this field from my bachelor, I was planning to do my master's thesis in the field of AR. I shared my thought with the company, and they were interested in collaborating with me during my master thesis to explore the use cases of this technology for NSM.

1.5 Strategic analysis

As mentioned earlier, an internal and external analysis of NSM was conducted in our Strategic Design project. There are some bonds between this thesis and that project, and my solution is in line with the strategic directions offered to NSM in our previous collaboration. So, an overview of the analysis and its results will be presented here.

1.5.1 Stakeholders network

The reason for employing stakeholders mapping was to develop a clear understanding of the relationships within their industry and market. This might help us define new connections between partners and/or remap them in order to create new strategic values that are achievable when different stakeholders cooperate (McKaskill, 2020).

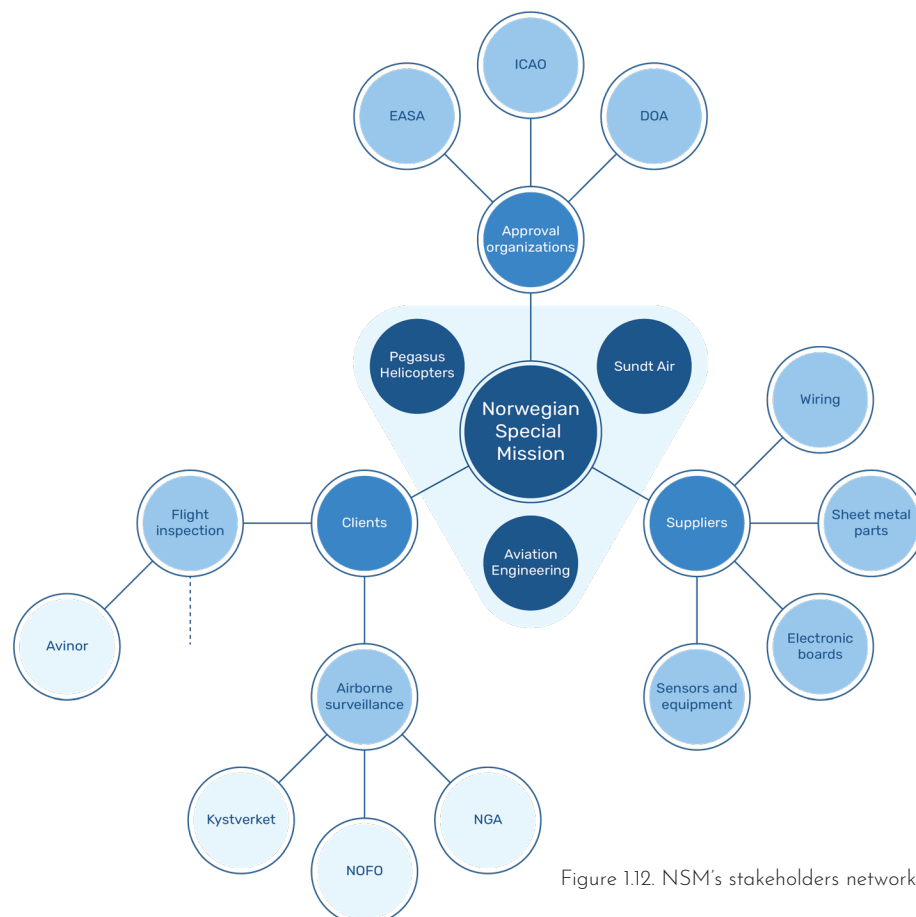


Figure 1.12. NSM's stakeholders network.

1.5.2 Workflow

NSM's workflow was depicted to get a better vision over the interactions they have with other companies and organizations, as well as their clients. After more discussion about how NSM delivers a product, we found out that, in reality, the workflow is not linear as it is depicted in the figure. It is more complex. This visualization is to represent how the company typically works and to depict how complex the workflow can be within the flight industry. NSM cannot

change their design without the approval from DOA or EASA which are organizations that test and approve equipment for the flight industry. This put them in a situation where it is easy to lose the will to innovate.

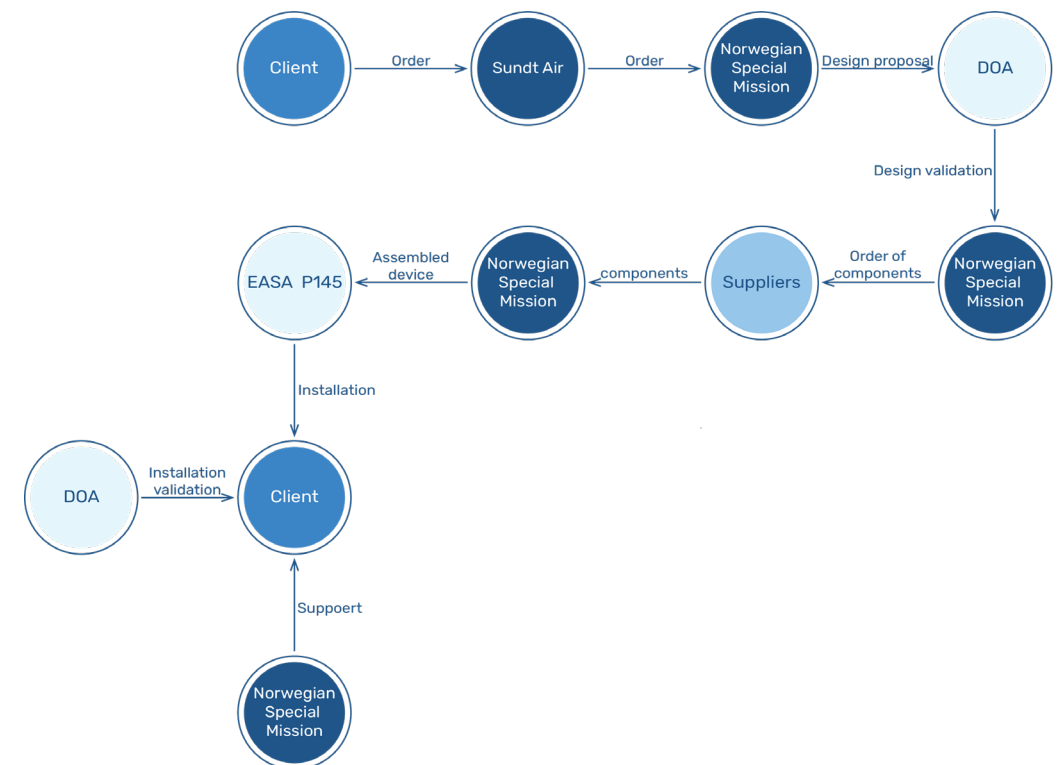


Figure 1.13. NSM's workflow diagram.

1.5.3 Mega trends

To gain insight about the future of NSM, our group chose to look into mega trends related to NSM's business. We knew from our internal analysis that NSM has a good foundation as a technology company to explore and go into trending technologies. According to our research, we decided on five mega trends that fitted NSM's already existing foundation of knowledge. Since the company knows a lot about the aeronautical industry, sensor technology, and data analysis they could easily be fitted into:

Autonomous vehicles:

Autonomous transportation means have a huge demand for sensors and technologies NSM already knows a lot about. By entering this market they can use their suppliers and stakeholders in a new way.

Smart cities:

Smart cities have a high demand for new technologies related to sensors and surveillance that NSM has great expertise about.

Drones:

An upcoming demand for drones with customized functions is predictable. The same way NSM customizes planes today, they can be adapted to drones customization in the future.

Selling data:

There is a spreading desire from customers to achieve their goals through buying services instead of products. Selling FI and AS data instead of the equipment can be a new source of income for NSM.

New media technologies:

Technologies such as AR/VR or other new interface solutions are getting popular within various industries. We are entering a time with more augmented reality and solutions like simulated senses or mixed reality are within our horizon (Ramella, 2018)

1.5.4 SWOT

By putting together the data gathered from the internal analysis (through observation, interview with NSM's managers, and studying their business mindset) and external analysis (through the study of the stakeholders and mega trends), we managed to do a SWOT analysis.

In fact, the data from the internal analysis formed the internal factors including strengths and weaknesses and the external analysis resulted in coming up with external factors including Opportunities and threats. The result is briefly presented in the chart below.

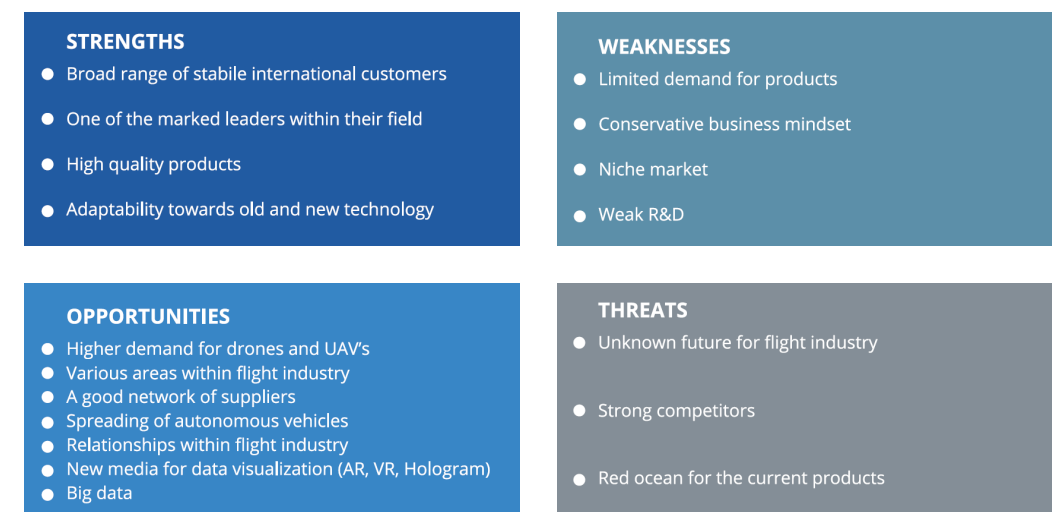


Figure 1.15. Results of SWOT analysis.



Figure 1.14. Mega trends.

1.5.5 Strategic directions

SWOT matrix was employed in order to generate future search fields. By using this method, the company's opportunities and strengths were mapped, and by crossing the items in these two groups, seven innovative search fields got developed.

Afterwards, by mapping the search fields up against the threats and weaknesses of the company, a bottleneck matrix was created. This method was helpful to filter the search fields and select three of them which matched the best with NSM's capacities.

The final strategic plans were described as below:

Short-term plan (2019 - 2023):

In the first four years, the company should finish their current undertakings and finish G2. They should focus on UI/UX and make a product that outperforms its competitors. This can be achieved by using a design consultancy that can understand the users and help them change the conservative mindset within the company. At this time the company should start to strengthen the R&D department and investigate the drones' market.

Mid-term plan (2019 - 2025):

At this time, the company should be the market leader within the FI industry and have the best product on the market. They should have employed in-house designers as well as enhancing the R&D department. During this period, they are getting their resources from the FI market and putting them into the drone market where they are establishing themselves as a company that customizes drones for different usages.

Long-term plan (2025 -):

At this point, the company is shifting entirely to the drones segment. They are the first company making customizing drones for a variety of functionalities including firefighting, parcel delivery, security, etc., as well as drones for FI/AS missions. They will become the leader within their field.

Opportunities	Higher demand for drones	Various areas in flight industry	Good network of suppliers	Good network of suppliers	Spreading of autonomous vehicles	Relationship within flight industry	New Media	Data selling
Strengths								
Broad range of stable customers						Security against drones		
One of the market leaders		Remote ATC tower						AS data selling
High quality products								
Adaptability to old and new technologies	Security against drones Customized drones		Autonomous vehicles Smart cities surveillance Customized drones				New interface for G2	AS data selling

Figure 1.16. SWOT matrix and the search fields.

Weaknesses/Threats	Red ocean for current products	Limited demand for their products	Conservative business mindset	Niche market	Weak R&D	Unknown future of the flight industry	Strong competitors
Search fields							
Remote ATC tower				⊗	⊗	⊗	⊗
Customized drones			⊗		⊗		
Security against drones					⊗	⊗	
Autonomous vehicles	⊗		⊗		⊗		⊗
Smart cities surveillance			⊗		⊗		
New interface for G2		⊗		⊗		⊗	⊗
Selling AS data		⊗		⊗	⊗	⊗	⊗

Figure 1.17. Bottle-neck matrix.

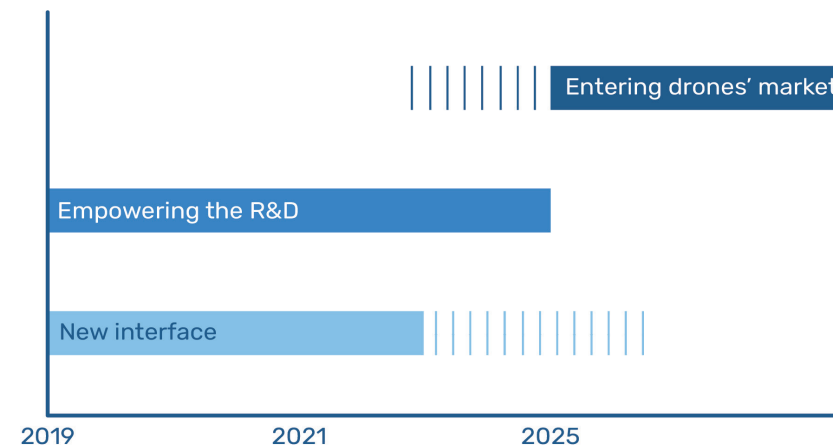


Figure 1.18. Timeline of the strategic plans.

1.6 Scope of this project

Considering NSM's approach in ADA project and the three strategic plans, I am investigating on the applications of AR that comply with the company's roadmap, and I will design a solution using this technology to facilitate NSM with product design, service delivery, or mission operation.

1.7 Process

The process in this project is based on Delft innovation model (Buijs, 2012). This circular model contains five stages, including product use, strategy formulation, design brief formulation, development, and market introduction. In fact, this project includes the third and the fourth phase of this model. While the first two phases were done in my strategic design course, I am basing my job on the strategic plans which were decided previously.

In "Design brief formulation" stage, holistic ideas and strategic directions should be transformed into concrete product ideas. The ideas should be formulated precisely so that they are ready for development. "Design brief", which is the result of this stage, will be the starting point for the next "Development" stage (Buijs, 2012).

In this project, the brief formulation stage will be called "Exploration". This phase contains three main parts. The first is case studies of current industrial AR solution. This is to nourish the mind and to get prepared for the ideation part, which is the second part. In ideation, brainstorming and co-creation workshop will be done to generate several product ideas for the company. Finally, in the third part, the ideas will be evaluated, and the design brief will be formulated.

The fourth phase of Delft design model is "Development". This is the stage of all traditional product design activities. Along with product development, technology and market development should also be considered. The development stage ends with at least prototypes that will be tested with the users (Buijs, 2012).

The development phase will be called "Conceptualization" in this project. The final product of this project is going to be a UI concept; therefore, this phase contains UI/UX design activities. There will be three parts in the conceptualization stage. As D. Norman (2013) says, "good design starts with an understanding of psychology and technology", therefore, this chapter begins with user research and it is followed by a review of the technology. Then, there is iterative design. For user research, methods like observation, interview, and task analysis, will help to shape an understanding of the user and his needs. In the technology analysis section, topics like current AR devices and their capabilities and limitations, as well as interaction methods and input techniques in AR environment will be investigated. Then in the iterative design part, scenarios, wireframes, and prototypes will be made iteratively in order to create, evaluate and improve the solution. The conceptualization phase is planned according to the human-centered design approach mentioned in ISO 9241-210: Ergonomics of human-system interaction – Part 210: Human-centered design for interactive systems (ISO, 2019).

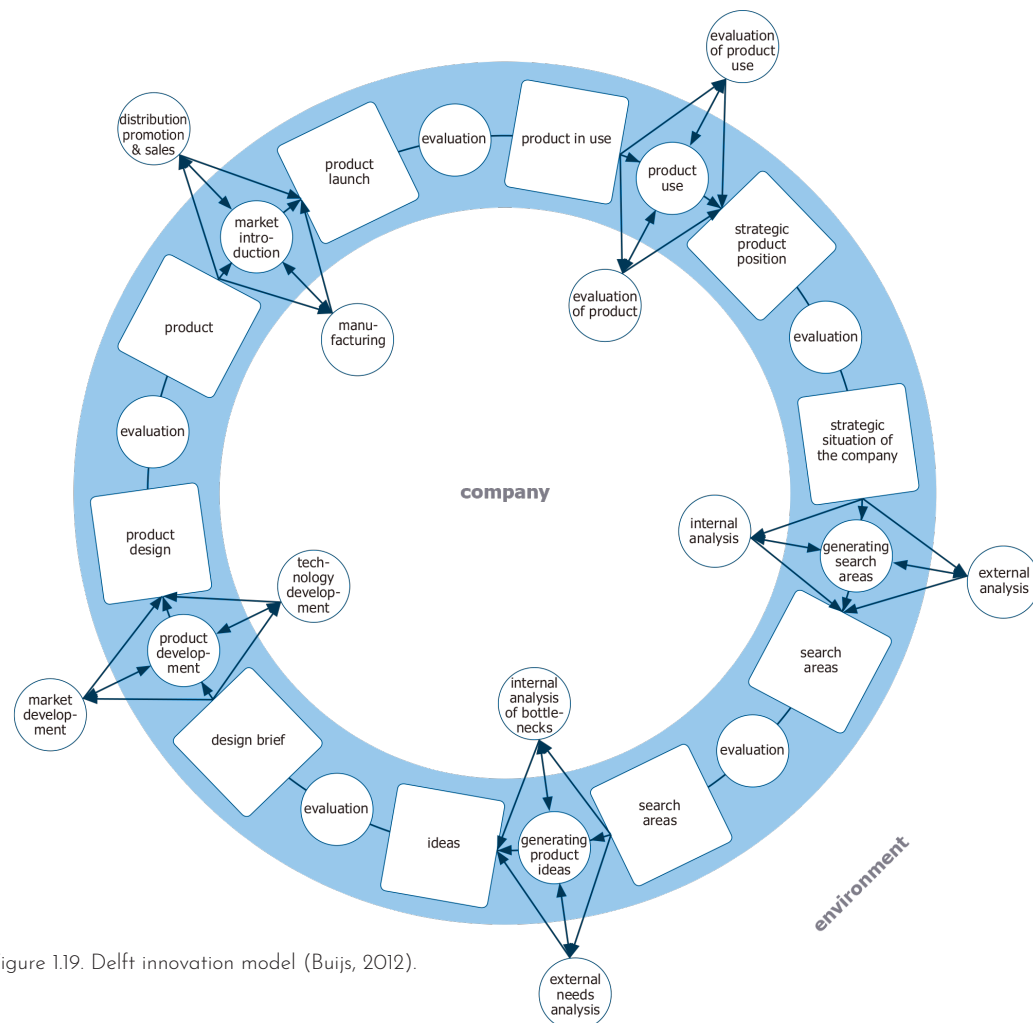


Figure 1.19. Delft innovation model (Buijs, 2012).

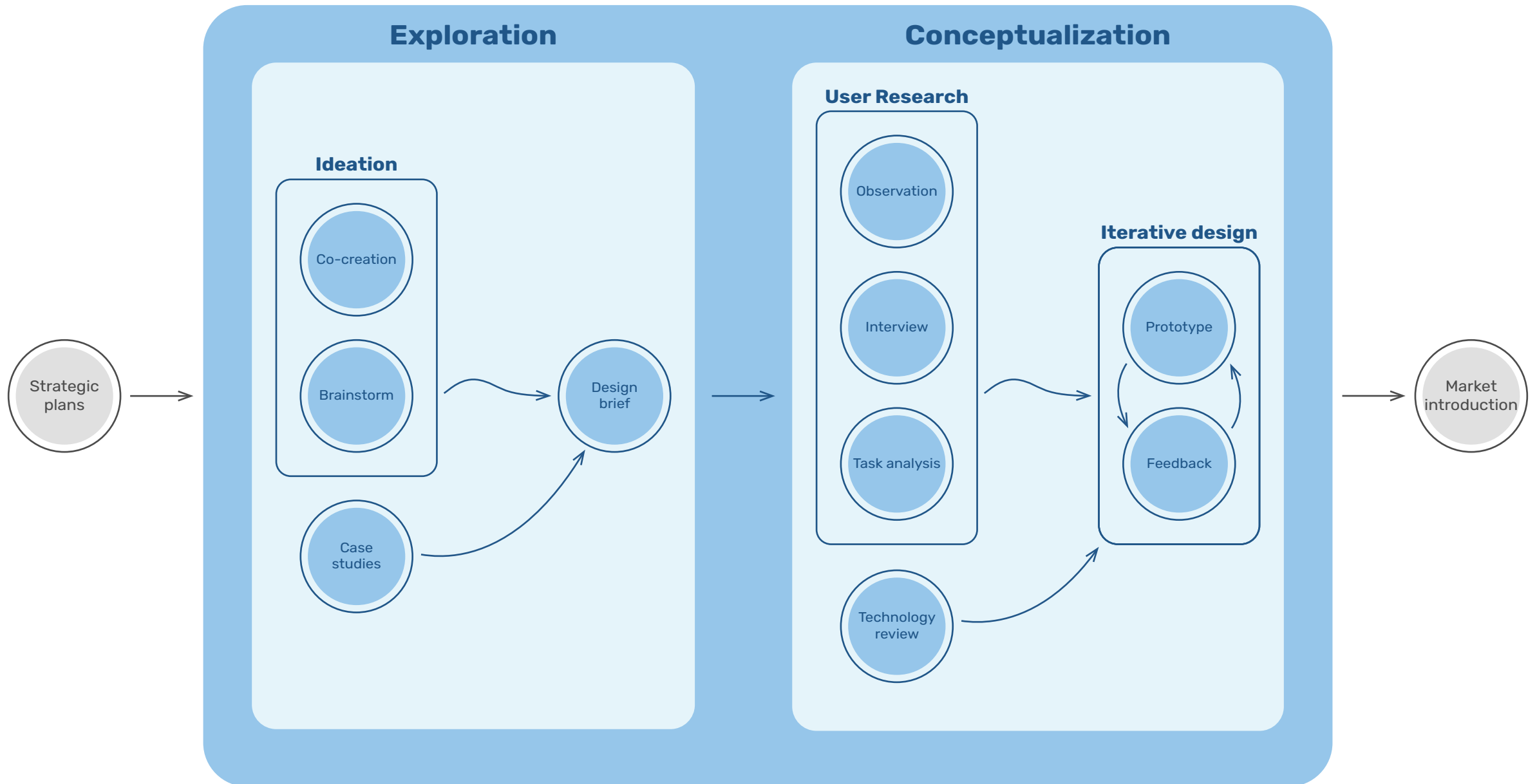
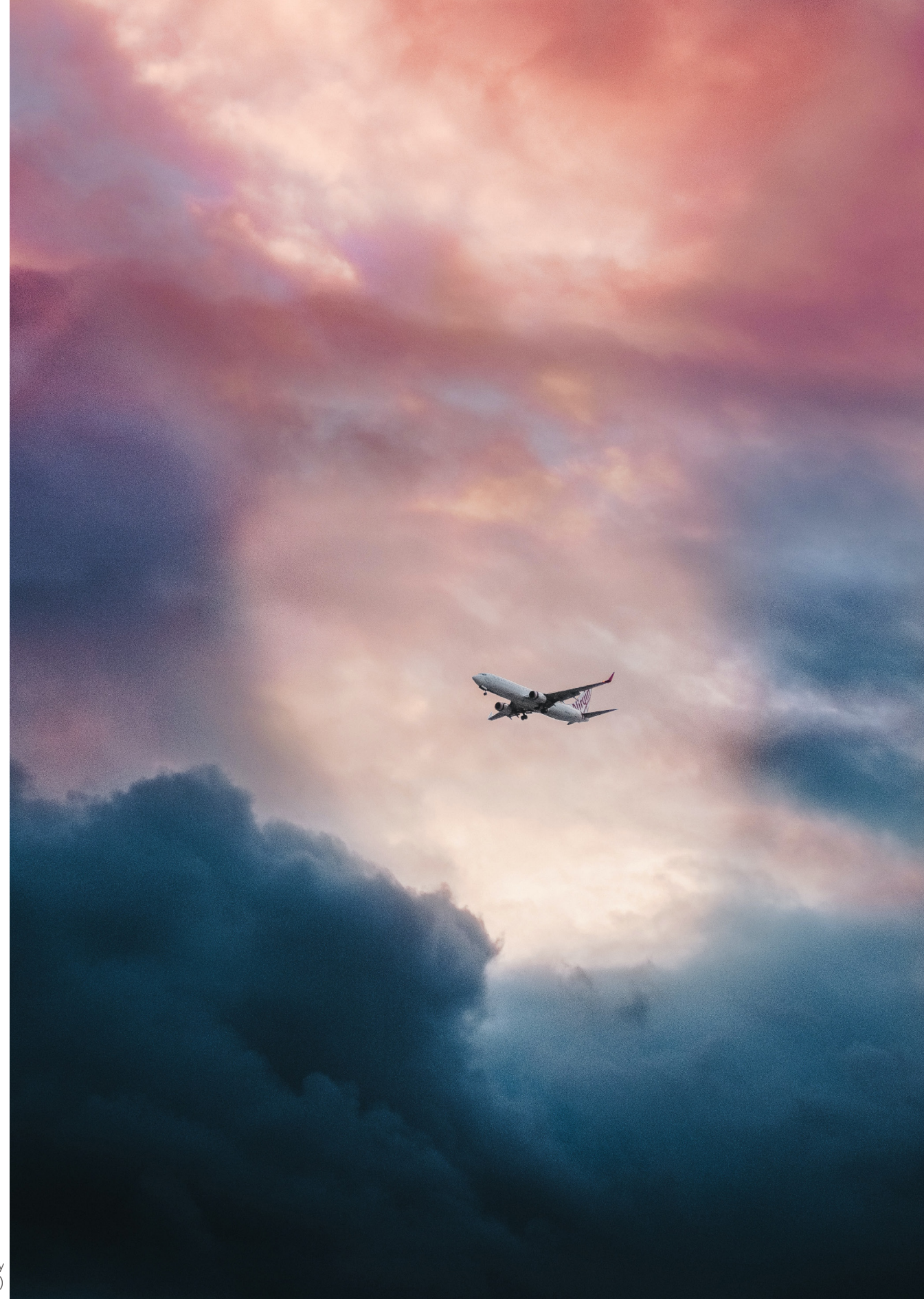


Figure 1.20. Design process diagram.

CHAPTER TWO

Exploration



2.1 Industrial use cases of AR

AR has been of popular technologies in recent years. Although the first properly functioning AR system was probably the one developed at USAF Armstrong's Research Lab by Louis Rosenberg in 1992 (Interaction Design Foundation, 2020), the first commercial application of this technology appeared not sooner than 2008 when BMW used it for marketing purposes. They designed a printed magazine ad of a model BMW Mini, which, when held in front of a computer's camera, also appeared on the screen (Javornik, 2016).

Later, AR became more attractive to different businesses, including tourism, health, education, manufacturing, industrial maintenance, game and entertainment, fashion etc.

In this section, the focus is on getting inspiration by the examples in which AR has been used as a solution to facilitate tasks for different professions. To find examples, keywords like "AR use cases" and "industrial AR" were searched in YouTube, then, the results were divided into the following categories based on their functions and purposes.

2.1.1 Presentation and marketing

Advanced AR tools can create real-time interactivity between products, physical environments, brands and consumers. This medium aligns the digital world on smart devices with the real-time environment so that the barriers between them fade. This provides a greater physical-virtual closeness between brands and clients. Marketers can digitally promote and present their products in a much more efficient way than before using AR's capability for simulation. As a result, customers' risk of uncertainty, linked with purchases of goods they have not tried or seen before, reduces by dint of product simulations and

virtual try-ons (Javornik, 2014).

In an example, Toyota employed AR to allow customers to gain a better understanding of the new C-HR model. The app works by mapping images and animation of the inner workings of the hybrid drivetrain onto physical vehicles. Customers could interact with the app to discover more about the car's key features, like the hybrid's motor, battery, and its fuel tank. They can also go in-depth into how the car's energy is used and how the drivetrain works in different drive states (Brandwidth, 2019).



Figure 2.1. Screenshot from a video. AR presentation of Toyota CH-R (Brandwidth, 2019).

2.1.2 Remote maintenance and training

A popular application of AR is to provide users with real-time guide in order to do maintenance task or to train them. In this scenario, a person who wears an AR head-mounted display can see real-time instructions given by a technician who is remotely

seeing the site. For example, the technician can point to a specific part and draw an instruction and the user can see the drawing as an added layer of graphical data to the part and execute the maintenance task (Fraunhofer FIT, 2016).



Figure 2.2. Screenshot from a video. Remote maintenance using HoloLens (Fraunhofer FIT, 2016).

In another example, AR is used to visualize underground infrastructure and pipelines. The system retrieves GIS data of a site and converts traditional 2D data into 3D visualization (vGIS, 2019).

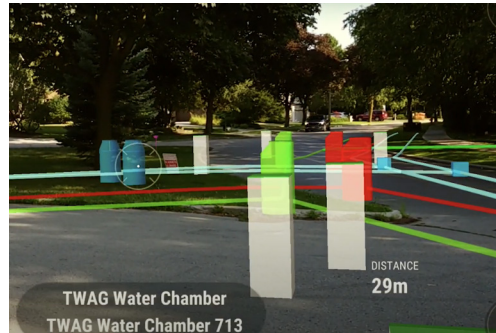


Figure 2.3. Screenshot from a video. AR visualization of underground infrastructure (vGIS, 2019).

2.1.3 Interactive user manual and catalog

Paper user manuals have been replaced with AR manuals by many industries. This type of manual can be shown on a phone or tablet by holding them in front of different components of a product. The software on the mobile device detects the parts and presents the relevant information and instruction of each part to the user. The information can be in different forms of 2D and 3D visual objects, as well as audio. Also, the manual may contain animations and videos to show instructions, for example, how to do maintenance (Ziegler, 2015).



Figure 2.4. AR user manual for Hyundai(The verge, 2015).

AR also makes it possible to bind virtual content to a paper catalog. The content can vary from a static datasheet to interactive 3D models with animation and audio. This method delivers more information through the same printed material, gives a better imagination of products to readers, and shapes a more engaging interaction (Mojoapps, 2019).

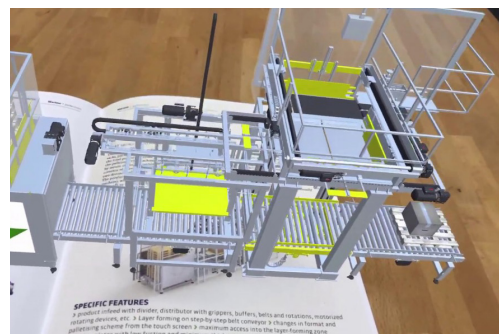


Figure 2.5. Screen shot from video. AR product catalog. (CADSchroer, 2019).

2.1.4 Design assistant

AR enables CAD operators to view and manipulate 3D models before any physical materials are brought into the process. Using either a mobile device or an AR head-mounted display, 3D models can be shown in their actual scale, so, designers can see the details in real size and figure out design mistakes that were not easy to find on a 2D display. This, of course, increases accuracy while reduces the costs of clay models or other expensive prototypes (Industr, 2020). Also, it is possible to see the model in the real environment where the final product is supposed to be and get a better understanding of the relation of the object with its context.

For example, we can see how the size of a model or the appearance fit to its surrounding. Moreover, different functions and mechanisms can be visualized, for example as animations, and become integrated with the AR models.



Figure 2.6. AR design viewer (Meta, n.d.).

2.1.5 Production and assembly

Augmented reality is, according to many experts, one of the most important elements of a smart factory, where assets are becoming increasingly smart and linked across disciplines. Manufacturers operating smart factories may use AR to guide workers through the manufacturing cycle and verify proper execution of assembly tasks (Weber, 2020). In assembly lines, AR solutions can facilitate workers with visual displaying of step-by-step instructions, components and details to assemble, and information about the necessary instruments for every stage. They may highlight the finished

pieces, give the whole 3D instruction, and what is even more important, AR devices like smart glasses enables hands-free work (Kovach, 2020).



Figure 2.7. Manufacturing assistant for Volvo based on HoloLens (Microsoft, n.d.).

2.1.6 Holoportation

The term holoportation was first introduced by Microsoft. It is a new type of 3D capture technology that allows high-quality 3D models of people to be reconstructed, compressed and transmitted anywhere in the world in real-time. When combined with mixed reality displays such as HoloLens, this technology allows users to see, hear, and interact with remote participants in 3D as if they are actually present in the same physical space (Microsoft, 2018).



Figure 2.8. Holoported person (Microsoft, 2018).

2.2 AR ideas for NSM

To ideate about AR solutions for NSM, first, the duties of each department were listed. This helped to get a better understanding of different tasks at the company and generate AR ideas to facilitate doing those tasks.

Then, a visualization was created that contained all the departments and their relationship with either other departments at the company or with the customers. To do so, I made a system map that covers almost all departments at NSM. The point of making this map was to get an overview of all the tasks and internal interactions between departments, as well as external relationships with clients. Then, based on the tasks, AR ideas were generated that help to operate tasks more productively or and simplify current routines. Furthermore, AR could also enable the company to create new values and services which were not feasible before.

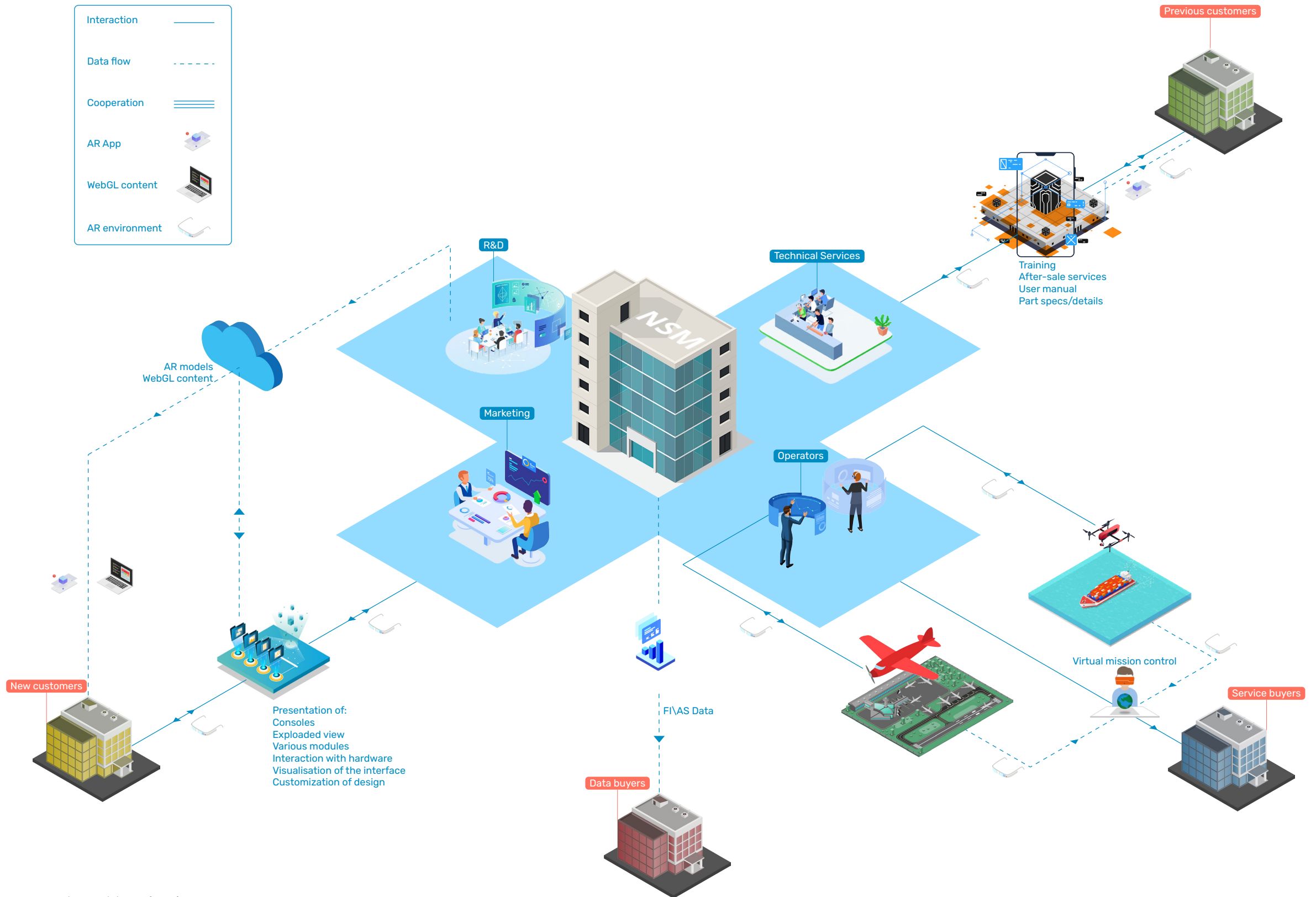


Figure 29. The possibilities of AR for NSM.

2.2.1 Virtual training

An important duty of the technical services department is to do training sessions for customers who purchase a product from NSM. Based on the interview with an employee of this department, now, the technicians must travel to a customer's place, or the customers should come to NSM to do a training course. This can be really time-consuming and costly,

because the customers are from all around the world. In addition, the training materials are slides containing pictures and text, and it can happen that the actual product is not available at the time of training. Therefore, the training can be so abstract and hard to understand for the customers.

Using AR, the trainers can holoport to a customer's place and do a course for them. They can also present an AR model of the products with all its features and the software, so, the training would be more fruitful since the trainees can interact with the virtual model. To run such a

session, the trainers should be in a room where they are 3D scanned in real-time, and on the other end, the customers need to wear AR goggles in order to see and interact with the AR content.

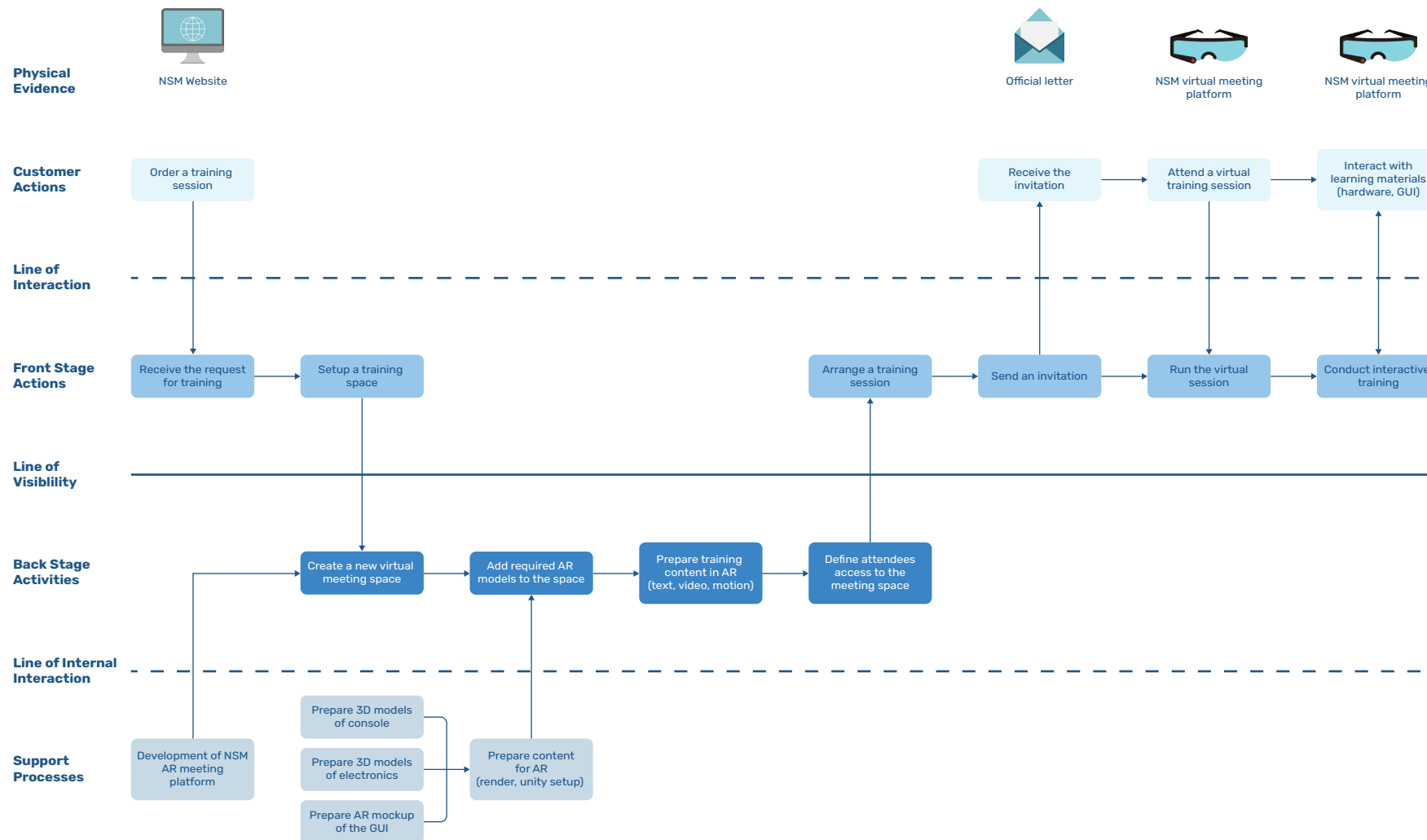


Figure 2.10. Service blueprint of the virtual training system using AR.

2.2.2 AR user manual

Providing an instruction manual for the clients is another duty of technical services department. Today, datasheets of the components and their manuals are all on paper. AR can bond the information about a part to its physical object. An AR user manual can detect a component when the component is exposed to the

camera of a mobile device. AR app can then overlay the specifications and information in different formats around the physical component.

Moreover, if there is a need to disassemble/assemble parts, the console should be returned to NSM or some technicians should go to a customer's place to do it. Using AR, the technical services department can embed these instructions as sounds, videos and animation, which are easier to understand than text, in an

AR app. Also, to do simple repairing, the department can help the clients by giving them real-time guides. To do so, the clients should wear an AR headset to see the guide that is being made by the technicians at NSM for the components.

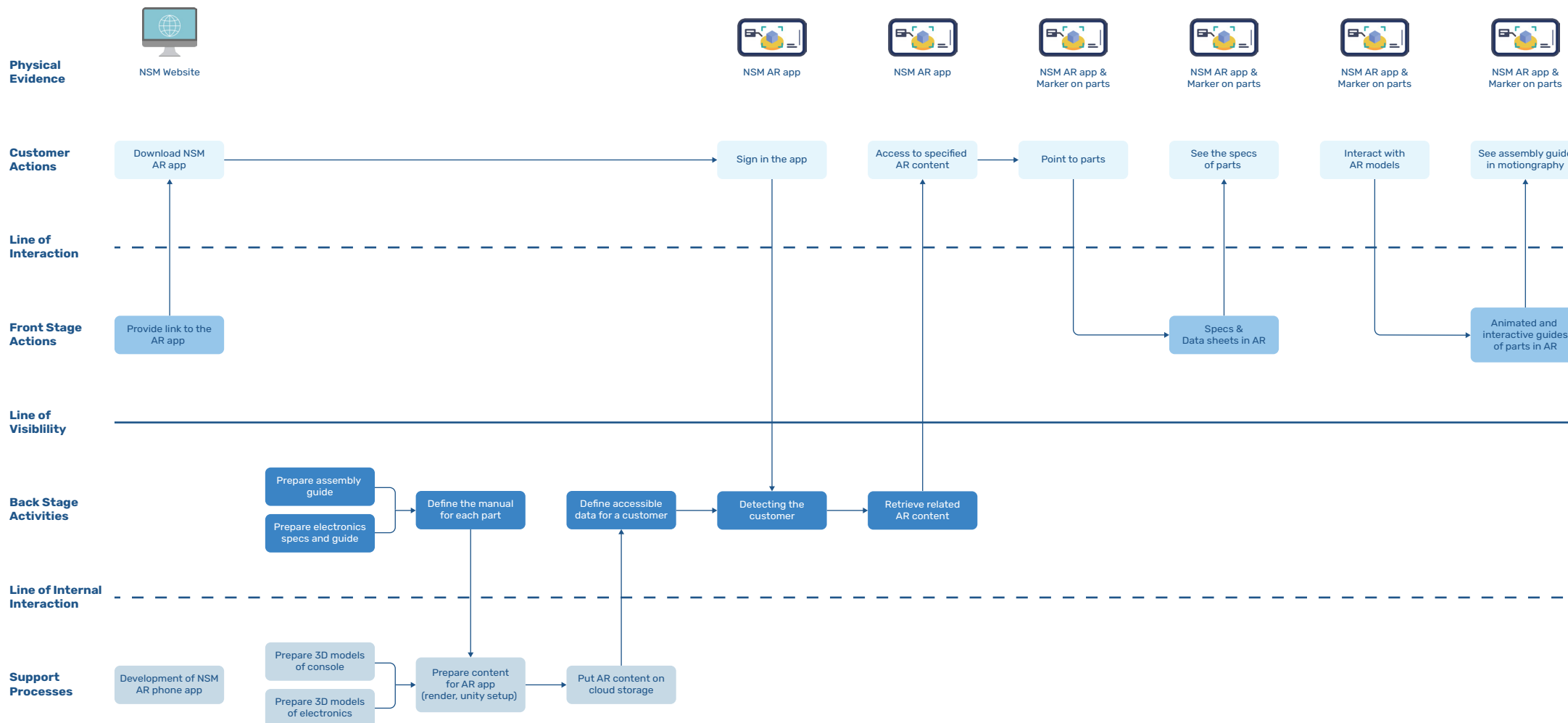


Figure 2.11. Service blueprint of the user manual using AR.

2.2.3 GUI interactive guide

For new customers, it is needed to provide training and instruction about the software of the system. Now, this task is done through training sessions. NSM can provide the users with an interactive AR guide over the software. By recognizing a customer, and so, the type of their system

and enabled software modules, the AR app can retrieve the relevant data from NSM's cloud storage and presents it to the customer. This eliminates the need for physical presence.

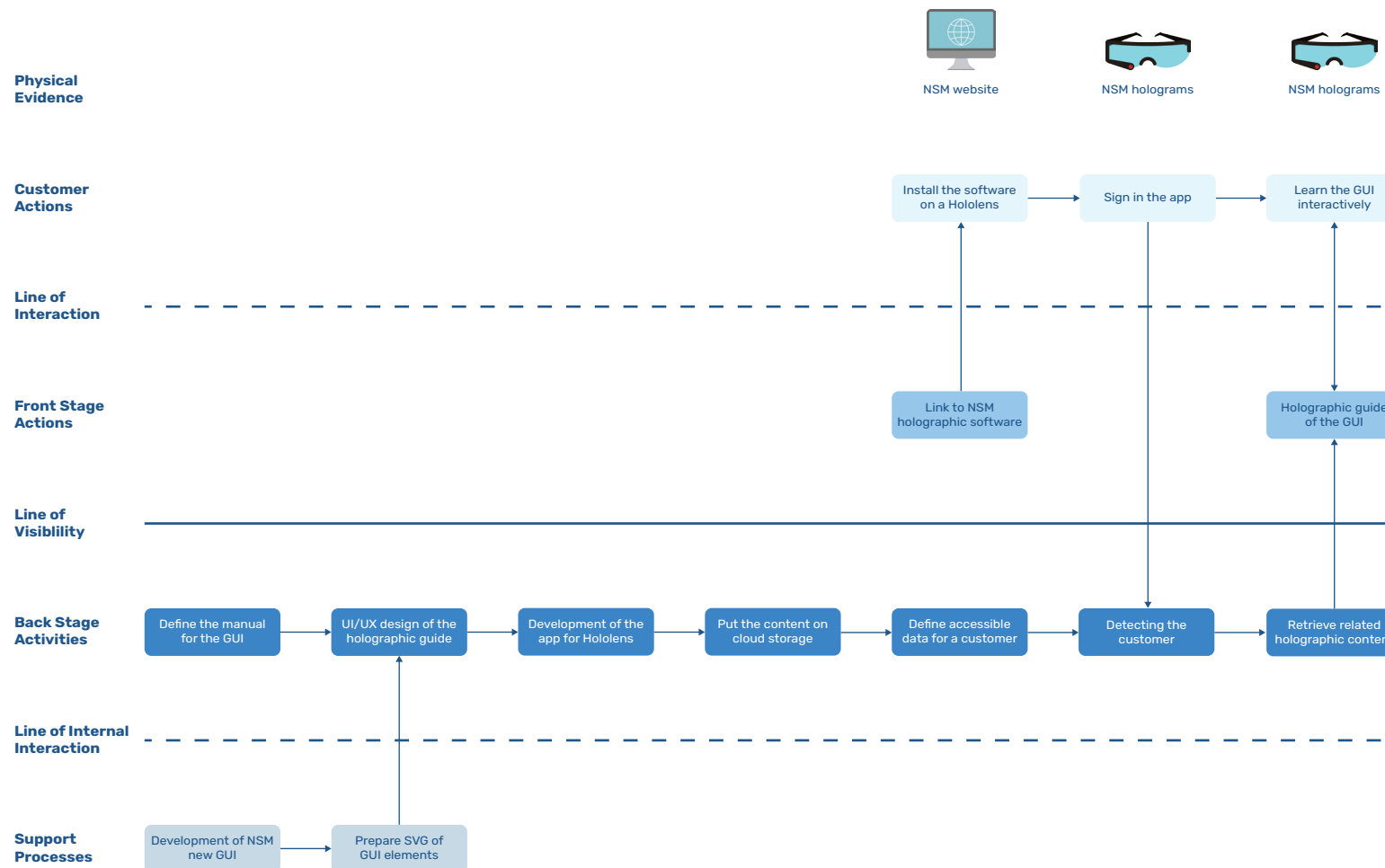


Figure 2.12. Service blueprint of the interactive guide for the GUI using AR.

2.2.4 AR for marketing meetings

When NSM's marketing team meets a potential customer, they use photos of previously delivered systems or rendered images to present their basket of products. If potential customers want to place an order, they usually select their required components and customize the system based on their needs. Today, the requirements are first discussed between the product managers

and the customer, then, the product managers ask the mechanical design department to create simple concepts of what the customers asked for, and then, they show it to the customer to check if the new design meets their needs. There are of course several iterations on this process until reaching to what a customer wants.

AR enables the marketing team to present NSM's product in a more tangible way than only images. Besides that, the available components can be presented in AR, for example on a virtual shelf, and the customers can select them and see a preliminary version of what is going to be delivered to them. Also,

the design modification phase can be facilitated by letting the customers to draw simple 3D models of what they want in AR when they are in a meeting with the product managers.

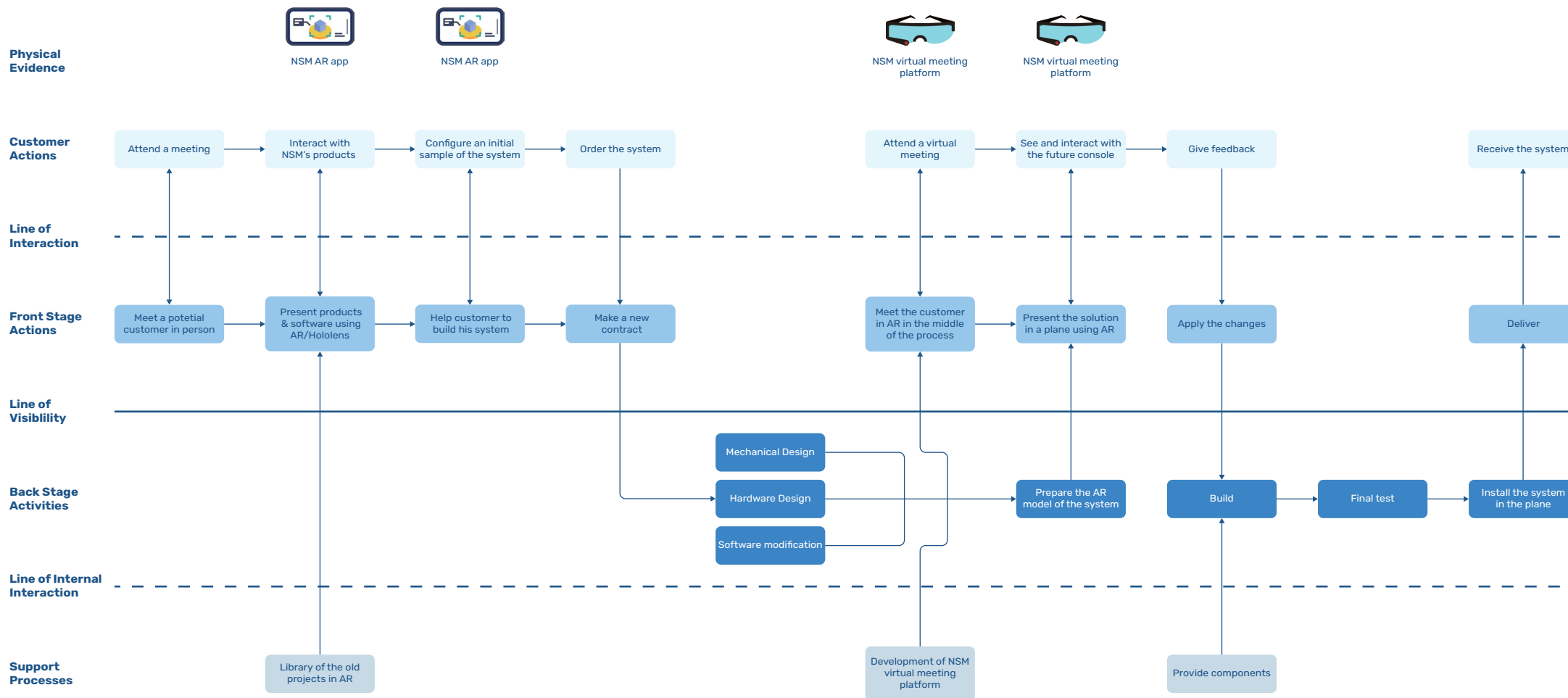


Figure 2.13. Service blueprint of the virtual meeting system using AR.

2.2.5 AR user interface

The systems that NSM currently produces usually have two displays and take considerable space in an aircraft. Usually, small aircrafts are used for operating the missions, so, several seats should be removed to install the system. However, the owners of these aircrafts usually use them for other purposes as well. Therefore, the system should be disassembled from the aircraft to return the seats after each mission. By replacing the current display-based user interface with an AR user interface, we can remove the displays, and then the console can be

moved to the back of the airplane. In this way, the issue of assembling and disassembling of the console before and after each mission will be solved. The mission operator can easily sit on a normal seat while his AR headset communicates with the device in the back of the airplane and gives him all controls and data in AR format. This solution also provides other possibilities to keep the operator on the ground and let him control the system remotely. This will be explained more in coming sections.

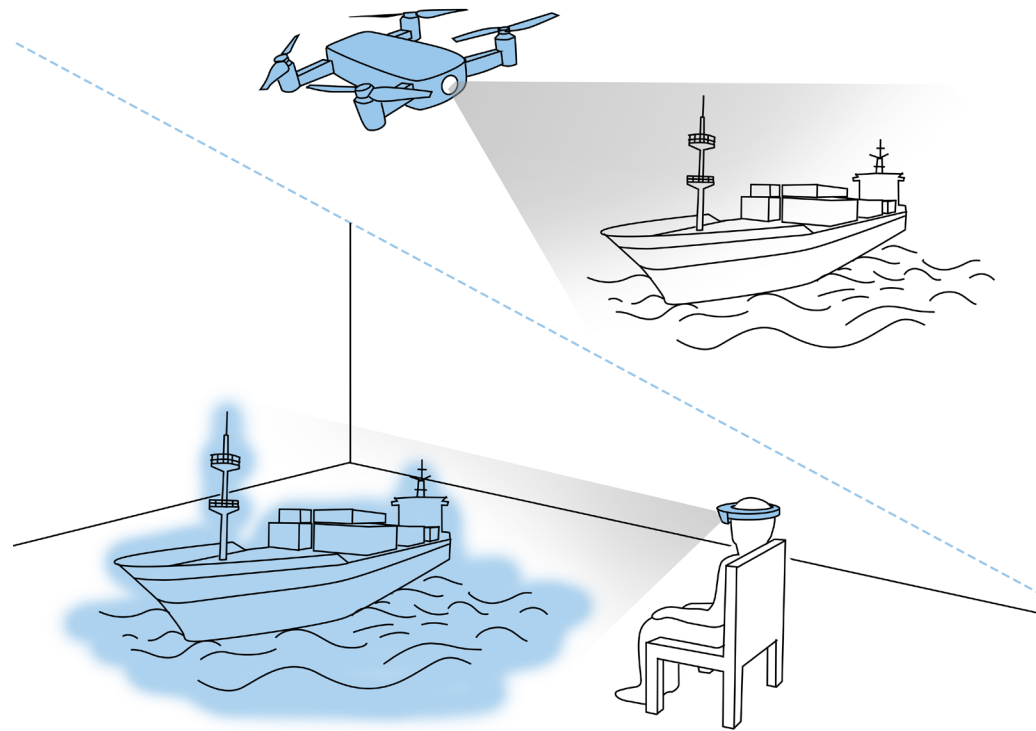


Figure 2.14. Holographic interface for doing missions remotely.

2.2.6 AR-aided design

When a product is modified for a new customer and a new aircraft, the mechanical design team should check if the new design is done correctly and if the new dimensions fit in the aircraft, and measure how the changes have affected the usability of the system for the user. To do so, they make prototypes which is not only expensive but also time

consuming. Using AR, the designers can go to the aircraft and simulate the virtual model with the real sizes in it, and check if it meets the standards. Also, if there is a need to design new mechanisms for the console, they can simulate them in AR and get a better understanding AR before making real models.

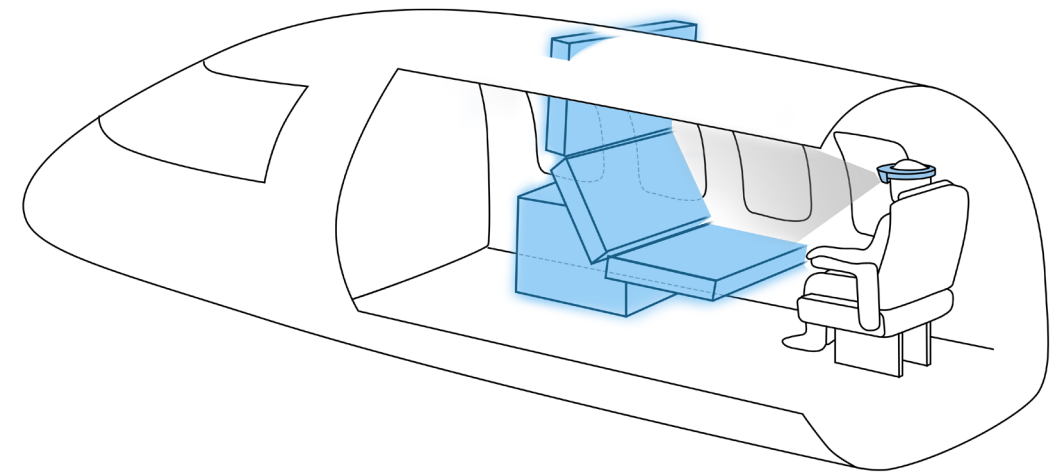


Figure 2.15. Checking the size of a console in an aircraft using HoloLens.

2.3 AR or VR?

A question may pop up about why we choose augmented reality over virtual reality. There are three important reasons for this decision.

- First and foremost, aviation safety regulations say that the eyesight of the people in an aircraft should not be blocked, so, they can quickly get off the aircraft in emergency. Therefore VR should not be used for the operators during a flight.
- The second reason has its root in user experience design. In VR, the user finds himself in a totally new environment. Therefore, it is required to design every single detail of that environment. This will be highly demanding and so complicated in terms of user experience design; while in AR, the users still see the real world and the virtual artifacts are added to them. So, we can base the augmented objects on real things (The Interaction Design Foundation, n.d.).
- The last reason is also about user experience. To use VR, the user should wear a headset that needs wiring to a computer. In fact, there are several components hung from the user's head. This makes the experience of current VR systems not so delightful. In contrast, AR headsets are stand-alone devices and have their own computing unit. So, the user needs to wear only a headset.

Based on these reasons, AR brings more opportunities for the company. It gives better mobility to the user in comparison to VR. Besides, AR helps to bypass limitations made by aviation authorities.

2.4 ADA service platform

During my internship at NSM, I was involved in another project that is a futuristic plan for ADA project. In the future, NSM wants to sell data of flight inspection, airborne surveillance, and remote sensing missions to customers instead of selling the product to them. In fact, the company wants to change its business model from a product-oriented model to a service-oriented one. On the other hand, NSM is working on replacing aircrafts with drones for operating missions. Here, another opportunity emerges. As a service-oriented business, NSM can rent out drones to customers and charge them based on their use.

In this scenario, the users should get access to the controlling system of a drone and its embedded sensors and cameras remotely. AR can be a solution to provide the users with such access. NSM can develop an AR user interface that can be used by clients who want to control a drone and do a mission themselves. The users can wear AR goggles to control the drone, see through the drone's eyes in real-time, and operate a mission.

An essential factor in delivering this service is to have a fast internet connection that provides enough bandwidth to transmit data between drones in the air and on-ground stations. 5G and satellite internet by Starlink as two emerging technologies can provide enough speed for such data transmission, and NSM needs to employ these technologies to implement the new service.

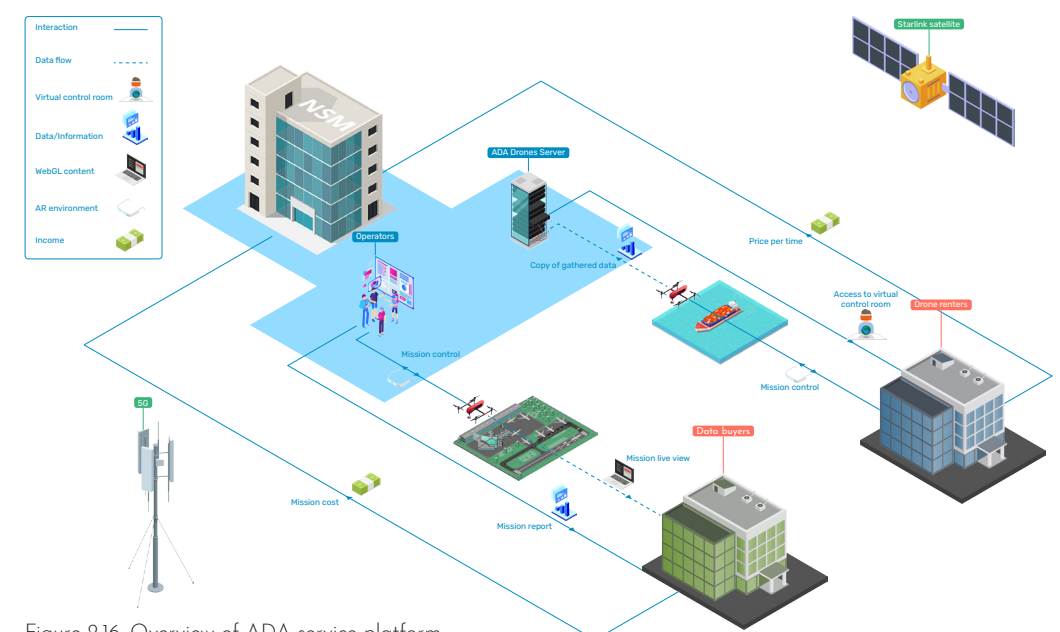


Figure 2.16. Overview of ADA service platform.

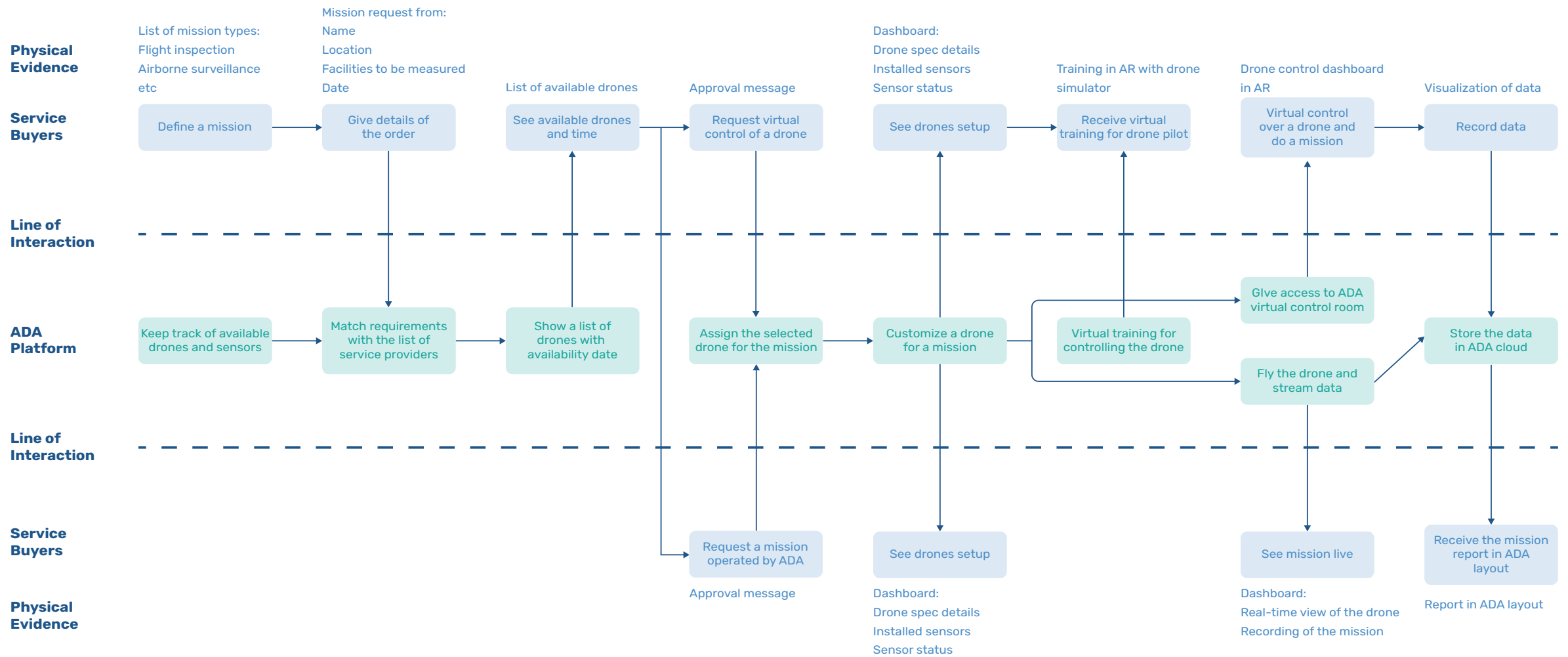


Figure 2.17. Blueprint of ADA service platform.

2.5 Co-creation

After the preliminary ideation phase, a workshop was run in two sessions with the heads of the departments at NSM. The purposes of these sessions were to gather their ideas, to decide on a number of criteria and prioritizing the ideas based on them, and to select one idea for further development. In fact, the result of the workshop will be a design brief that clarifies my task and the object of design for the next phase.

The workshop was held in two sessions. On the first day, participants were asked to brainstorm about AR applications for NSM, and on the second day, they created a list of criteria and sorted the ideas based on them.

There were seven participants who were selected and invited from different departments to assure that the upcoming ideas have a variety of applications for different departments and not limited to one or two specific tasks.

2.5.1 The first session: Brainstorming

The first session was held on July 14, 2020, and seven people participated. In the beginning I explained the goal and the procedure of the sessions to them. The time was divided into three parts.

1. In the beginning, four videos about different applications of AR were played to them. The videos were selected from different themes in order to be inspirational and to expand the imagination of the participants. In this step, there was no discussion about the ideas from the videos or between the participants.

2. Thereafter, they were asked to write down 30 ideas about AR applications for NSM in 15 minutes. The goal of

generating that many ideas was to go put aside typical ideas which come to everyone's mind and reach more creative ones. In fact, the quantity of ideas was substantial. In this phase, participants were not allowed to share their ideas with each other.

3. In the last part and after listening to each other's ideas, the attendees had another 15 minutes to build on each other's ideas and make more detailed suggestions. At the end of this step, each person was supposed to have three ideas as their final suggestions.

In the end, each person shared his ideas with the others.



Figure 2.18. The first co-creation session.

By merging similar ideas together and removing the ones which were identical between different persons, we came up with a list of eight ideas about AR application for NSM at the end of the first co-creation session. They are listed below:

1. RPAS GUI: an AR GUI for flight inspection drones.

2. Infrared camera overlay: an interface in which IR images of a target are updated and mapped on the scene view in real-time.

3. Product showcase: Using AR to present products to new potential customers.

4. Pilot guidance: Using AR to facilitate pilots with controlling airplanes and landing.

5. AR for air traffic control: AR control room for ATC.

6. Interactive reports: Presentation of data of missions using interactive 3D representations in AR.

7. Maintenance and training: Remote training and maintenance services for customers using holoportation and AR manuals.

8. Virtual user interface: New human-computer interaction using AR instead of 2D GUIs.

2.5.2 The second session: Prioritizing

On July 15, the second session was held with the same attendees. The goal of this session was to prioritize the ideas from the first session and decide on one idea for further development. The session had two main parts: deciding on criteria for prioritizing and voting to ideas. The procedure of this session and the evaluation method were derived from the book "Value proposition design" (Osterwalder et al., 2015).

In the first part, the attendees were asked to create their own list of criteria to evaluate the ideas based on them. The reason to do such was that the participants had different roles at the company, so, they had different perspectives for evaluations. To facilitate them, they were given examples of different criteria from the book. They had 10 minutes to decide on the items on their lists. After that time, each person shared his list with the others, and at last, people all together decides on four criteria that they all agreed on their importance:

1. Providing competitive advantage
2. Low technology risk
3. Differentiation

4. Short delivery time to market
In the second time of the session, participants evaluated the ideas from the first session according to the intended criteria. To do so, each person should vote for an idea that fulfilled the best each criterion. There were four criteria, so, each person had four votes. The method is called dot voting (Dotmocracy, n.d.). After all attendees voted, the ideas were sorted according to their votes.

Financials and Growth			
Market size	Revenue potential	Market growth	Margins
Fit with Customer Insights			
Important job	No good solution exists	Visible and tangible pain	Strong customer evidence
Implementation Criteria			
Time to market	Cost to build	Do we have right team and skills	Access to target customers
Technology risk	Implementation risk	Risk of management resistance	
Competition and Environment			
Provides competitive advantage	Fits with tech and other trends	Allows differentiation	
Relation to Current Business Model			
Fit with brand	Fits current business model	Builds on strengths	Plugs weaknesses
Disrupts current cash cows			
Fit with Strategy			
Aligns with strategy	Good timing	Fits with desired risk level	Can replace outdated business models

Figure 2.19. Examples of criteria (Osterwalder et al, 2015).



Figure 2.20. The second co-creation session.

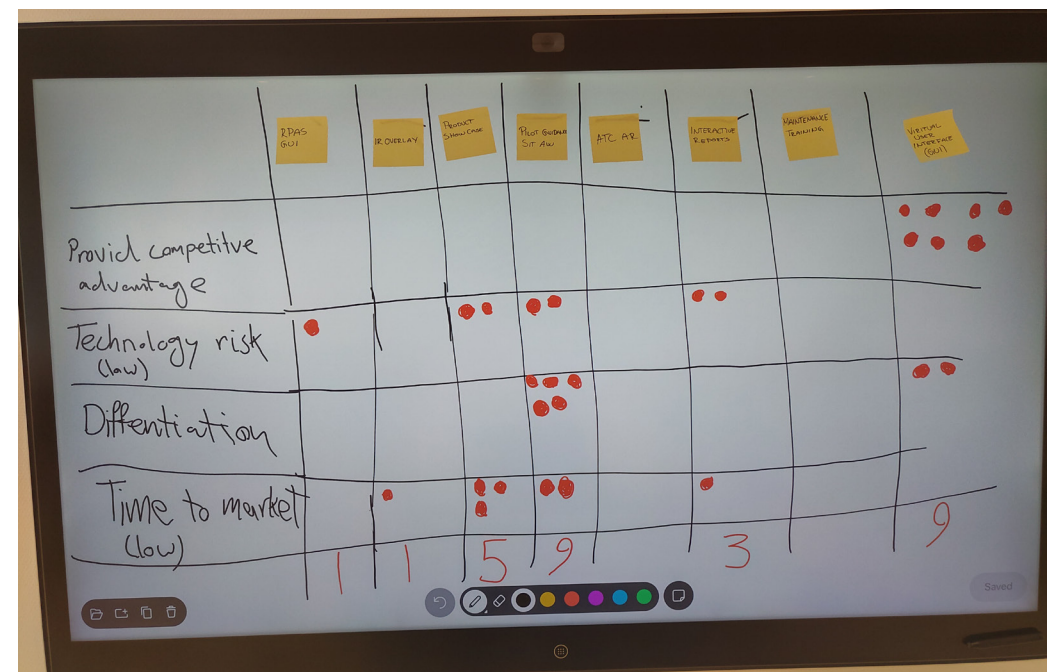


Figure 2.21. Board of the votes.

2.6 Results of the workshop

The outcome of the workshop was a prioritized list of ideas. This would help define the design brief and specifying the object of design in this master's thesis. As it is depicted in the table, two ideas "virtual user interface for NSM's product" and "pilot guidance" had the same number of votes. However, it was understood later that these two ideas have many features in common.

Ideas Criteria	RPAS user interface	Product showcase	Pilot guidance	AR ATC	Interactive report	Maintenance/ Training	Virtual user interface
Provide competitive advantage							●●●●●
Low technology risk	●	●●	●●		●●		
Differentiation			●●●●●				●●
Short time to market		●●●	●●		●		
	1	5	9		3		9

Figure 2.22. Table of ideas and their votes based on the evaluation criteria.

Therefore, the design brief was defined. We agreed on designing a new human-computer interaction using AR for flight inspection and airborne surveillance systems. This new HCI shall be compatible with their current system, namely, it will be used by the mission operators in an airplane. In addition, based on the company's future plan, the solution will be used by the operators on the ground when drones will be in operation to do special missions.

The focus in this project will be on the user experience and figuring out the UX design considerations in designing an AR-based user interface. By this I mean that the final delivery will not be a functional user interface, but a simple visual representation of the idea which contains the important UX design factors and new methods for data visualization in AR.

Also, this new user interface should comply with the approach in ADA project, namely, it should be modular and customizable based on the type of a mission.

2.7 Validation of ideas and design brief

After the workshop, a meeting was held with the R&D director to decide on one idea for further development. In that session, the preliminary ideas, the AR idea for ADA service platform, and the ideas from the workshop were presented to him.

Apart from the ideas which were suggested in the workshop, that session had another benefit to this project. The ranking of the ideas and the idea on top of the list helped to "triangulate" the hypothesis that the idea of an "AR user interface for the system" is the most beneficial for NSM. This idea was not only the top-ranked idea in the co-creation session, but also, I came up with that in two other stages (ADA service platform and AR interface instead of display-based UI).

In fact, the opinion of NSM's specialists, who are more aware of both technical and market situation, helped to validate this idea and choose the direction of this project.

CHAPTER THREE

Conceptualization



3.1 User research

“Human-centered design starts with a good understanding of the people and the needs that the design is intended to meet. This understanding comes about primarily through observation.” By recognizing the objectives that users are seeking to achieve and the challenges they face, the problem definition for the product design can be described. One of the most important strategies to shape this understanding is to observe the users in their natural environment where they will use the product or service being designed (Norman, 2013).

So, this section is focused on building a robust comprehension of user’s needs, capabilities and conditions in their operating environment. For this purpose, interview and observation have been done with the mission operators. The outcome has helped to do task analysis and define the activities and tools which are critical and most frequently used during a mission.

3.1.1 User observation (airborne surveillance)

To get a better understanding of what an operator does during a special mission, I joined him for an airborne surveillance mission. In that mission, an airplane flew over an offshore area to observe and check if there was, for example, any ships polluting the sea.

Every mission of this type is first requested by a client (in this case it was Kystverket). They provide the operators with the region and targets they want to be surveilled. Then, the operator along with the pilots get in the airplane and start the mission. During the flight, the pilots are given the information about the path they should fly through, but the operator can also ask them to do a turn or change the direction for more observation. The communication

between the operator and the cockpit is via the transceiver of the aircraft and the operator can also listen to what the pilots hear from ground stations.

There are two displays that the operator uses. One shows the map and the other one is the camera view. The flight path is visualized and overlaid on the map. The pilots also have access to this map on their individual displays in the cockpit.

The information about each ship is retrieved from AIS (automatic identification system) of the ship through VHF band and the operator has access to it in the console, and their positions are represented live on the map. To observe a target, the operator can touch the glyph of the target on his display. The camera

then automatically zooms and focuses on that. But the operator is also able to control the camera manually and this task is the dominant task that the operator performs during a mission. To do so, the operator uses a controller that is so heavy (~ 3.5 kg) and has several input functions for camera positioning and rotation, zoom, focus, turning on/off layers. Zoom and focus functions are the ones that the operator uses the most. The operator should hold the joystick in his hands during almost the whole mission.

The console also has infrared and SLAR sensors to measure different values, and the operator can activate them as different layers on the map or see them in separate windows. If there is a case that should be

reported to authorities, the operator can send a message or communicate to them from the air during the mission.

After flying the whole path, the operator starts to create the report of the mission and mentions if there was any suspicious cases. The report will be then copied to a USB memory that the operator plugs in.

Moreover, there were other considerable factors about the condition of the job during the flight. The airplane had much severe turbulence. This is the reason for having the hand-held controller instead of using only the touch-screen. In addition, the noise level was considerably high, so, it was not easy to hear each others’ voice.

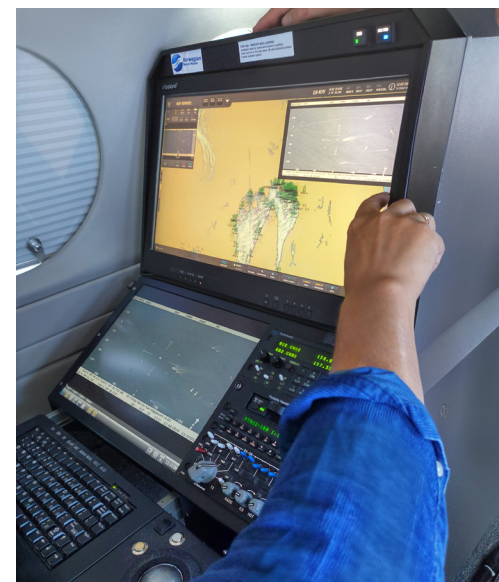


Figure 3.1. The console and its several display windows.



Figure 3.2. The hand-held controller of the camera.

3.1.2 Mission walk-through (flight inspection)

I did not get any chance to join a real flight inspection mission. However, an employee from the technical services department helped me with gaining an understanding of how this kind of mission is operated. He ran a mission replay software on his PC and showed me a mission walk-through of how a mission is done from the beginning to the end.

The operators of flight inspection missions are usually different airports. The software contains airport profiles including their geographical position, facilities (sensors and navigation equipment on the ground), and the flight procedures for different measurements. Flight inspection consoles usually have only one display.

A mission starts with selecting an airport and choosing the facilities which should be measured. Then the operator selects the flight procedure. The procedure refers to the way that the aircraft should fly toward a target area. During a mission, multiple facilities are measured, so, it may take several hours. After picking an airport and selecting the facilities and procedures, the operator sees several panels on the display.

The panels can be categorized to three groups. On the left side, there are navigation instruments like an altitude indicator, a heading indicator, and a compass. The right

side shows the information about the mission, type of the procedure, numeric values coming from the sensors. The calculation table is also shown here.

The center part of the display is usually divided into two rows. On the top, there is map that shows the path of flight. Below that, there is a curve plotter. This is the most frequently used panel by the operators. When the sensors inside the console communicate with the facilities on the ground, the values are represented as curves to the operator. There are several curves while measuring a facility, and two of them are more important, the read signal and the reference value. By comparing these two values (curves), the operator can say if a facility works properly or needs to be calibrated. During a flight inspection mission, the operator is focused on and observing this panel most of the time.

When the mission is done, the operator can save the results on a USB memory. The results contain both the graphs and the table of numeric values.

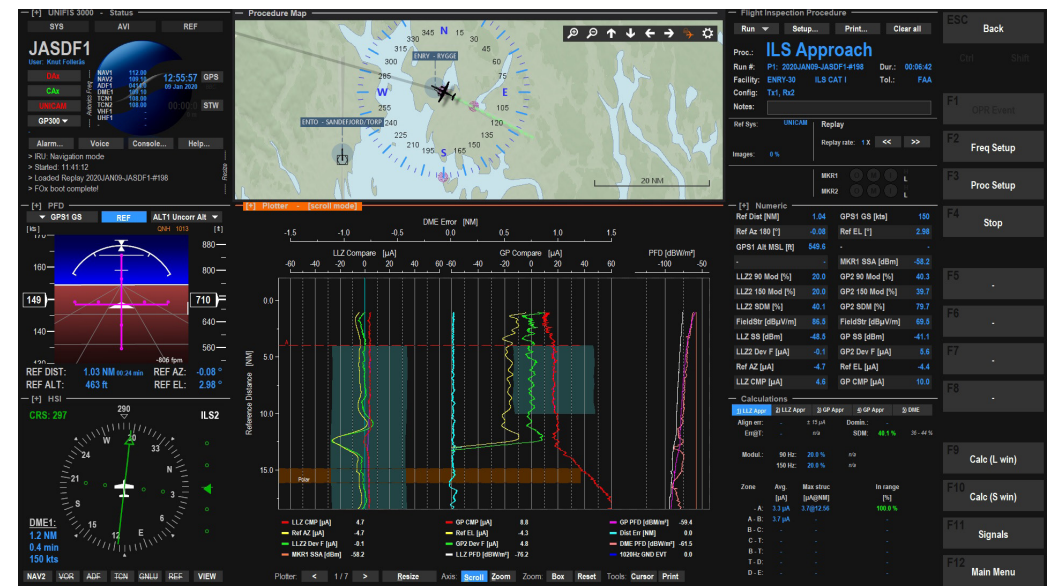


Figure 3.3. NSM's current flight inspection software.

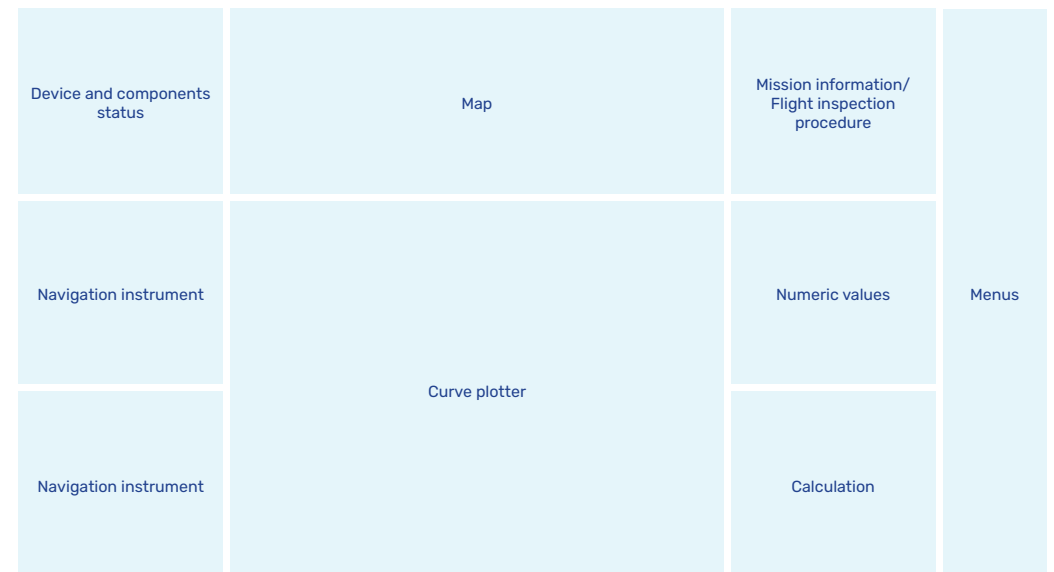


Figure 3.4. UI layout of the flight inspection software.

3.1.3 Task analysis

The term “task analysis” refers to the study of actions a user performs to achieve an intended objective. Task analysis is helpful to recognize the tasks that an interface should support, and it helps to improve the journey of reaching a goal (Usability.gov, 2013).

Hierarchical task analysis (HTA) is a popular task analysis method that breaks down the user’s tasks into sub-tasks. To represent HTA, main tasks and their sub-tasks are shown in different layers in a diagram. The goal is to identify sequential, conditional, and iterative tasks (Usability BoK, n.d.).

Based on the user observation and the walk-through, a hierarchical task analysis was done to get a better overview of the operator’s course of action. The actions are categorized and shown in the diagrams.

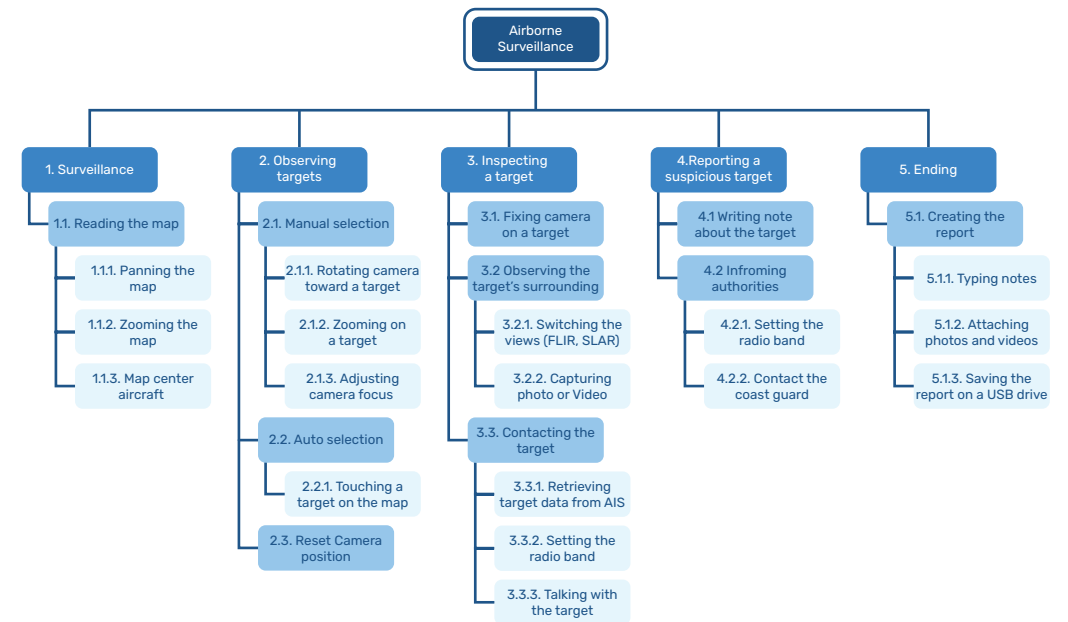


Figure 3.6. Tasks hierarchy diagram of airborne surveillance.

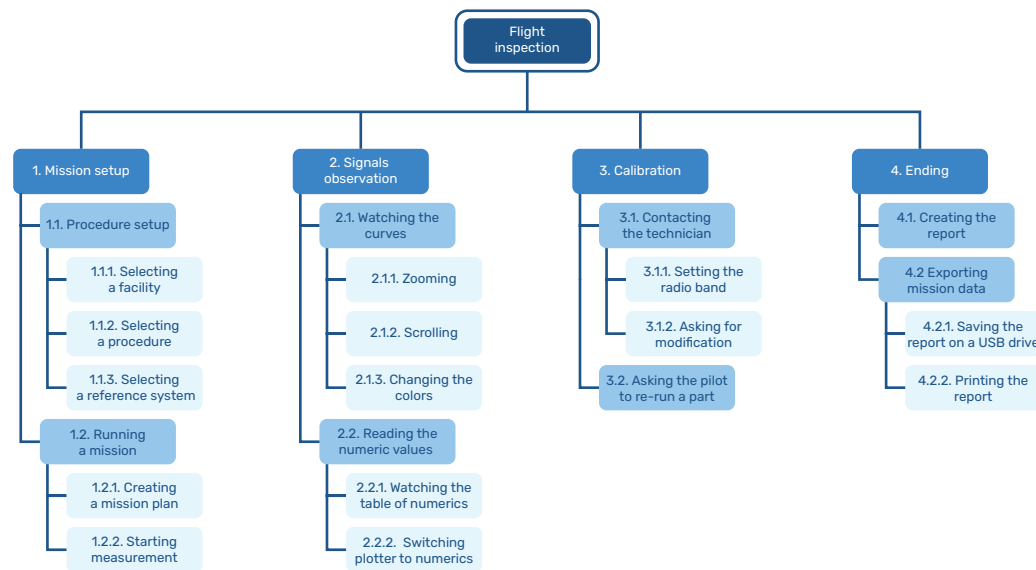


Figure 3.5. Tasks hierarchy diagram of flight inspection.

3.1.4 Data from Halogen

During the user research stage, I got a chance to get in touch with a team of designers from Halogen who were collaborating with NSM in ADA project. As a part of their job, they joined a flight inspection mission in Italy as well as an airborne surveillance mission in Norway and observed the whole process. They could create a timeline of their observation and map the critical and most frequent activities during the missions. I have been lucky to get access to these materials which are greatly valuable to get a better insight of the user’s situation and tasks during flight.

3.1.4.1 Observation timeline

The team has presented the result of their observation as a timeline. They have mapped out all activities that the operator and the pilots did, the relevant equipment and tools for each task, and the corresponding part of the UI to each task. In addition, they have written notes about the conditions during the flight.

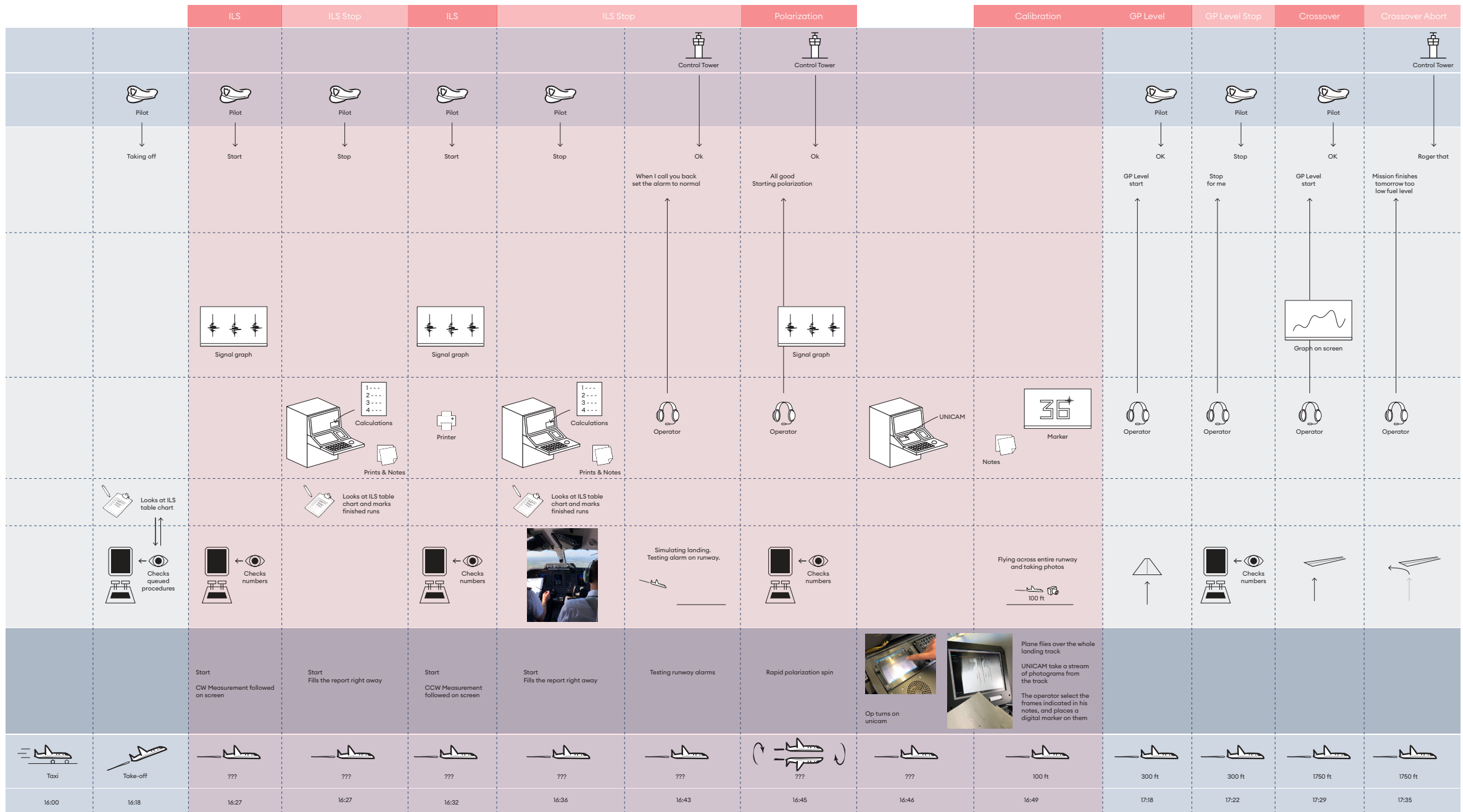


Figure 3.7. A part of the observation timeline of flight inspection mission in Italy, made by Hologen's team.

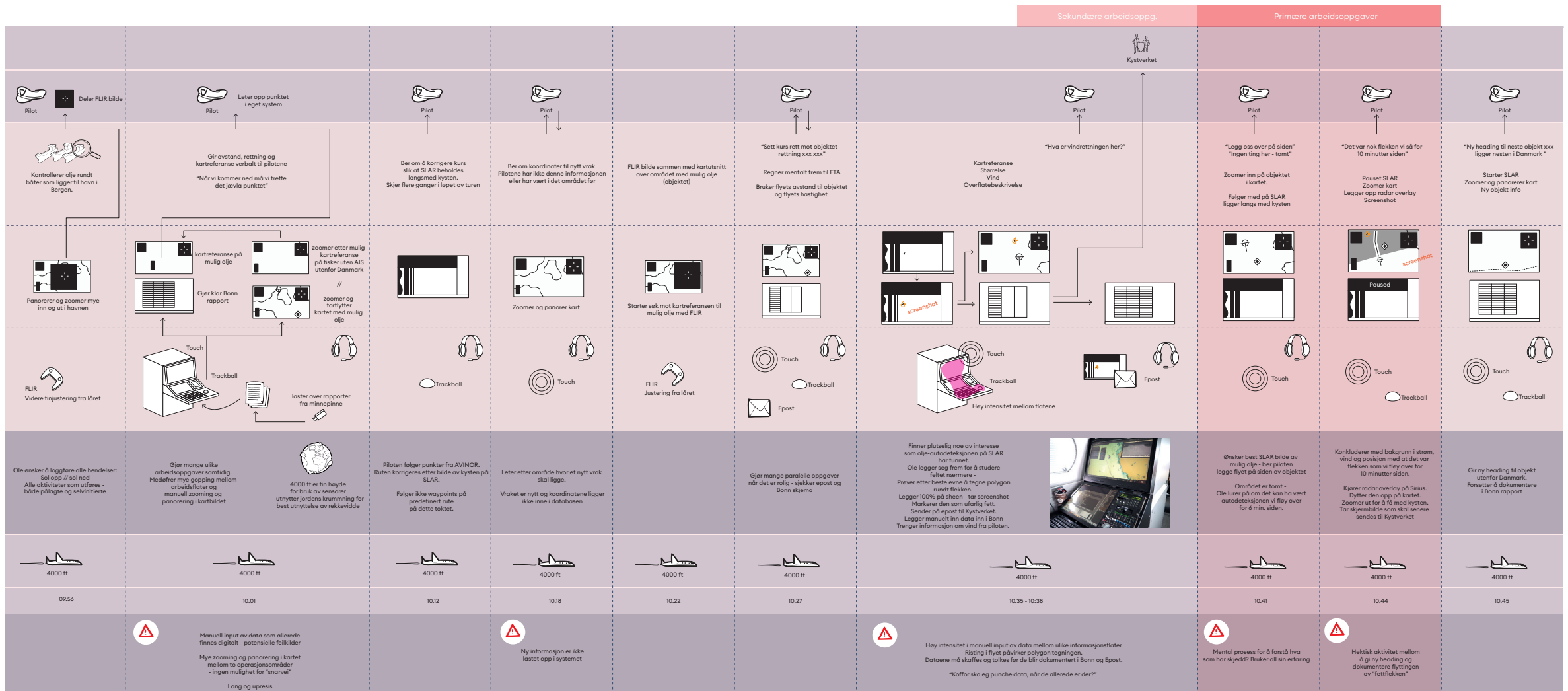


Figure 3.8. A part of the observation timeline of airborne surveillance mission in Italy, made by Hologen's team.

3.1.4.2 Criticality/frequency matrix

Based on the observation, the team managed to sort different components of the UI according to their criticality and frequency of use. In the matrix, there are two axes: Low criticality-

high criticality and low frequency-high frequency. The functional and informational components of the UI are represented as dots. The yellow dots stand for the information, and the green dots represent functions.



Figure 3.9. Criticality/frequency matrix of the flight inspection tasks.

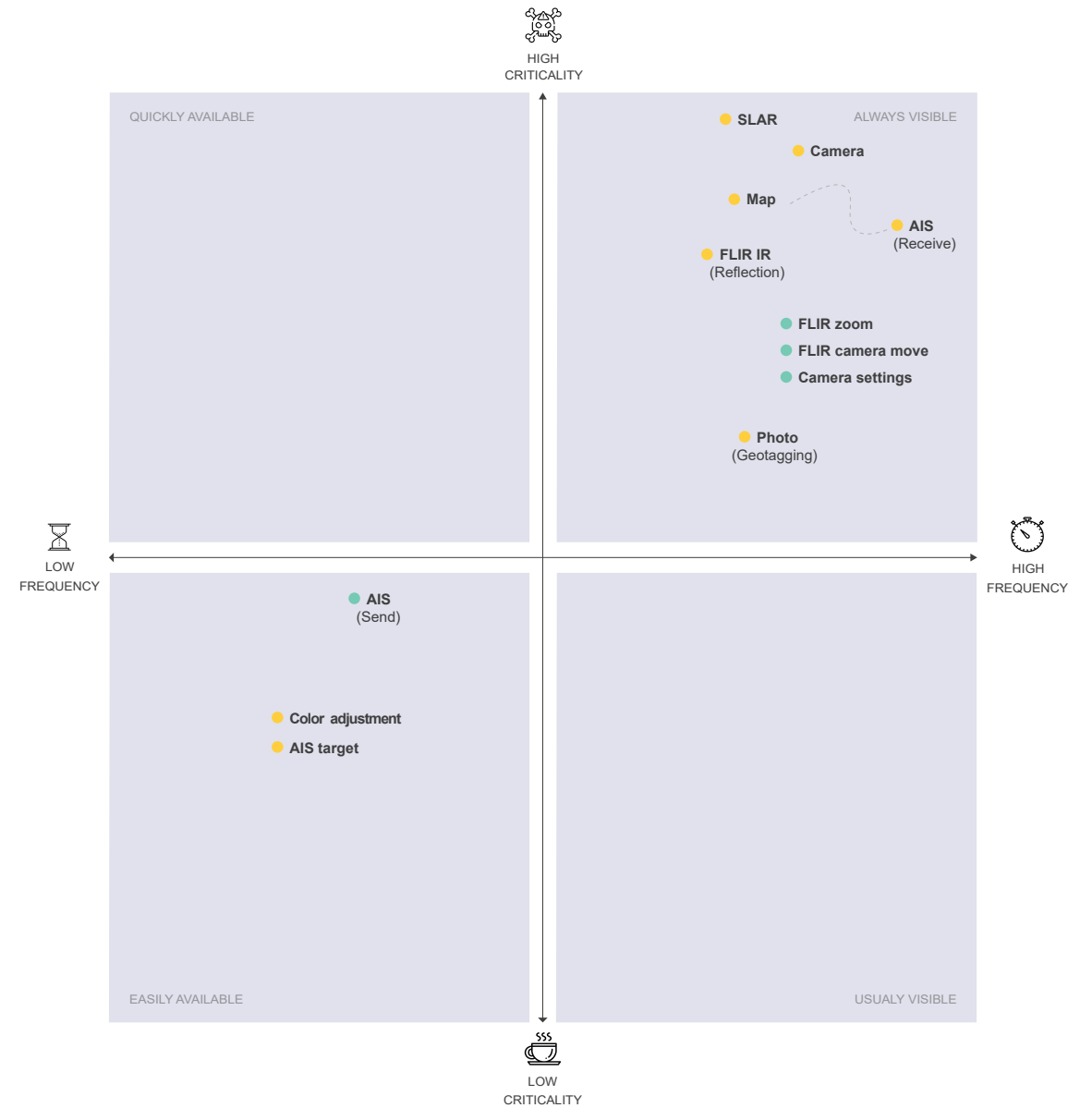


Figure 3.10. Criticality/frequency matrix of the airborne surveillance tasks.

3.1.4.3 The new software

During ADA project, a new modular software has been developed which can be used for both flight inspection and airborne surveillance missions. This software along with a new console is the current project that NSM is working on. The UI/UX design phases of the new software are done by the team from Halogen, and now, it is under development. Although this software is not implemented and tested yet, it is a great step forward from the old software. Review of

this system is beneficial to get a better understanding of the most updated tools, instruments, and data visualization which are needed and used by the mission operators.

In addition, the designers have put a great importance on the user experience and tasks flow based on several theories like situation awareness theory. Therefore, this solution can be a reliable source of inspiration for UX design of the new interface in AR.

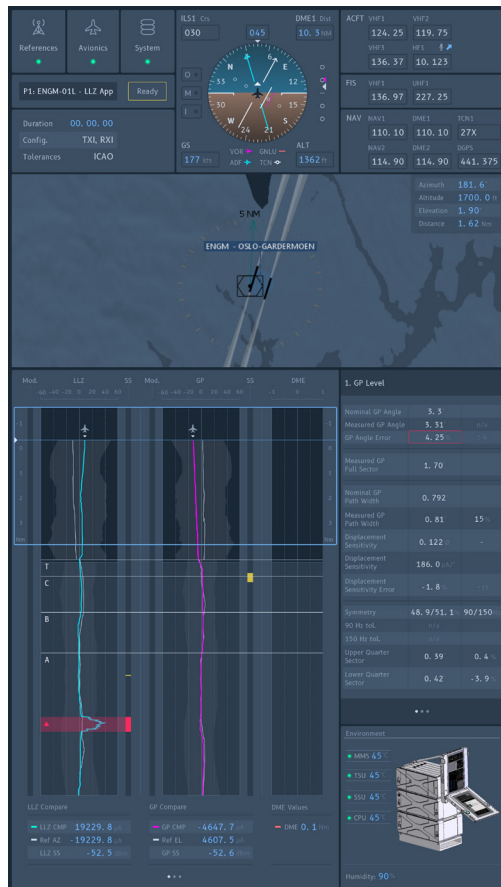


Figure 3.11. Default layout of the software in flight inspection mode.

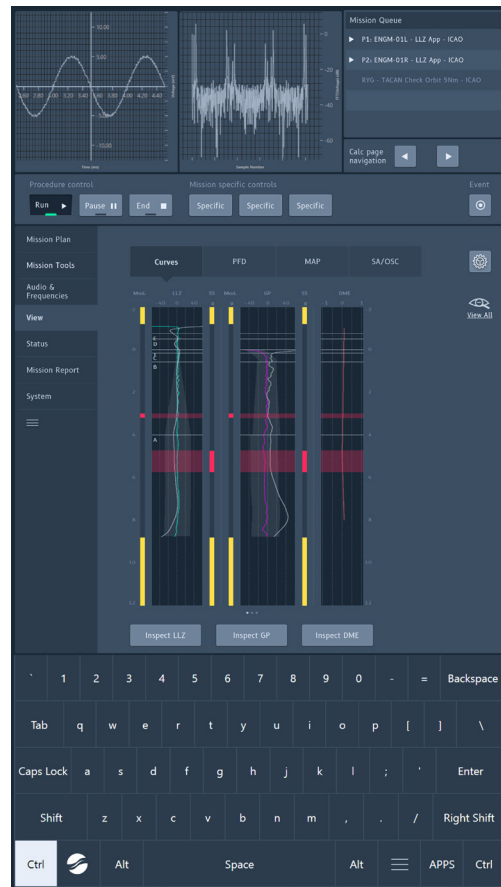


Figure 3.12. Plotter panel of the software in flight inspection mode.

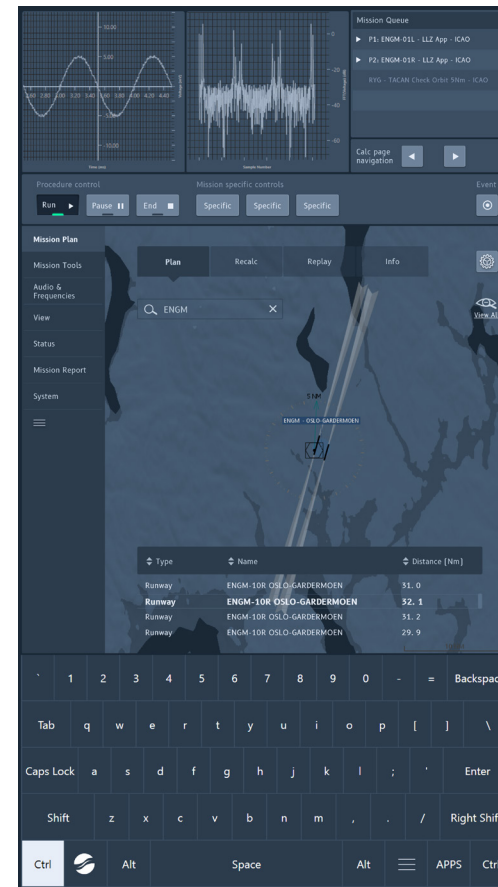


Figure 3.13. Mission plan panel of the software in flight inspection mode.

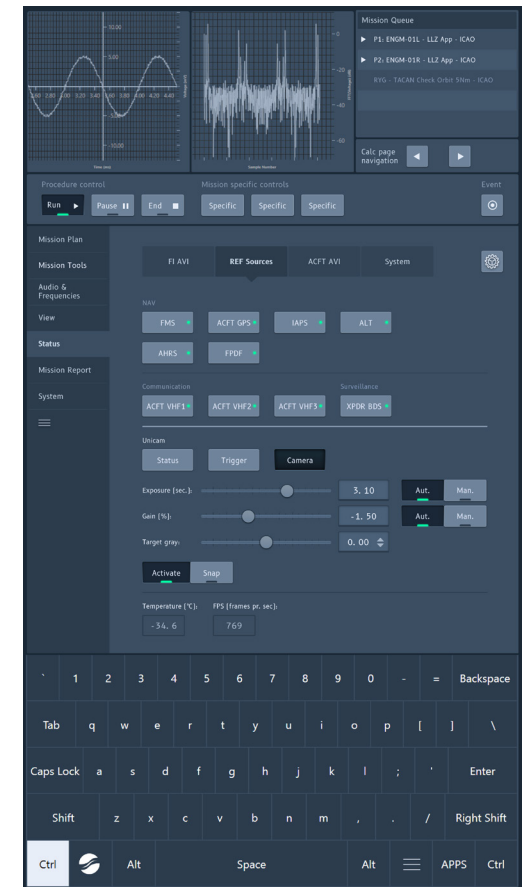


Figure 3.14. Sensors status panel in flight inspection mode.

3.1.5 Workflow diagram (Results)

To sum up all information from the user study stage, two workflow diagrams are drawn to present the important tasks and key UI elements during the two types of missions. The actions are taken from the hierarchical task analysis and they are the dominant activities during a mission. Also, the corresponding UI element to do each task is shown. These elements are selected to be translated into new forms for the interface in AR.

For flight inspection, the operator should first verify that all components are connected and working properly. Then he sets the procedure and runs a mission. After that, the facility (airport) and the flight path will be shown on the map. During the mission, he observes the graphs, read numeric values, does calculation. If it is needed to have a change in flying path, he talks with the cockpit through radio. These steps are iterative and are done multiple times. When the missions are completed, he should make a report.

For Airborne surveillance, the operator first defines the mission type and sees an overview of the mission timeline. When the aircraft flies over the intended area, the ships are represented on the map and the operator can select them to get their AIS info and track them. He can zoom on a target, auto-track that, and inspect it through different overlays. It is also possible to take photo or record video from a target or a special case, for example in case of oil leakage from a ship. During a mission, the operator performs these tasks iteratively for various targets. The report is usually written when the mission is finished and the aircraft is heading back to the airport.

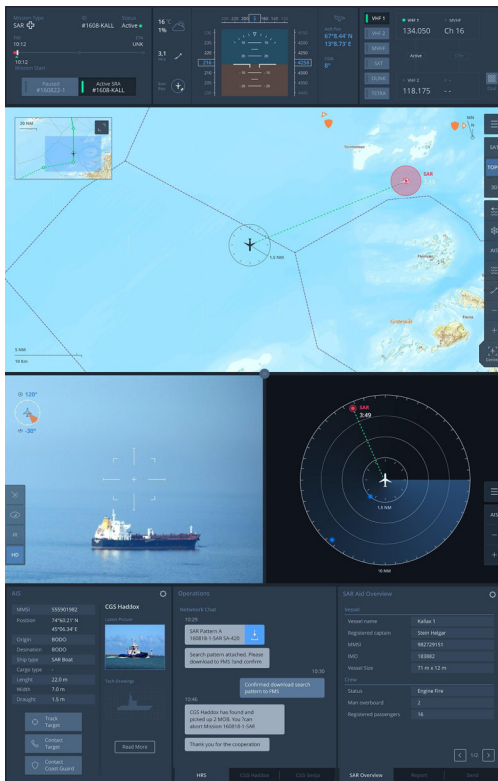


Figure 3.15. Radar-enabled view of the software in airborne surveillance mode.

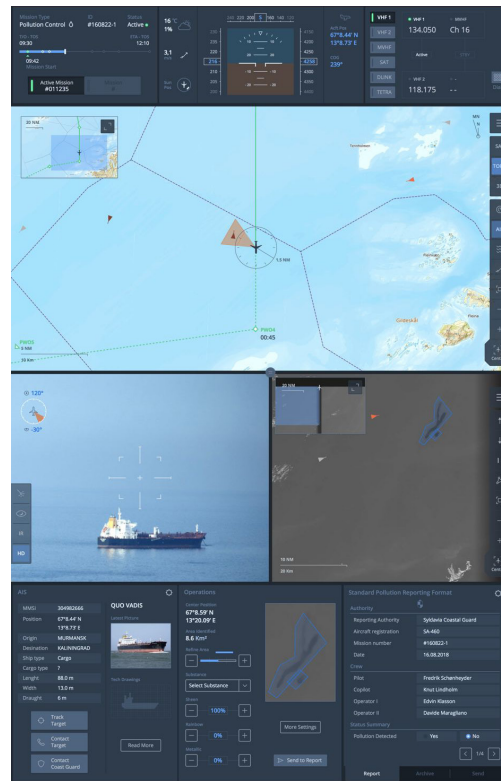


Figure 3.16. Plotter panel of the software in airborne surveillance mode.

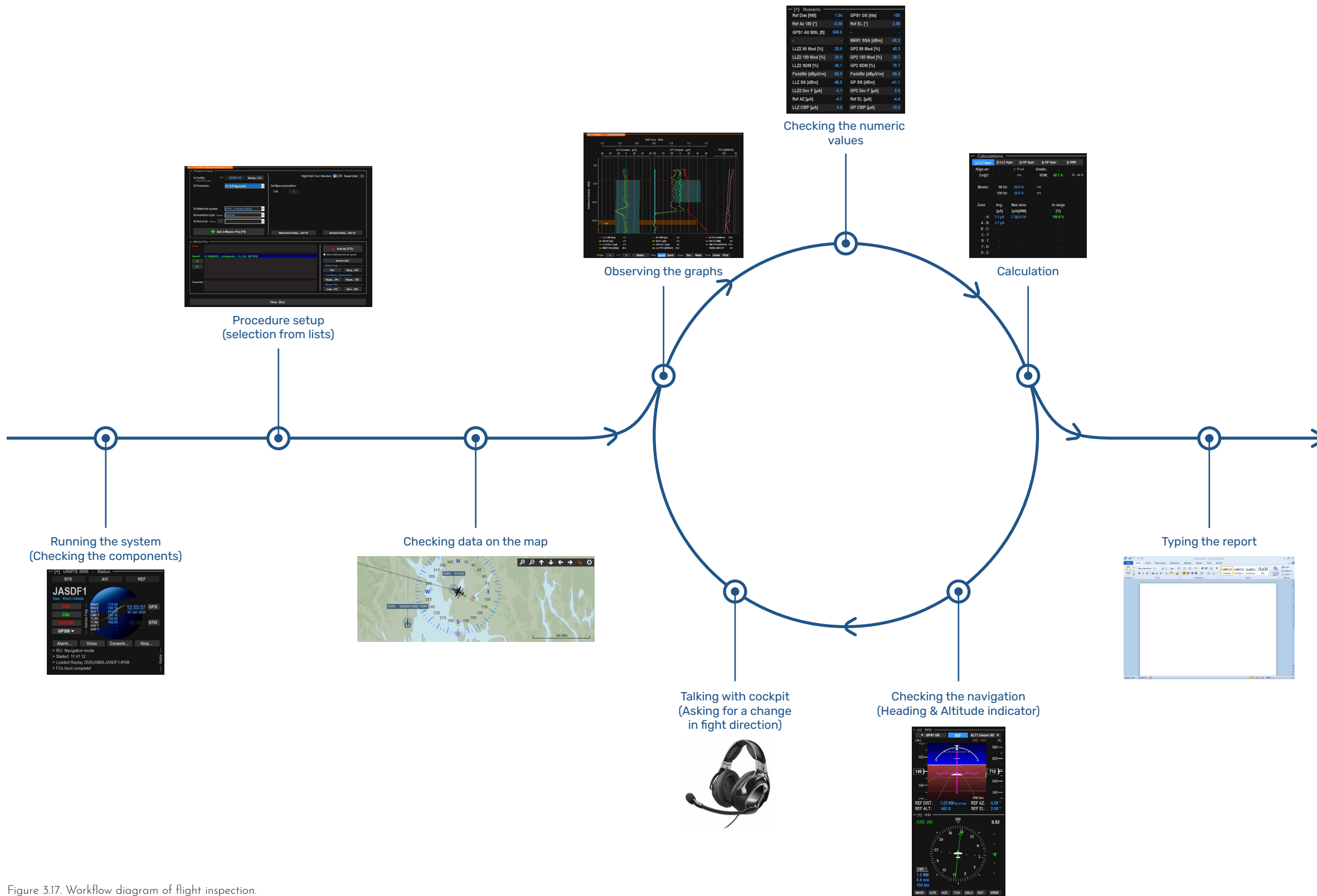


Figure 3.17. Workflow diagram of flight inspection.

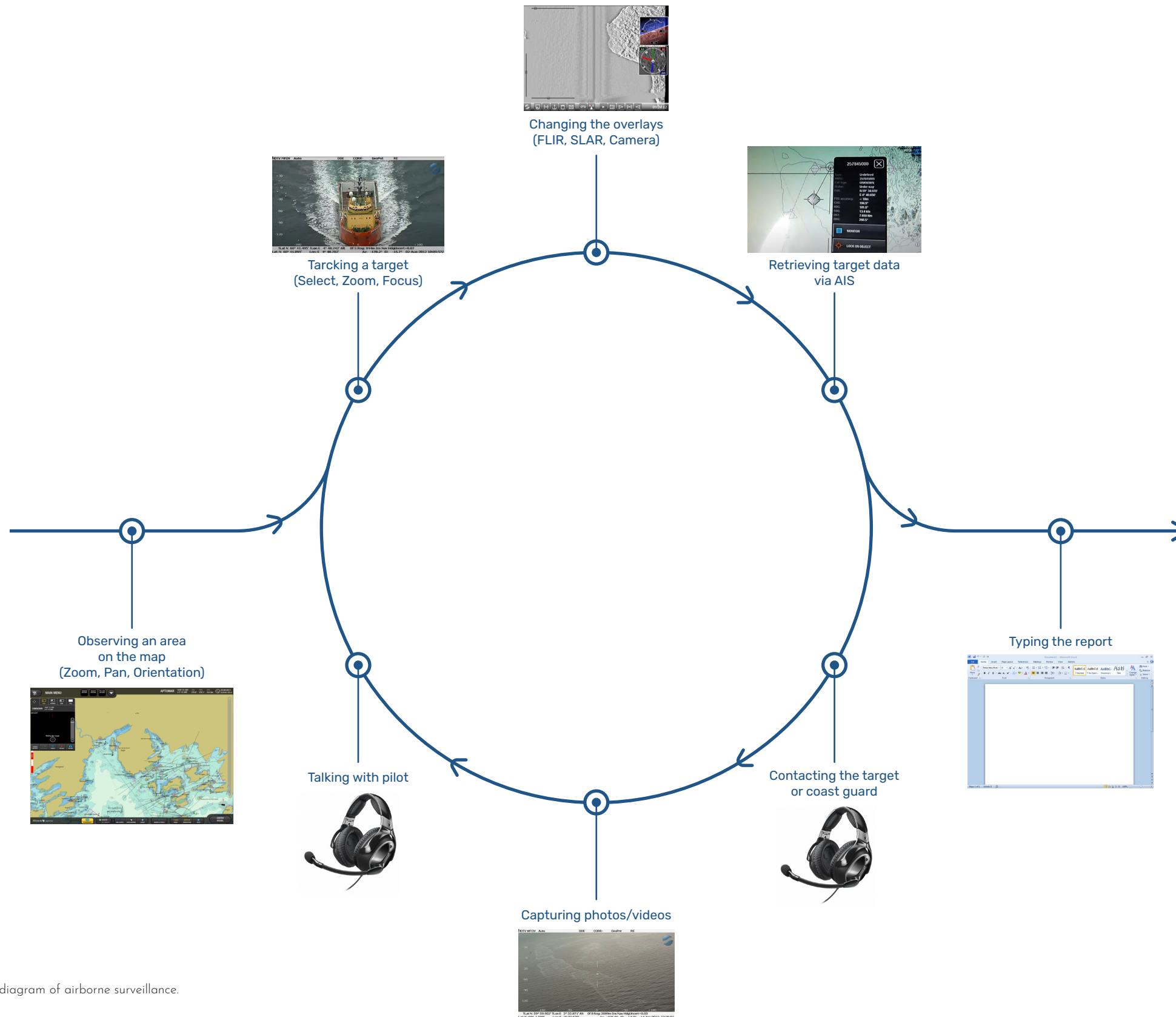


Figure 3.18. Workflow diagram of airborne surveillance.

3.1.6 Interview with flight inspection operator

An online interview was conducted with a flight inspection operator to verify the understanding of the tasks and their sequence (the workflow) in a mission. The workflow diagram of flight inspection was presented to him and he was asked to explain his tasks and mention the missed items and inconsistencies between the diagram and the real situation. Below is a list of points from the interview.

The first point he made was that communication with the technician at a facility on the ground is a prominent task which was not considered before. As the interviewee mentioned, in the very first step, he should verify the communication with the technician. Then, before starting a measurement, he should check with the technician if the facility is started. During a measurement, the operator may need to talk with the technician to make changes to the facility, so, he may mute the voice of the pilot, the ATC, and the radar station in order to focus on the conversation with the technician. In addition, based on the values, it might be needed to rerun a measurement. To do so, the operator asks the technician to do modifications for the next run.

Another point was that the numeric values inform the operator about the connectivity of sensors to a facility. Change of numbers means that signals are being retrieved and the facility is ready to be measured.

Regarding the map, he mentioned that it is not frequently used during a mission. For example, if he sees that the aircraft is turning around for a while, it means that they are waiting to get permission from air traffic control.

Another important document for a mission is the flight profiles. A flight profile describes the path that the aircraft should fly through in order to do a measurement. These profiles are standard and defined by aviation authorities. The operator mentioned that the flight profiles are not embedded in the map in the current software, and they should check them on paper. Providing the flight profiles on the map along with the geographical information of an area may affect the mission planning. For instance, he mentioned if a flight profile contains a clockwise turn, a mountain on one side of the path can cause that they do a counterclockwise turn instead, or if they want to do three measurements, weather information on the map may help them to organize the order of the runs.

He also said that he sometimes changes the display layout and switches the curves plotters to the calculation table in order to focus on the values.

Based on these insights, the workflow diagram was modified.

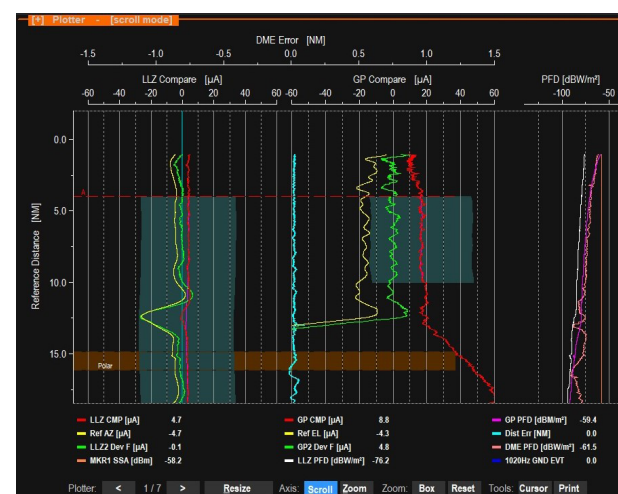


Figure 3.19. Plotter panel is activated by default.

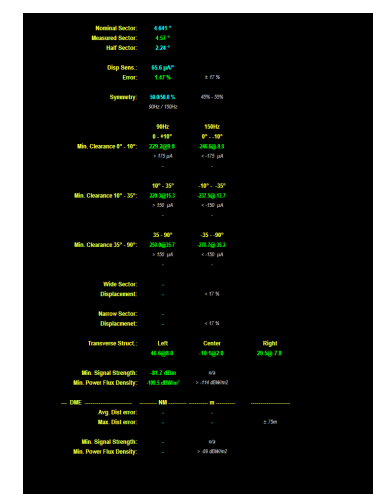


Figure 3.20. The operator may switch the plotter to this numeric list.

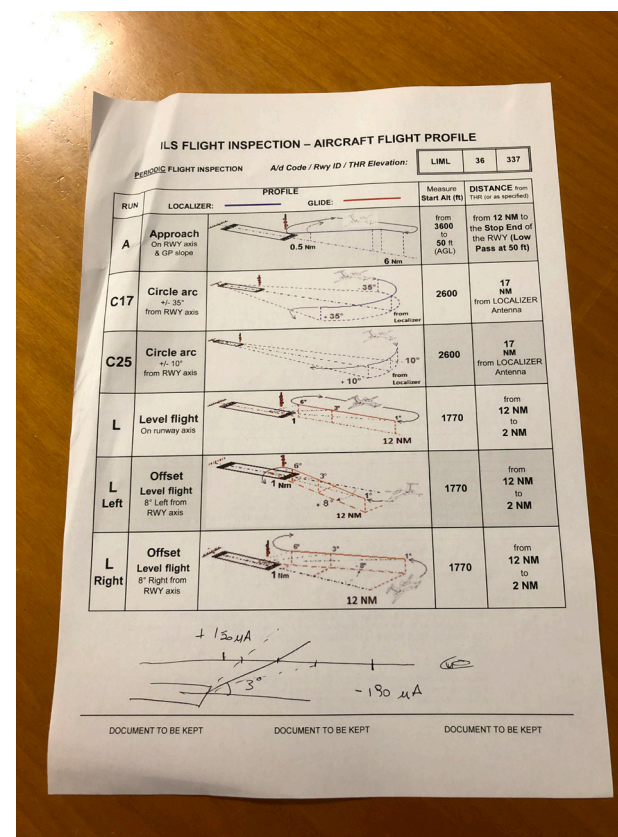


Figure 3.21. List of flight profiles for ILS flight inspection.

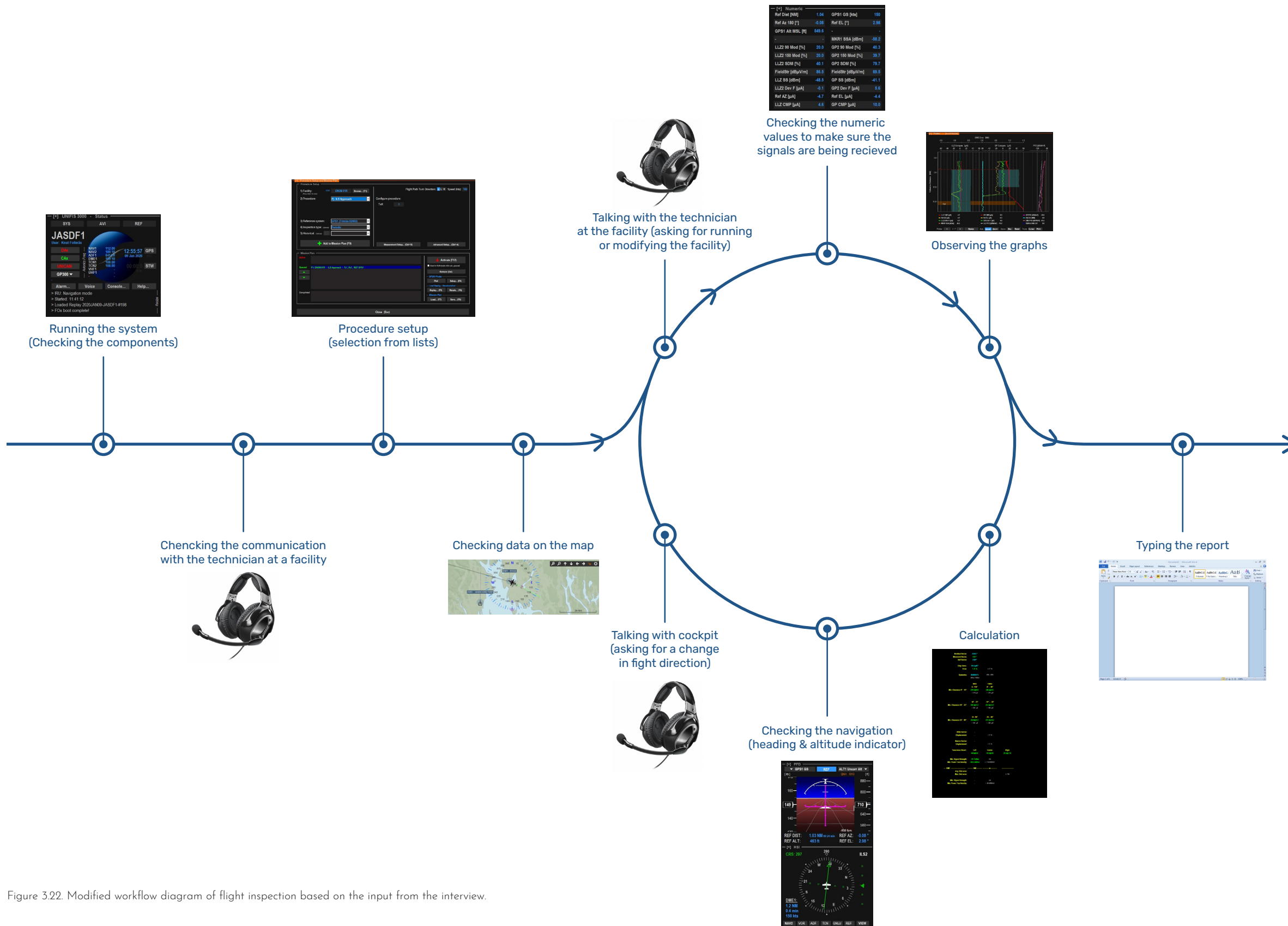


Figure 3.22. Modified workflow diagram of flight inspection based on the input from the interview.

3.2 Technology analysis

An important part of designing a good user experience is familiarity with available technologies, their capabilities, and limitations. So, the solution will be technically feasible to be implemented (IDEO, 2015). The way a product or service is implemented has a direct impact on the users' experiences (The Interaction Design Foundation, 2020).

For this purpose, first, there is a short paragraph about immersive computing. Then, three of the most popular head-mounted AR products that have their embedded computing unit (not smart glasses) will be reviewed. The goal is to figure out the features which can affect the implementation of the solution, and as a result, the user experience. At the end of this part, it will be decided on an AR platform to base our solution on it.

3.2.1 Immersive computing spectrum

Immersive computing is a new term to describe the technology that provides users with an experience of being immersed among virtual content. This can be done in the form of augmented reality or virtual reality. In augmented reality experience, the user can see virtual objects in his surrounding using a hand-held or head-mounted device that overlays the content on the real world. On the other hand, virtual reality takes the user to a completely virtual space and gives him the maximum level of immersion. However, there is another term which is mixed reality. This term drew attention after introducing the first HoloLens by Microsoft in 2016.

In fact, this term does not refer to any new kind of immersive computing, but it is a concept that contains both virtual and augmented reality. Today, mixed reality is usually used for wearable devices, while AR refers to the same concept but implemented with hand-held devices (Lanham, 2018). Actually, the theoretical definition of mixed reality, which was first introduced by Milgram and Kishino (1994), differs from its today's commercial definition.

In this project, the original term, namely, augmented reality will be used and it does include head-mounted AR devices.



Figure 3.23. Reality-Virtuality continuum (Milgram & Kishino, 1994).

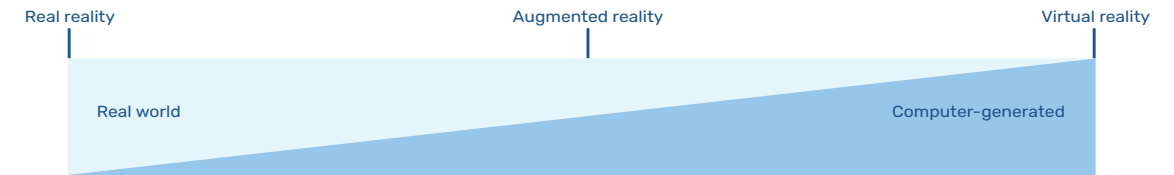


Figure 3.24. Immersive computing spectrum (Lanham, 2018).

3.2.2 Available devices (Benchmark)

Even though googling "mixed reality device" or "AR headset" results in a long list of products, there are very few items that are actually stand-alone AR systems. These are Microsoft HoloLens and Magic Leap. The other solutions are either smart glasses with limited functions or devices that should be tethered to a stationary computer. In this part, the two AR headsets will be reviewed. The purpose is to compare the factors including field of view and input methods that can affect the user experience.

3.2.2.1 Microsoft HoloLens

HoloLens was the first head-mounted AR display manufactured in 2016. This device has its own computing unit in its frame and runs a holographic version of Windows 10. HoloLens supports hand tracking. So far, two generations of HoloLens are introduced. While the first version detects only a set of pre-defined hand gestures, the successor can recognize both hands and all fingers. Also, the first generation has a physical input device that is called Clicker. It can be used instead of hand gestures

to select, scroll, move, and resize the content. Moreover, both devices support voice commands. The fields of view are $30^\circ \times 17.5^\circ$ and $43^\circ \times 29^\circ$ in the first and the second generations respectively (Microsoft, n.d.).

3.2.2.2 Magic Leap

Magic leap one is another AR headset from a company of the same name. In contrast to HoloLens, this device has a pocket-size computing unit that should be connected to the goggles. Users can use a physical controller with 6 degrees of freedom or use their hands. The device detects eight gestures. It also has speech recognition. The field of view in this headset is $40^\circ \times 30^\circ$ (Magic Leap, n.d.).

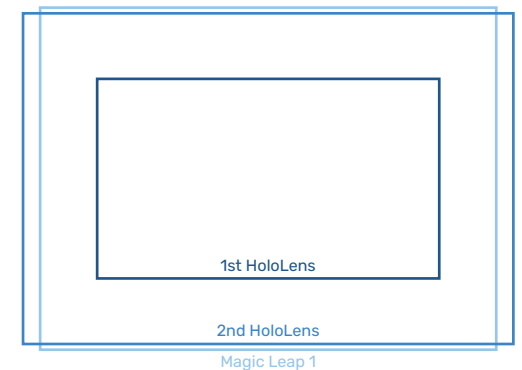


Figure 3.25. Comparison of the fields of view.

3.3 Ideation for flight inspection

Based on the insights from studying the users, the inspiration from the current AR solutions, and the technical possibilities, the initial ideas are formed. At this stage, they are mostly general ideas about how to navigate and interact with objects in AR environment. They are presented here in the order that they were sketched.

1. In this idea, different components of the UI will be on separate AR canvases. The operator can pan them horizontally using hand gestures. According to what step in the mission they are, the user can place the required panel in front of him. The canvases become smaller as they go further from the user.



Figure 3.26. Microsoft HoloLens 1 (Microsoft, n.d.) .

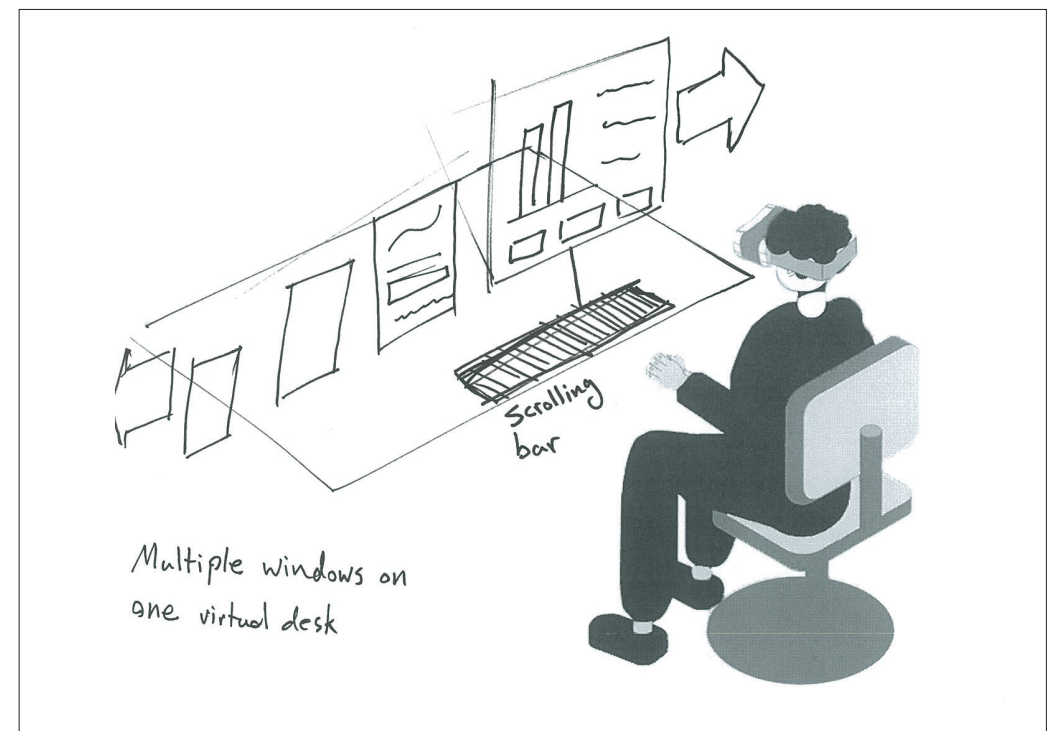


Figure 3.27. Microsoft HoloLens 2 (CNet, 2019) .



Figure 3.28. Magic Leap one with its computing unit and controller (Magic Leap, n.d.).

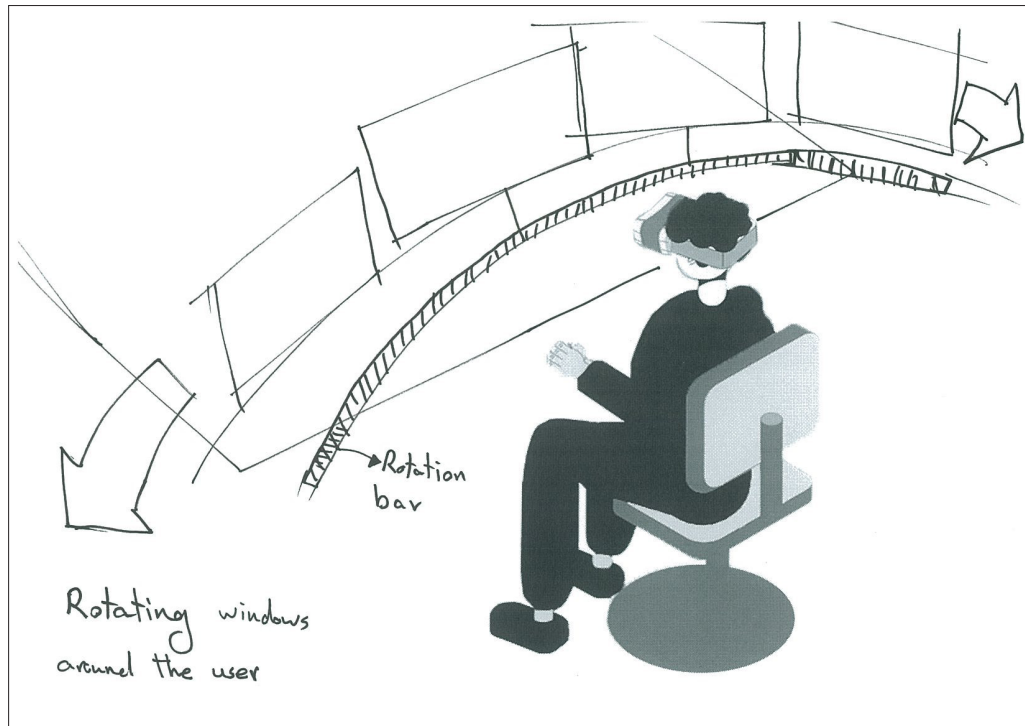
According to this comparison, HoloLens 2 seems to be the best choice, because it has the widest view, the best gesture recognition, and an integrated computer that results in better portability and ease of use. Furthermore, there are more resources and development libraries available for this headset. Therefore, this item provides the most possibilities for this project. However, since the company already has the first version of HoloLens, the prototyping will be done using that device.



Pros: separation of elements based on the tasks, easy to switch between windows (interaction).

Cons: the user may need to switch the windows many times, not using AR possibilities (2D content).

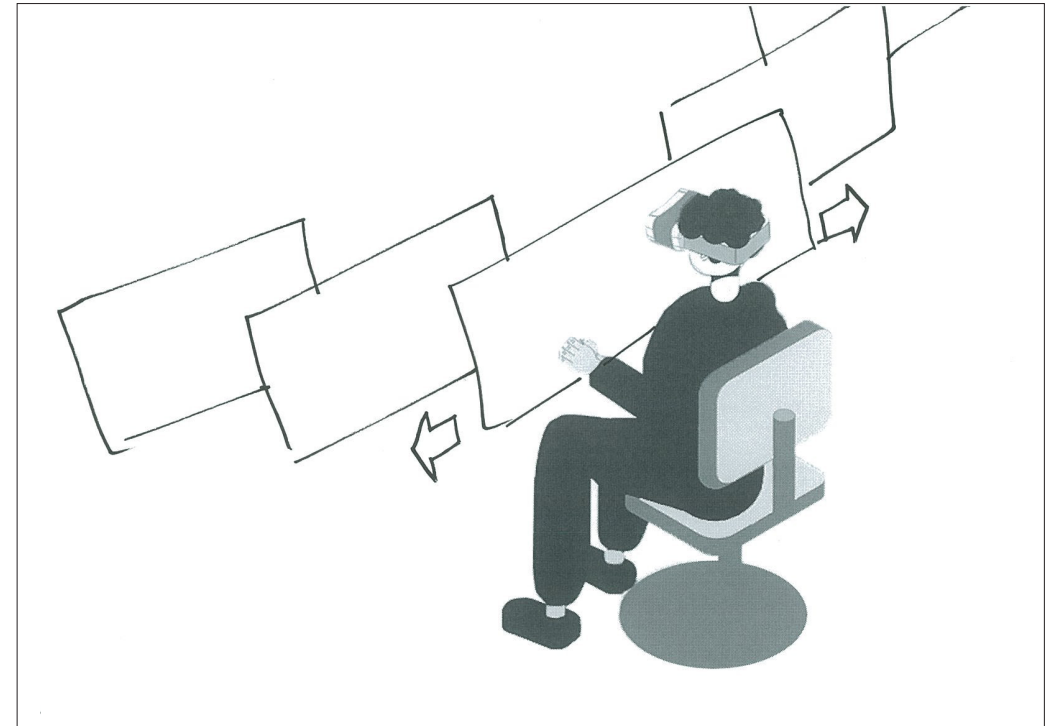
2. This idea is similar to the first idea except that the canvases move along an arc.



Pros: Separation of elements based on the tasks, easy to switch between windows (interaction), the curved panning path results in equal distance between all windows and user.

Cons: The user may need to switch the windows many times, not using AR possibilities (2D content).

3. In this idea, the UI component are again on different canvases. The canvases go behind each other toward the world in front of the user.



Pros: Separation of elements based on the tasks, easy to switch between windows (interaction).

Cons: The user may need to switch the windows many times, long switching time because of only one scroll direction, not using AR possibilities (2D content).

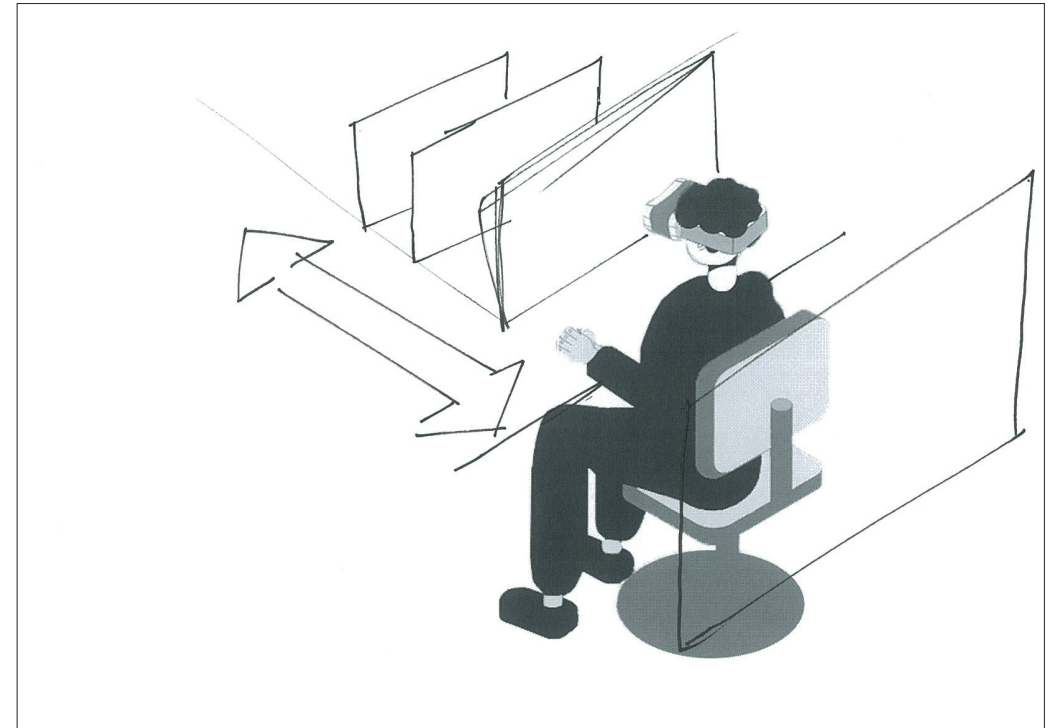
4. Here, windows are located next to each other and the user can pan both horizontally and vertically.



Pros: separation of elements based on the tasks, less need to scroll because the displays are distributed in two directions.

Cons: the user may need to switch the windows many times, not using AR possibilities (2D content), the user should turn his neck both vertically and horizontally.

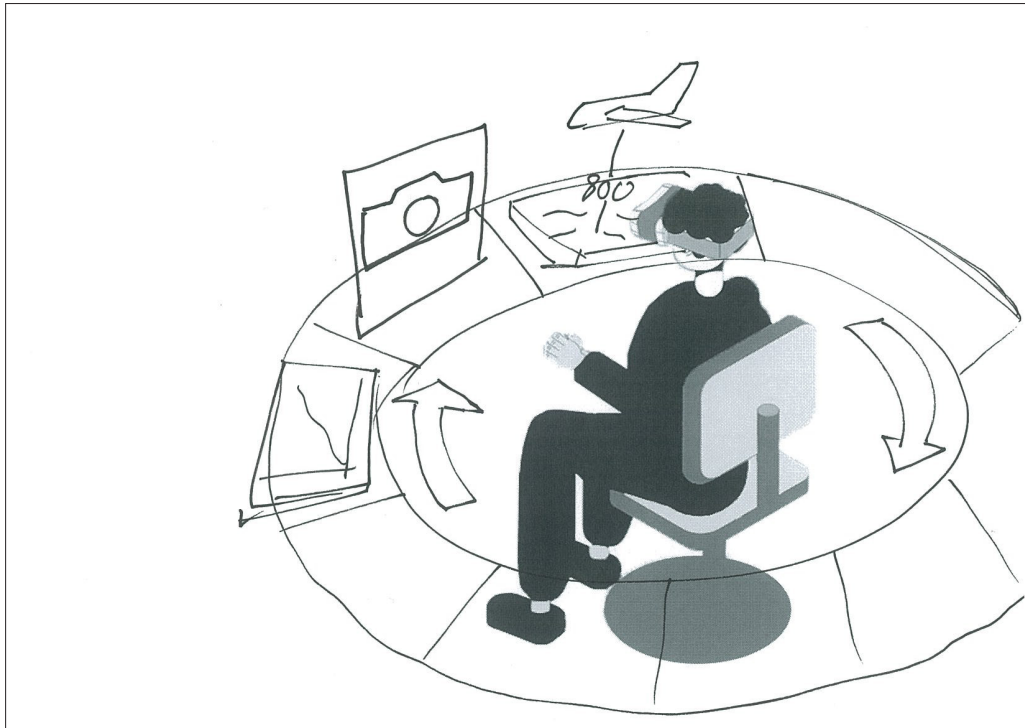
5. This navigation model lets the user zoom in and out to switch between the windows.



Pros: separation of elements based on the tasks.

Cons: the user may need to switch the windows many times, not using AR possibilities (2D content), forgetting the order of windows.

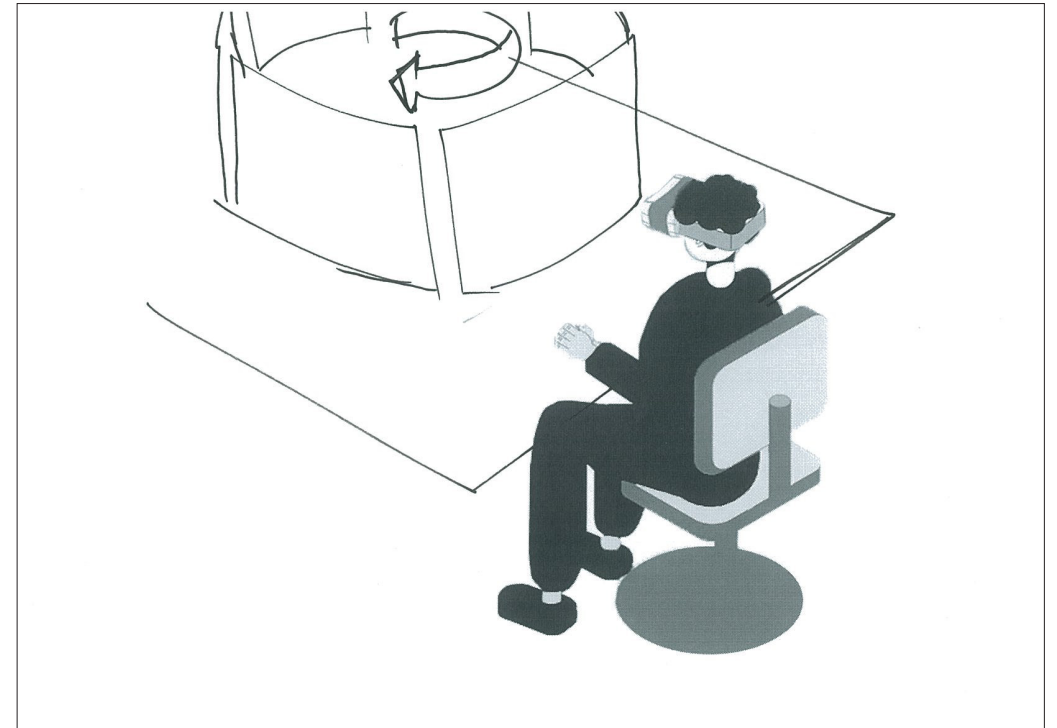
6. In this model, different instruments are located on a turning desk. The user can rotate the desk to bring the needed part.



Pros: separation of elements based on the tasks, easier navigation due to the loop shape.

Cons: the user may need to switch the windows many times, not using AR possibilities (2D content).

7. In this model, there is an AR panel for each stage of the mission. For example, planning, measuring, and reporting. The user can rotate the panels to the intended one for each stage of a mission.



Pros: separation of mission phases, only three pages to switch between.

Cons: not using AR possibilities (2D content).

8. This idea contains three virtual desks which contains the required components for different stages of a mission. The operator starts planning the mission at the first desk. Then he rotates toward the second desk to observe the data during measurements. At last, he creates the report at the third desk.

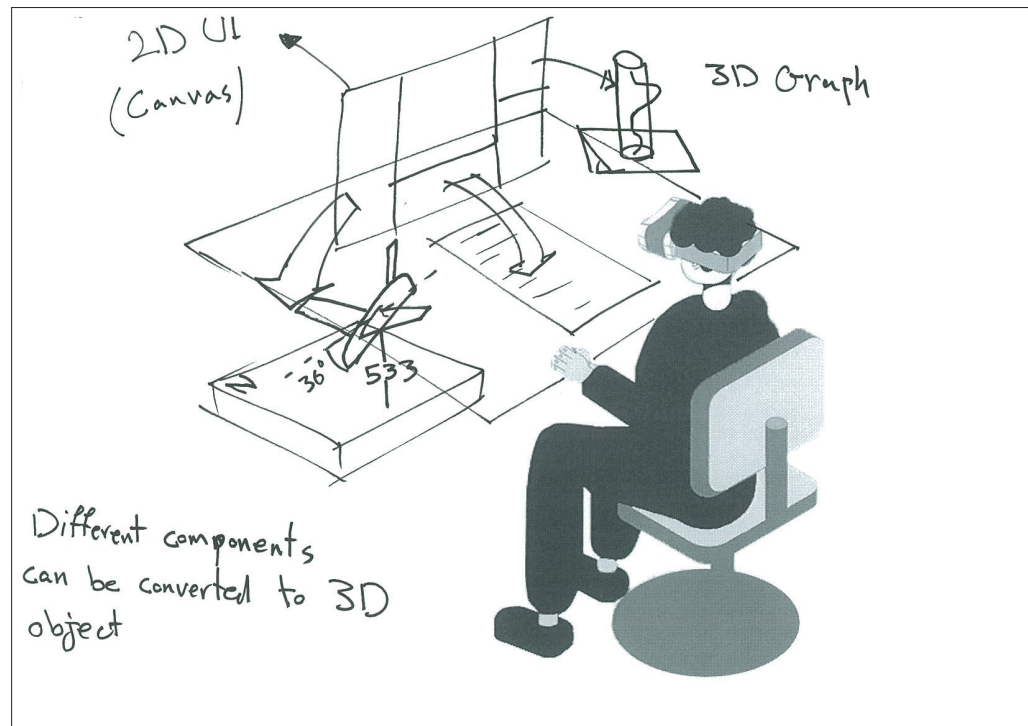


Pros: separation of mission phases, only three stages to switch between. **Cons:** not using AR possibilities (2D content), the user needs to move.

The previous ideas were about having virtual displays in AR and navigating among them. In fact, the UI components remained 2D.

The following ideas are about combining the current software with AR elements. The reason to do so is the conservative mindset of the business and their resistance to change. In this way, the operators still have access to the older UI while they are given AR solutions as well.

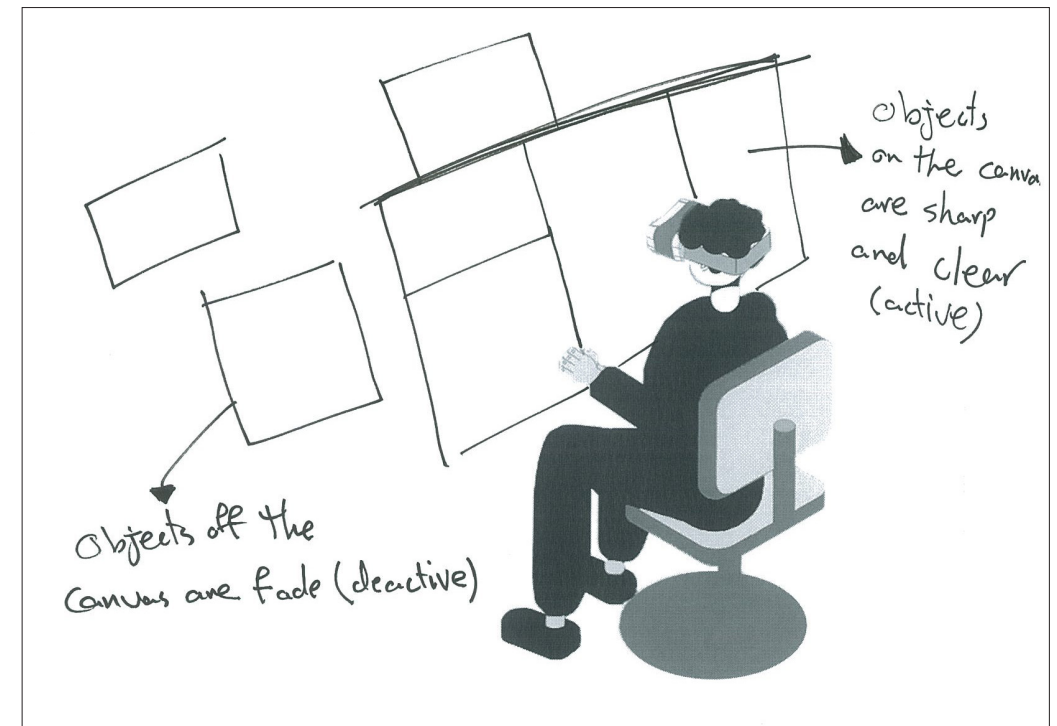
9. In this scenario, the user sits at a real desk. When he runs the software, he sees the current UI on a virtual display. If he drags the components out of the display and places them on the desk, they transform to a 3D representation of the tools.



Pros: availability of the old UI.

Cons: the workspace may become cluttered, the user may never try the AR mode.

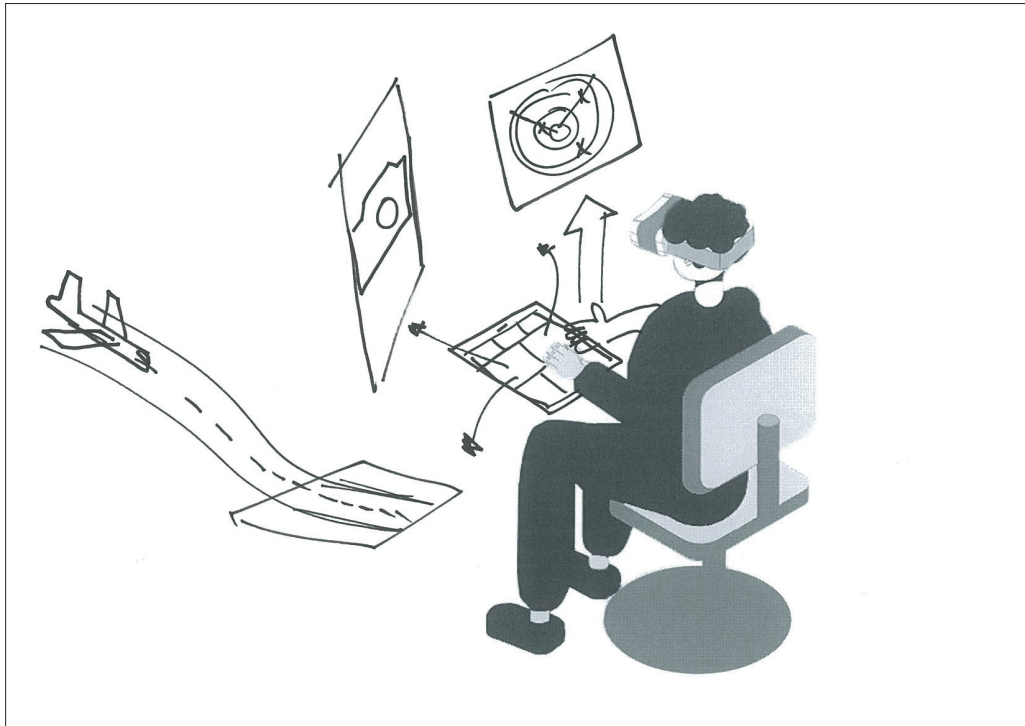
10. In this model, different components are deactivated and located around an empty canvas. When the user places one or more components on the canvas, they become activated.



Pros: separation of activated and deactivated components.

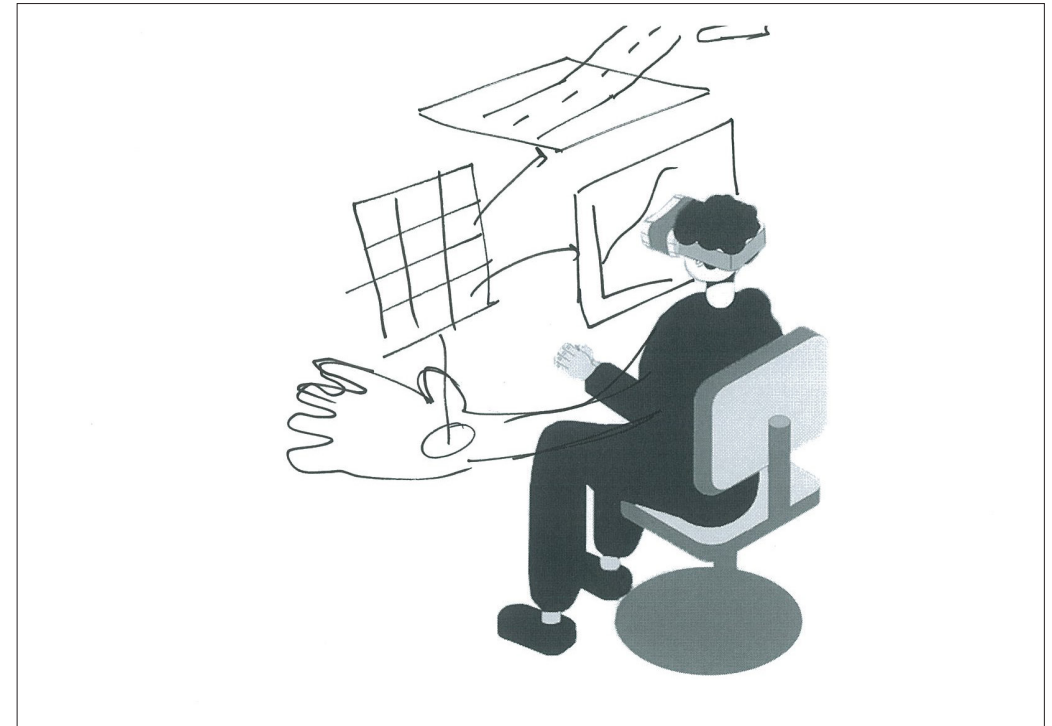
Cons: not using AR possibilities (2D content), the workspace may become cluttered.

11. This idea is a combination of the current UI on a tablet and AR. The operator can drag the different parts of the UI out of the tablet. Then, that part switches to AR Mode. Using the tablet makes the interaction tangible, so, easier.



Pros: easy interaction (touch), bond to the old UI. **Cons:** the workspace may become cluttered.

12. In this model, a menu containing the UI component pops up when the user gazes at his wrist. Then, he can drag the components and drop them in the air to switch them to AR 3D elements. This idea was inspired by Microsoft HoloLens 2 that the user sees the start menu floating on his wrist.



Pros: easy access to the menu, good organization of components. **Cons:** the workspace may become cluttered.

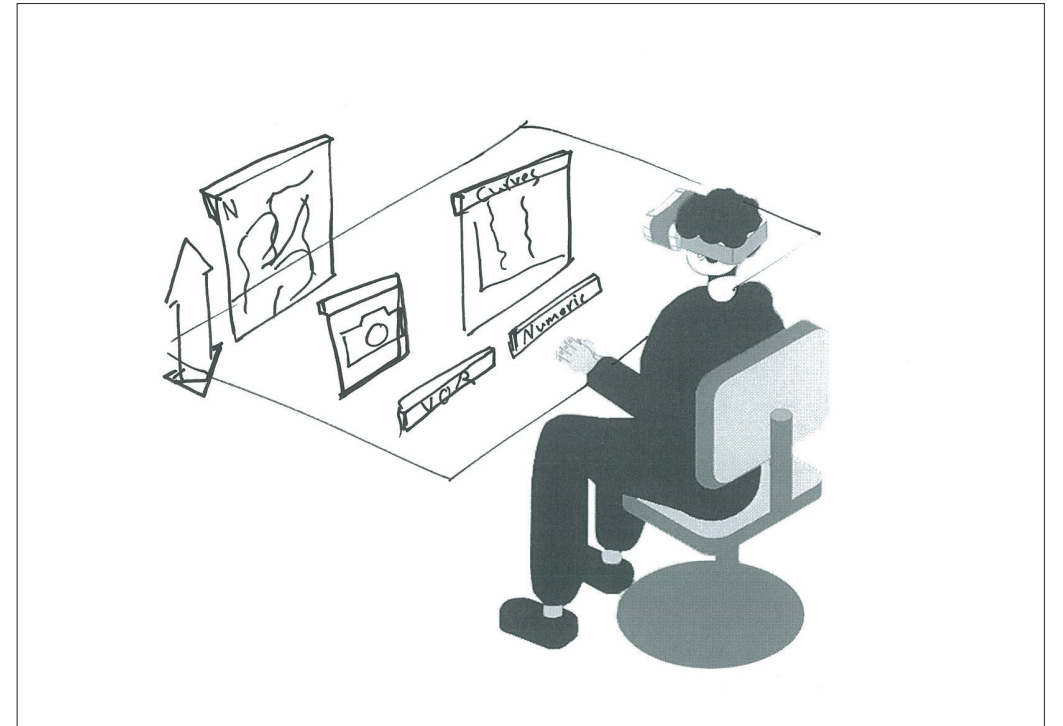
The coming ideas are generally about organizing the components.

13. In this idea, the UI components are floating around the desk and the operator can place them on the virtual desk to switch them to 3D mode. He places the tool(s) that he needs to focus on.



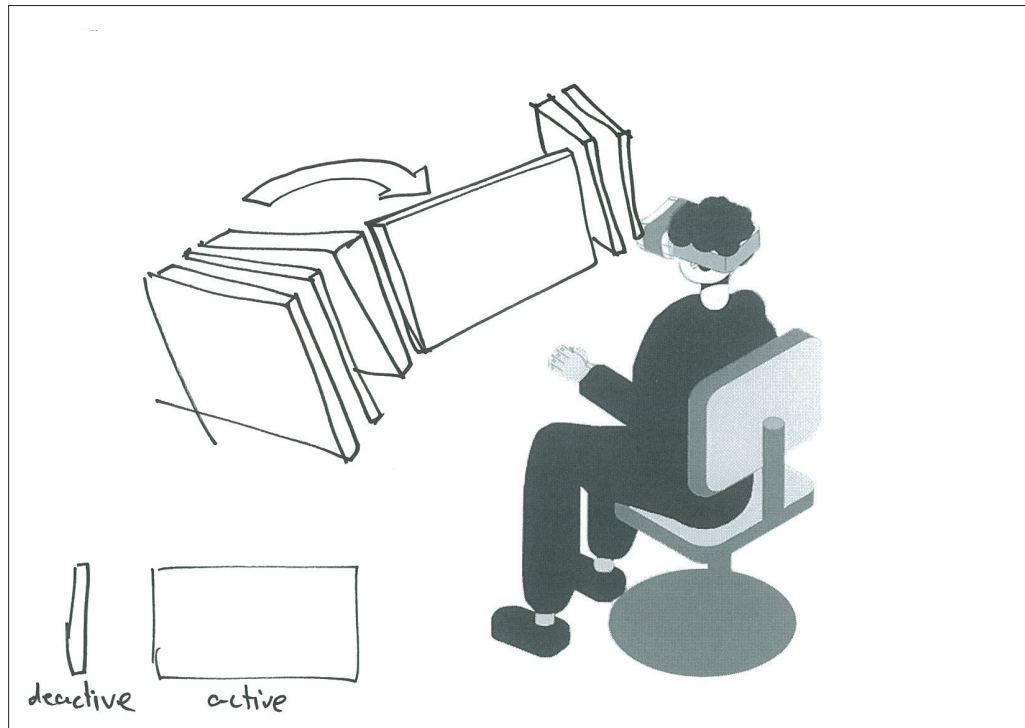
Pros: focus on the activated components. **Cons:** the workspace may look cluttered.

14. In this idea, the components go and hide under the desk surface. The user sees the headers and can take out the elements(s) he needs based on the phase of the mission.



Pros: the user can visually memorize the location of components, tidy workspace. **Cons:** not using AR possibilities (2D content), different distances between user and objects.

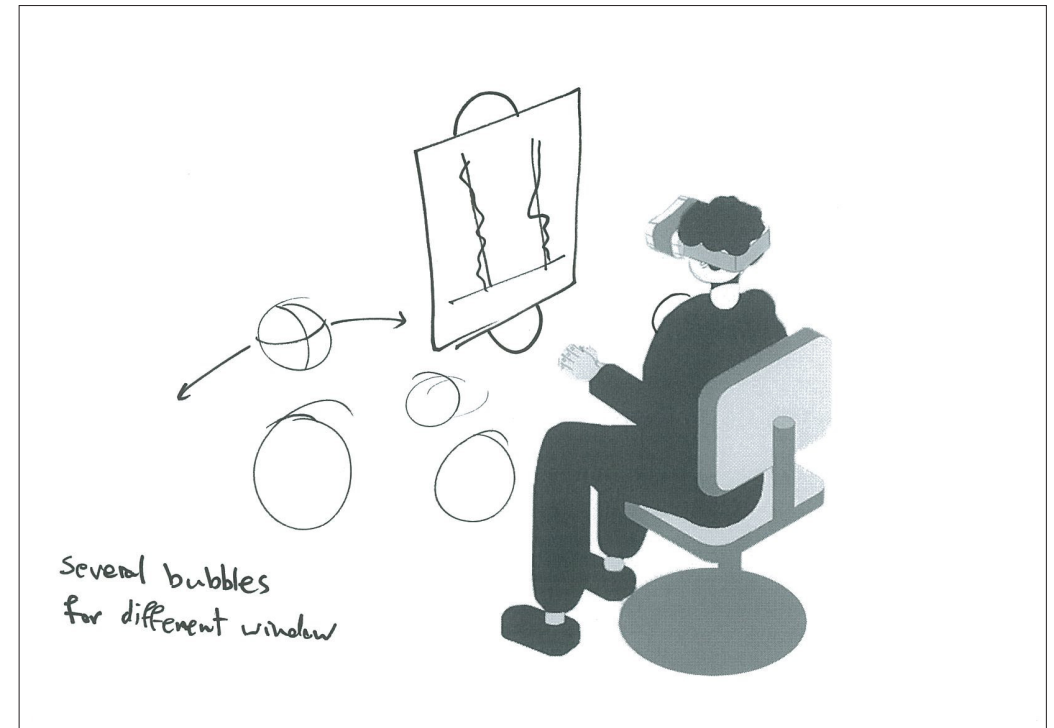
15. This idea is like a bookshelf. The user sees the deactivated from a narrow side. If he rotates them, the component becomes activated.



Pros: the user can visually memorize the location of components, a minimal arrangement of elements.

Cons: not using AR possibilities (2D content), the workspace may become cluttered after activating multiple elements.

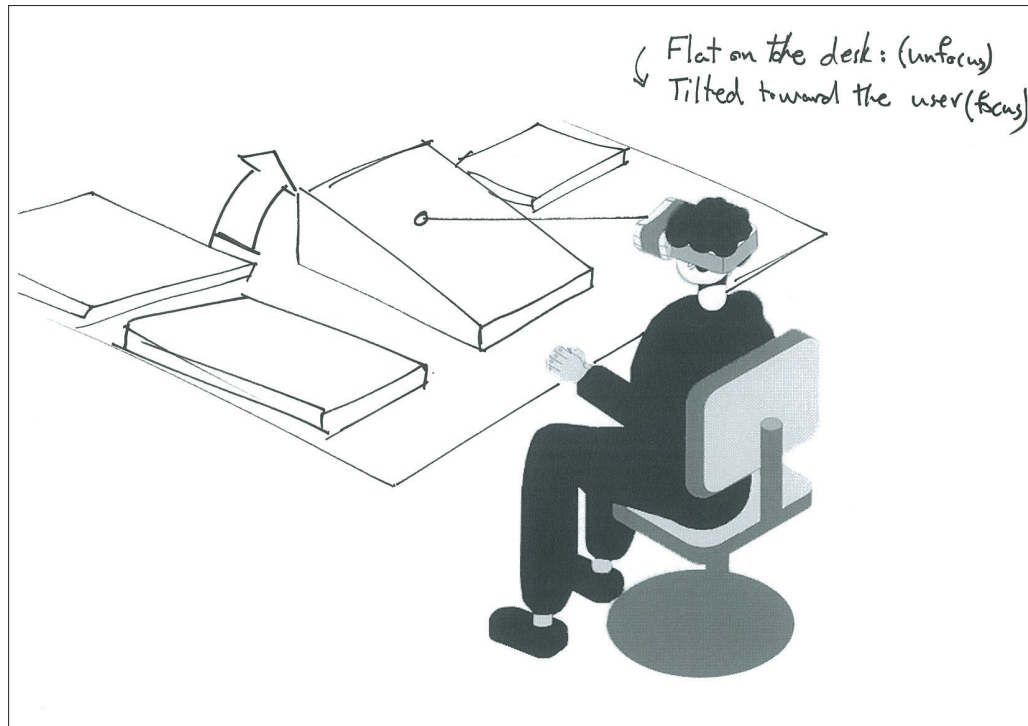
16. The components are represented as bubbles in this idea. Each bubble has a glyph standing for the inner component. The operator can open a bubble to activate the component.



Pros: a minimal arrangement of elements.

Cons: the workspace may get cluttered after opening multiple bubbles, it may look too fantasy for this context of use.

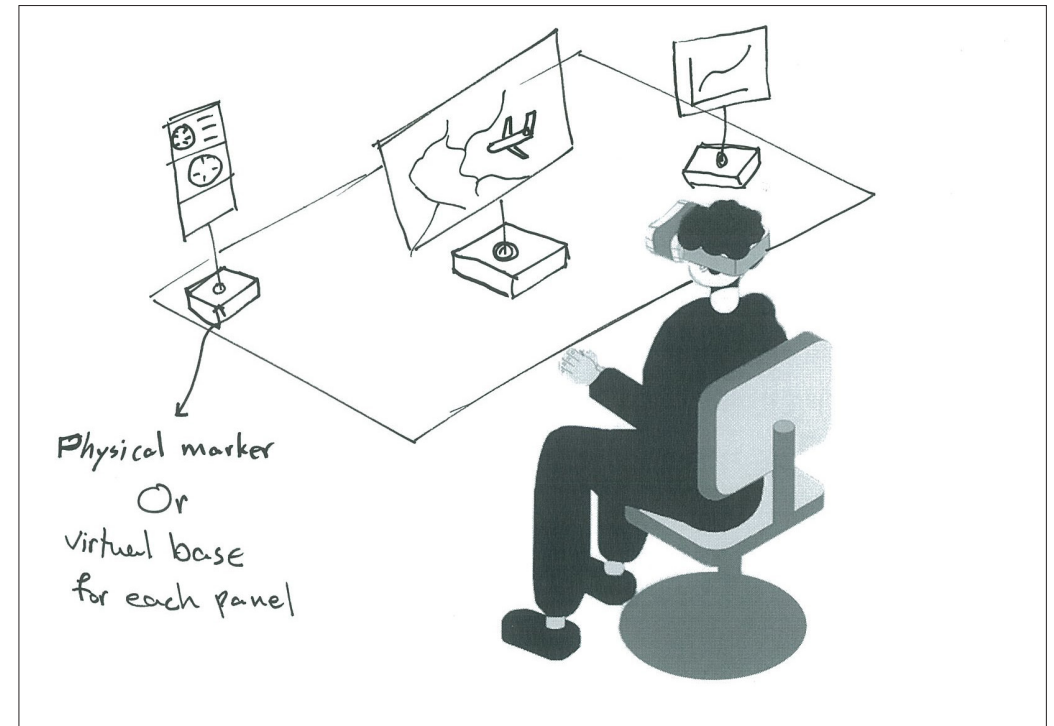
17. In this model, components are flat on the desk. When the user gazes at them, they tilt upward toward him. Each part is activated as long as the user looks at it.



Pros: hands-free interaction to activate a component, bond with user's visual memory.

Cons: different distances between user and objects, not using AR possibilities (2D content).

18. In this scenario, there are multiple physical objects on the desk that work as markers for AR elements. Since the gesture recognition might be challenging, the user can move the markers and the assigned components follow.



Pros: easy interaction with the physical markers.

Cons: dependent on the markers, not using AR possibilities (2D content).

The next two ideas are focused on two tasks during the missions, namely, communication and making the report.

19. During a mission, the operator hears voices from the cockpit, the tower, the radar stations, and the technicians at the facilities. He can also talk to the cockpit and the technicians at the facilities. In this idea, each of these items are represented as 3D avatars. Placing an avatar far from the user makes that voice mute. If the operator places the avatar(s) close to his head, he can communicate with those people.



Pros: easy to understand the function (suitable affordance). **Cons:** it may look too fantasy for the context of use.

20. After completing the measurements, the operator should create a report of the mission. In this idea, there is a white AR canvas in front of the user where he can type. Also, the graphs, photos, tables etc., are available as AR elements and the user can drag and drop them on the canvas. For typing, the user is provided with a physical (real) keyboard.

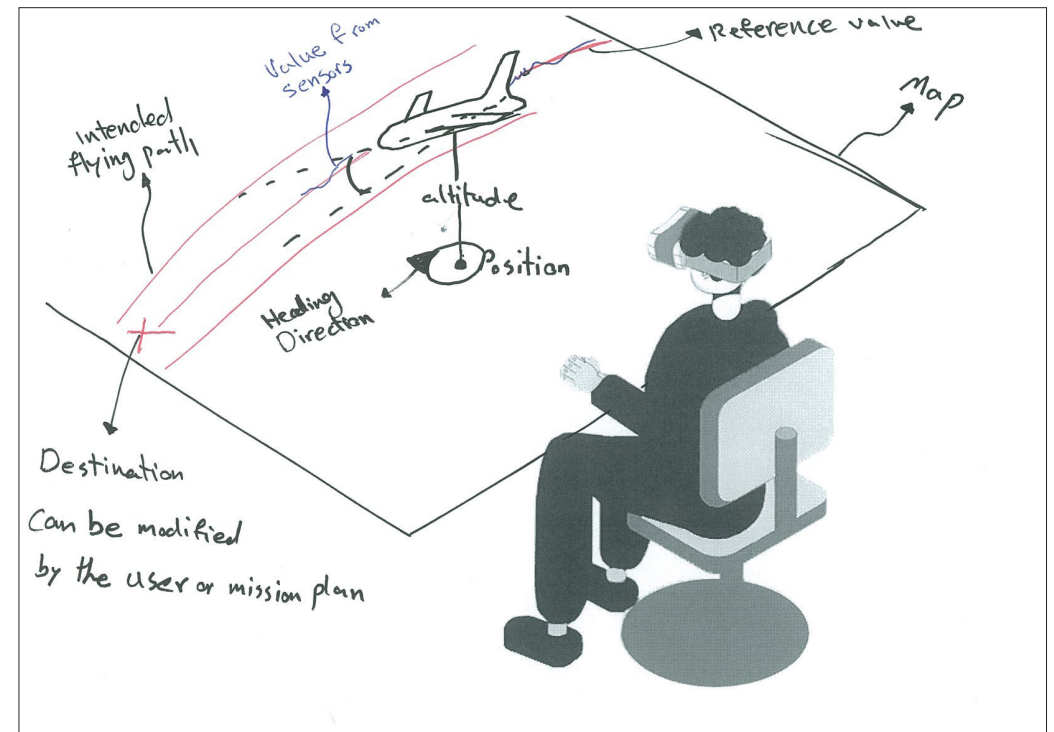


Pros: easy access to different materials for the report. **Cons:** drag and drop with hands may need more effort than working with a mouse.

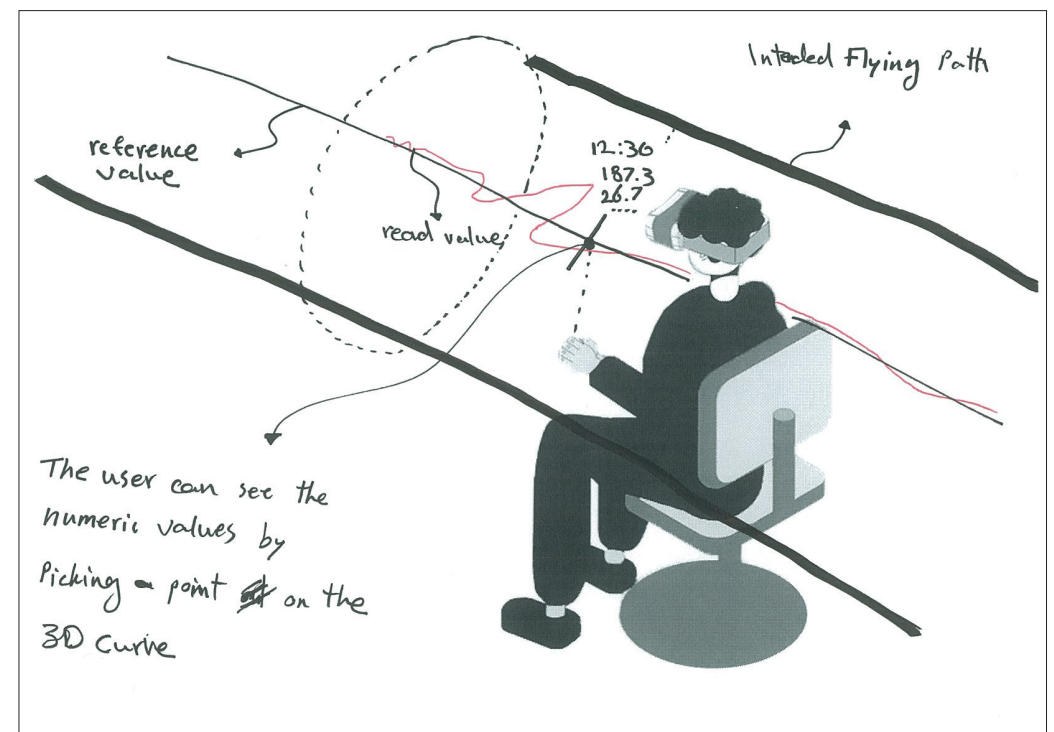
3.3.1 Reflection on the ideas

After the first round of ideation, it was found that most of the ideas borrowed classical 2D UI elements and did not actually use the potential of AR technology, namely, 3D and spatial content. Therefore, there should be an iteration on ideation to generate a concept that makes use of AR capabilities. In addition, the advantages of previous ideas are considered and integrated with the new ones.

To use the most of AR capabilities, a new idea will be proposed that is focused on transforming 2D elements into 3D so that various data becomes more tangible. This idea is mainly for the flight inspection missions but provides the possibility of being expanded for airborne surveillance missions, as well.



21. The concept presents a piece of the world in AR to the operator. He sees an AR 3D map of the flight area, a 3D representation of the aircraft along with visual information about navigation through an exocentric perspective. To focus on the retrieved data from sensors, he can switch to an egocentric view where he can observe the curves of signals in comparison to their permitted tolerance.



3.3.2 Reasoning for the concept

3.3.2.1 Knowledge in the head vs. knowledge in the world

The need for us to learn decreases whenever information needed to do a job is readily available in the world. If people are in an environment containing the relevant knowledge required for a task, they can usually perform even if they have not learned and memorized everything about that task. Knowledge in the world is usually easy to perceive. Natural mapping is a form of placing knowledge in the world (Norman, 2013). In this concept it has been tried to integrate the knowledge with the world, that is the AR environment. This knowledge has to be learned and memorized by the operator in their current system.

The concept provides the operator with a 3D representation of the mission flight profile. A flight profile is the path that the aircraft should fly through in order to perform a specific measurement. Today, the operator has a list of the profiles on paper. However, this concept integrates the profiles with the map. Namely, a tunnel shows where the aircraft should fly through, where it should turn, ascend or descent. This reduces the need for imagination and the cognitive load. In fact, the knowledge is placed in the world the operator sees instead of a separate document (on paper) or his memory, and the flight profile is naturally mapped to the location where it should be

performed. As a result, it will take less effort for him to recognize the position of the aircraft relative to the profile.

3.3.2.2 Frame of reference

The perspective through which a user looks at an environment is his frame of reference. Cognitive frames of reference are categorized to egocentric and exocentric. Accordingly, a map is which is a piece of world, is an exocentric view of that area given to users. On the other hand, our subjective view of the world is called egocentric frame of reference (Ware, .

In this concept, the operator is provided with these two perspectives for different purposes. At first, he is given an exocentric perspective. The view can be like god's-eye or wingman view. According to Ware (2012), these views are more advantageous for controlling moving objects than an egocentric perspective. In this mode, the view includes a 3D map of the area, the aircraft, the flight profile, and visual aids for navigation and positioning. This view will be used when the operator wants to plan the mission and check the position of aircraft during a mission.

When the measurement is started, the operator can switch to egocentric view to focus on the signals. In this mode, he finds himself in the center

of the flight path (tunnel) and the signals come toward him. The wall of the tunnel stands for the allowed tolerance. In the center of tunnel, there is a centric line which shows the reference value. So, the operator can compare the signals from the sensors with the reference value, and if they collide with the wall at some point (out of allowed range), he can ask the technician at the facility to calibrate it.

The decision of combining the egocentric and exocentric views is supported by Wang and Milgram (2001). They proposed that the combination of these frames of reference "may improve performance for those navigation and control tasks that depends on both global spatial awareness and local guidance concurrently."

3.3.2.3 Situation awareness

Situation awareness is a three-step process of recognition of objects in a context within a range of time and space, understating what they mean, and foreseeing their status in near future. After these steps, an operator would decide and perform an action (Endsley & Jones, 2012).

In a flight inspection mission, it is crucial that the operator perceives all values, their changes, and changing trends in order to verify a facility is performing properly or not. Safe

landing of aircrafts carrying people are dependent on the accuracy of these facilities, so, the new interface must provide the operator with an easy and assured way to comprehend all intended data.

As said before, the combination of the two perspectives affect the situation awareness. When the user is in exocentric view, he sees the aircraft over the map. The better spatial understanding which is the result of the broad view of the surrounding area creates better awareness for the operator in different manners:

He is able to see the weather status and the geographical characteristics of the target area. This lets him plan the mission and organize the measurements order. For example, if he sees that it is raining in a specific area, he may postpone the measurement which should be done over that are and do another measurement first until the rain is stopped for the postponed measurement.

The geographical information also helps the operator to decide on the flight path (mission profile) for a measurement. For instance, there is a clockwise turn in the mission profile, but there is a mountain on one side of the path that makes the turn difficult. The operator sees the 3D representation of the

mountain on the map and plans to turn counterclockwise. This point was exactly mentioned by the operator during the interview.

The egocentric view, on the other hand, would improve awareness of the changes in signals. If the operator is placed in the center of the tunnel, namely the reference value, he can recognize the difference in the coming signals easier. Therefore, his decision making about whether a facility is working properly or not will be more precise.

3.3.2.4 Sensory vs. arbitrary data

Sensory representation refers to symbols and visualizations that get their meaning from their ability to use the perceptual processing power of the brain without learning. Arbitrary representations are the ones that must be learned, because they have no perceptual basis. There is no pure arbitrary or sensory representation, however, the more sensory a representation is, the easier it will be understood because they are matched to the early phases of neural processing in the brain (Ware, 2013).

A key feature of this concept is the new way of showing navigation and orientation data. In the current software, there are classic navigation aids like those which can be found in the cockpit. These instruments

mostly show arbitrary data and the user must learn how to read and use them. In the new concept, this information is represented in a more sensory manner. Pitching and rolling of the aircraft are shown through the 3D model of it, so, ascending and descending are visible. The heading direction (yawing) is understandable from the head of the 3D aircraft or from the arrow which is projected in the map. The altitude is mentioned on a vertical line that goes from the aircraft to its position on the map.

In addition, the essential numeric values including signals and their allowed range are presented as 3D curves and elements in our concept. This sensory mode of data representation is easier to interpret than the table of values. If a value is within the intended range, the user can see that signal inside the path. If a value is out of the range, it collides with the wall of the tunnel and goes out of it.

Generally, the effect of having more sensory data relative to the arbitrary data is similar to the effect of having more knowledge in the world than in the head. Namely, they impose less cognitive load on the brain.

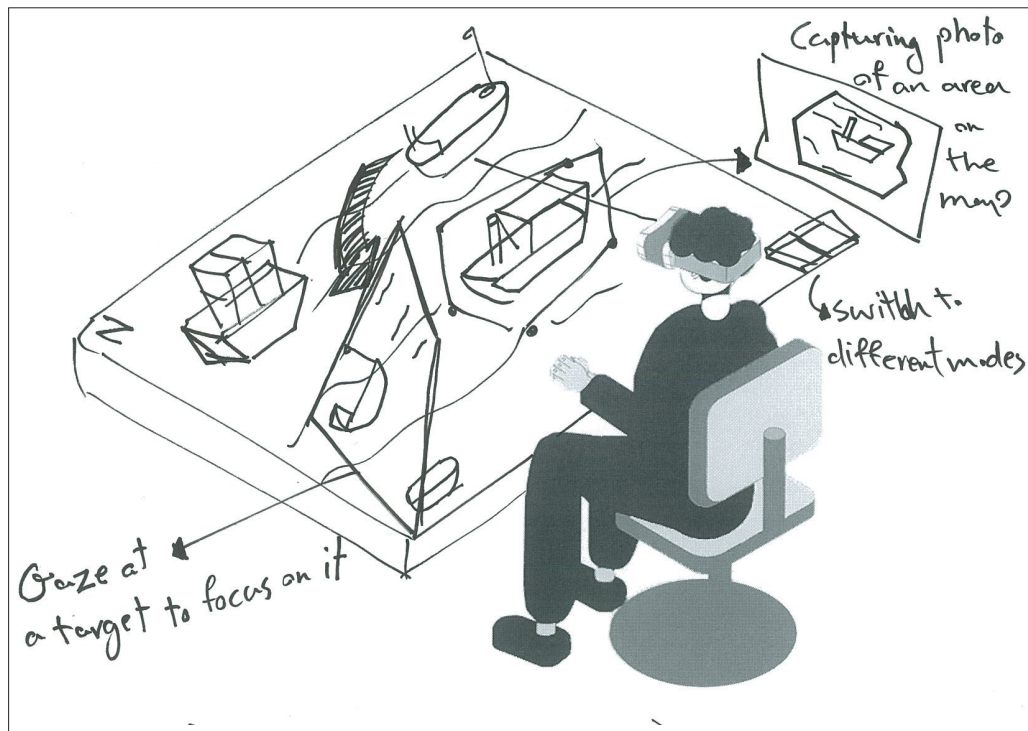
3.3.3 Expansion for airborne surveillance

Based on the previous concept, structure of the new ideas is based on three new models were proposed for on the two view-ports which were airborne surveillance missions. The considered in the last idea.

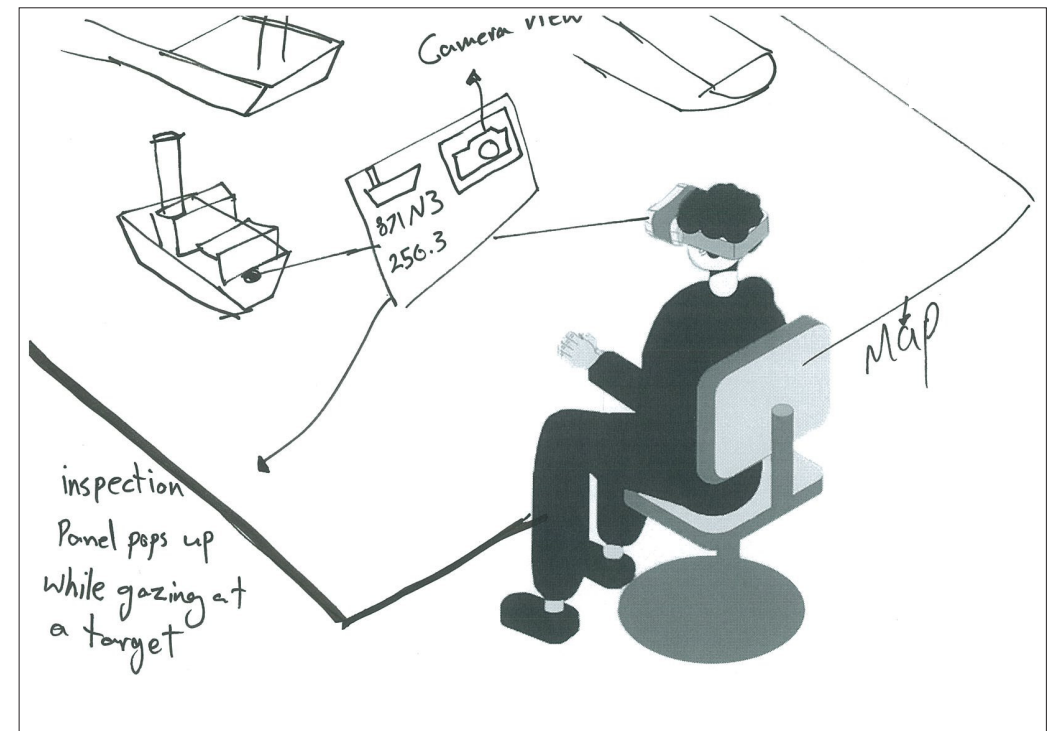
22. In this model, the user is given a subjective view (egocentric) of the sea. The vessels are mapped around him according to their position in the ocean and relative to the location of the aircraft. The interface (the world) is represented around him, and he is located at the center. So, he should turn to see the targets in different directions. A 2D tool shows him the field of view and the direction he is looking at. Also, the AIS data of the boats are pinned to them. To inspect a target through different lenses, the operator should select it. Then, a window will pop up and show the intended view of that ship. He can choose between different views, for example IR or SLAR, by rotating a cube.



23. This idea is based on the exocentric view of the area. The operator has a map of the flight area in front of him. So, all targets in that region are visible to him and he does not need to turn. To retrieve the data of a ship, he should gaze at it. When he stares at a boat, a window containing its information appears next to the target. Furthermore, if he observes for example an oil leakage around a target, he can draw a polygon around it and capture a photo of that. This idea is similar to the previous one, except the perspective is changed from egocentric to exocentric.



24. The perspective of this model is all the same with idea no.23. But, here, when the operator looks at a boat, the information window will be shown in front of it, between the eyes and that target. The user can switch the views (camera, IR, SLAR) of that target on this window.



3.4 Iterative design

After getting an insight of what the users need and generating ideas, the loop of prototype-feedback starts to see if an idea meets the needs. Iteration lets us improve the concept after each test. The iterative part of the design process may also be called rapid prototyping or spiral prototyping (The Interaction Design Foundation, 2020).

This part begins with the first prototype of the preliminary concept. Then, the idea gets modified based on the user's input in three steps.

3.4.1 The first prototype

The first version of the concept was made and presented to the mission operator and NSM. The Prototype was made in Unity3D and ran on Microsoft HoloLens. So, the user could be in an immersive AR environment and see the content in the form of holograms in his surroundings.

In this prototype, the focus was on transforming the 2D information of the current software to 3D visualization which are more sensory. There are two main categories of information:

1. Information about the orientation and navigation of aircraft which is accessible through different navigational aids and instruments, for example, altimeter, attitude indicator (artificial horizon), heading indicator (compass), and turn indicator.

2. Information of flight inspection which are available to the operator in form of both curves and values.

It is not decided yet about how the opening scene of the AR interface is. This scenario depicts the solution in the step that the operator has started the software and selected the facility that should be measured.

After selecting a facility, the operator is provided with an exocentric view. In this view he sees a scaled down 3D map of the area where they should fly over, an aircraft 3D model at the position which is retrieved from GPS (the real position of the aircraft in real world), and a tunnel. This view provides the user with the information needed for planning the flight.

The tunnel represents the flight profile (ideal path), where they should fly through to do the measurement. This is a new feature which does not exist in their current software. The yellow part of the tunnel shows the guide path that leads to the starting point for measurements. Then the green part is where the measurement

should be done. Based on the type of a measurement, the tunnel will be set on the map. For instance, we have the approach part of ILS at Genoa airport in this prototype.

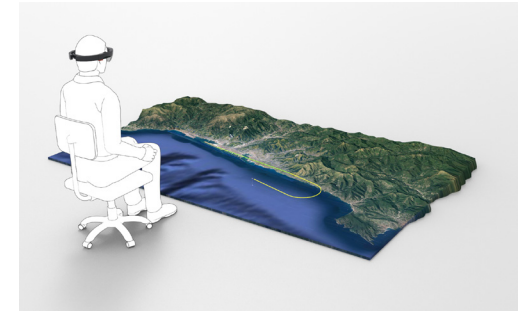


Figure 3.29. The user has an exocentric view of the area.

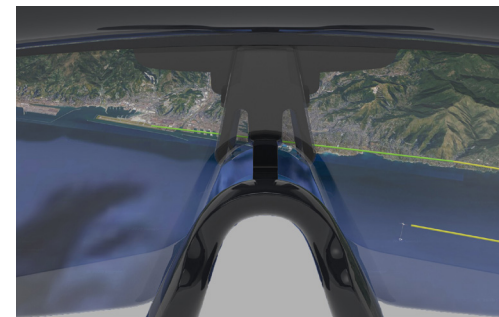


Figure 3.30. What the user sees through HoloLens.



Figure 3.31. The tunnel.

The operator can zoom in and focus on the aircraft. He can change the view of the aircraft to tethered views like wingman's view, god's eye view, or orthographic views like back, top, or side.



Figure 3.32. The god's eye view.

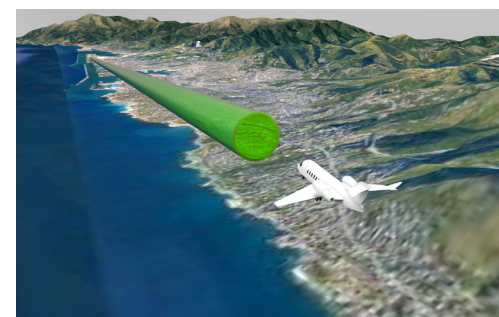


Figure 3.33. The wingman's view.

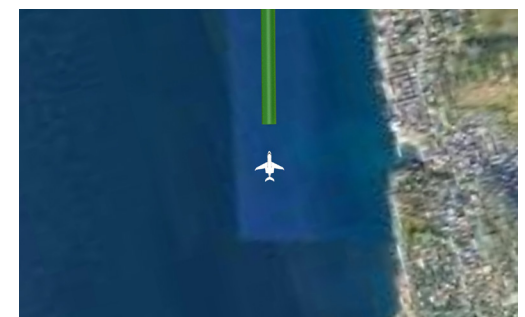


Figure 3.34. The top view.

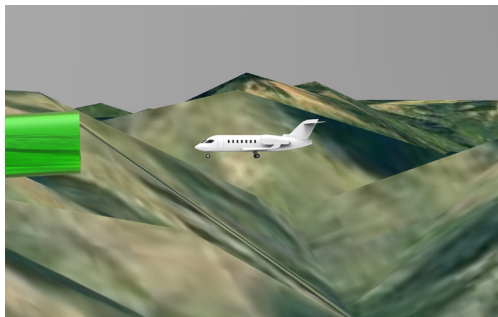


Figure 3.35. The side view.



Figure 3.36. The back view.

Through these close views of the aircraft, the operator can get the information about the orientation and navigation of aircraft in a more sensory way than the current navigational instruments.

To show the glide angle, there is a line along the movement direction which is always parallel to the horizon.

When the aircraft pitches, another line will become visible which shows the angle relative to the horizon.

Rolling angle is depicted using the same method. There is a line parallel direction of the wings. This line always remains horizontal. If the aircraft turns, another line which is fixed to the wings will show the rolling angle.

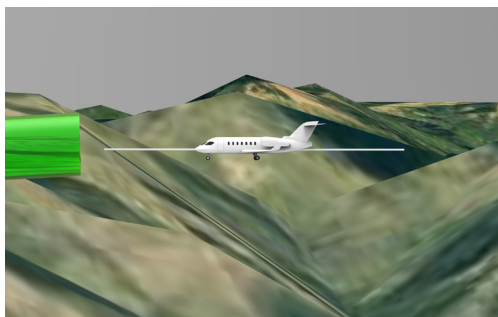


Figure 3.37. The aircraft is keeping its altitude.

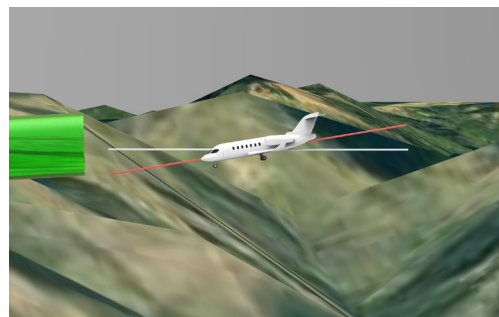


Figure 3.38. The aircraft is descending.



Figure 3.39. The aircraft is flying straight.

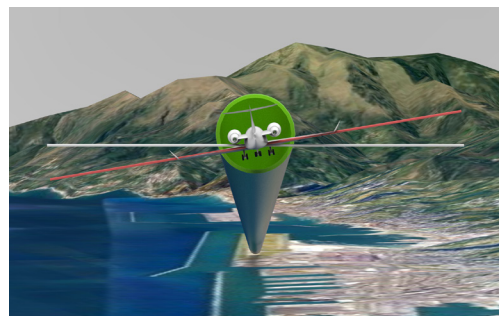


Figure 3.40. The aircraft is rolling to the left.

The altitude is shown using a vertical line that goes from the airplane toward the ground. Also, the heading of the aircraft is projected on the ground.



Figure 3.41. The altitude and heading of the aircraft.

The centerline of the tunnel represents the exact position of the flight profile (optimum path). The tunnel can be divided into four quadrants to make it easier to compare the position of the aircraft to the path.

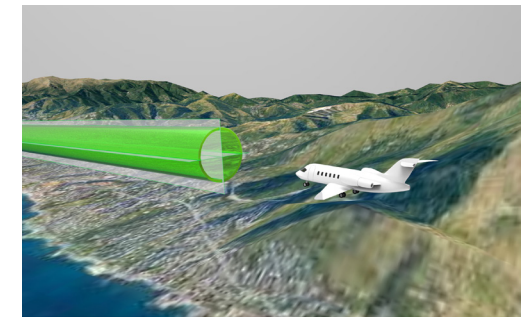


Figure 3.42. The tunnel is divided to four quadrants.

Before explaining the rest of features, it is needed to explain what flight inspection is in practice. Briefly, the goal of flight inspection is to measure the accuracy of navigational aids which are used by pilots during a flight, approach and landing. To do so, a flight inspection operator compares data from GPS with the data from the navigational aids. The GPS data, which is more accurate, is considered as "Reference" data, so, the reference position is the position of the aircraft according to GPS. On the other hand, there is data from navigational aids. For instance, in an ILS approach, localizer and glideslope indicate respectively the

horizontal and vertical deviation of an aircraft in comparison to the optimum approach path. The difference between these two data is the error of the navigational aids. To put in a nutshell, the goal of flight inspection is to measure and compare this error with a tolerance and decide if a navigational aid works properly or not.

When the measurement is started, there will be a second aircraft which is rendered like a shadow. This aircraft will be called "ghost aircraft" in this concept. The ghost aircraft is at the position which is retrieved from the navigational aids (localizer and glideslope). Therefore, the distance between the real aircraft and the ghost one indicates the error of the navigational aids. The values are typically in microamp unit, however, they are proportional to the distance between the two aircrafts.

During the measurement, trail lines will be drawn behind both aircrafts. These lines help the operator to keep track of where the airplanes have gone through. In addition, the trails are for review and analysis of the mission data after the measurement.

Another feature of this concept is the egocentric view from inside the airplane. In this mode, the camera is tied to HoloLens orientation and all information and 3D content including the tunnel, ghost aircraft, and flight trails are visible to the operator in 1:1 scale. This feature will also be useful at the time when flight inspection is done using drones instead airplanes and the operator remains on the ground. In this way, he will be able to have a perspective as if he is up in the air.

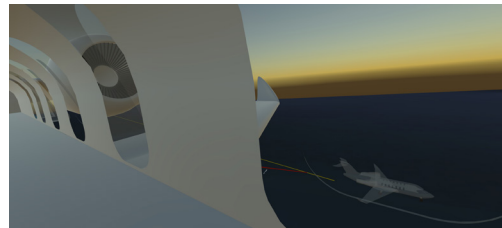


Figure 3.43. The egocentric view from inside the aircraft.



Figure 3.44. The ghost shows position based on nav data.



Figure 3.45. The red line shows the error of the nav aids.



Figure 3.46. The green curve shows trail of the reference data, the yellow curve shows the trail of the nav data.

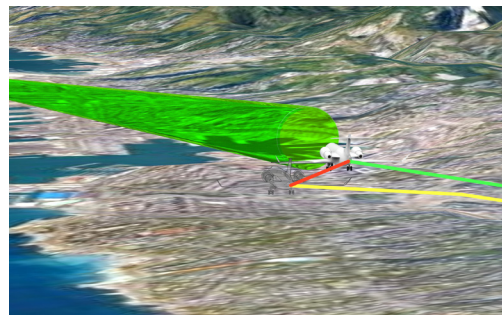


Figure 3.47. The trails and the error.

3.4.2 Feedback session

Due to the restrictions caused by Covid-19, I was not able to meet the operator in person to perform user testing. In addition, NSM has limited the entrance of non-employee people to their office.

On the other hand, the type of the solution and complexity of the job makes it difficult to test the model with random people. In fact, the test users need to be familiar with flight inspection. Therefore, online meetings were the only way for me to gather feedback about the concept. To do so, the prototype was presented to the operator, the R&D director, and the director of flight inspection systems at NSM who is also a member of the international committee for airspace standards and calibration. During the presentation, I wore a HoloLens and ran the prototype app, and the live scene was shared with them.

During the meetings, all features of the concept were discussed. For required changes, the participants and I generated new ideas and rapid sketches through a participatory approach, and together, we decided on the differences which should be made in the second prototype:

1. The information about the navigation and orientation of the aircraft is easier than the classical instruments to understand although the operator does not need them very often.

2. Distance from the ideal path is not a key data because the aircraft may not follow this path.

3. The deviation between the reference position (GPS) and the localizer-glideslope position is the most important data.

4. The concept of tolerance was misunderstood. In fact, the tunnel should not be along the ideal path. Instead, it should be along the reference path. If done so, then, the tolerance value can be represented through the size of tunnel.

5. Although the distance between the real aircraft and the ghost one shows the error but since the position of the latter one is based on two different aids (localizer and glideslope), it takes more effort for the operator to calculate the vertical and horizontal deviations based on the diagonal distance.

6. The profile of the tunnel should be rectangular and not circular. Since there are two sources of data from the ground (localizer and glideslope) there will be two tolerance parameters, one for each. Therefore, the profile of the tunnel should be rectangular to cover all the range within the tolerance.

7. It was recommended to keep the color of trails consistent with the color of curves in their current software.

3.4.3 The second prototype

According to the feedback and the discussed changes, the second prototype was made. In this version, the focus was on visualizing the flight inspection data and make it easy for the operator to notice the changes between the reference and the localizer-glideslope data.

The most dominant difference in this version is the tunnel. As said before, the tunnel should be along the reference path and not the ideal path. Also, it should have a rectangular profile. But there is another big change. Since tunnel should be along the reference flight path (real aircraft path), first

we need to know where the real aircraft is, and then we can continue generating the tunnel around it. As a result, the tunnel will be generated like a 3D trail behind the aircraft with the flight trail as its centerline. The ideal path is, however, still available but in the form of a line, not a tunnel.

During the 3D modeling phase of the prototype, I came up with an idea about showing the tunnel with discrete sections instead of a continuous profile. This new mode provides an easier 3D perception. So, both models were included in the model to be evaluated by the user.

The point of having the tunnel is to show the tolerance in a sensory way and understand if the error is bigger than the tolerance. To do so, we can apply the two tolerance values to the height and width of the tunnel. So, the height will show the tolerance of glideslope and the width depicts the tolerance of localizer. Therefore, when the ghost aircraft is out of the tunnel, it means that the error is more than the allowed value. If this happens, that section of the tunnel will be shown in red color. This is to increase the operator's awareness of the issue.

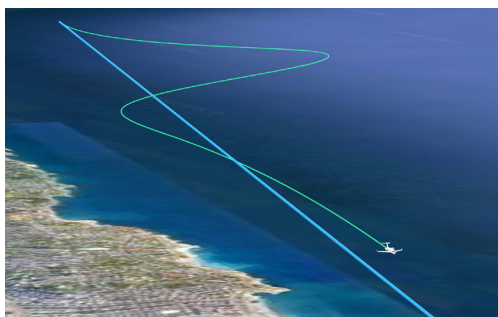


Figure 3.48. The ideal path (blue) and the reference trail (green).



Figure 3.49. The tunnel should be drawn along the reference path and shows the tolerance.

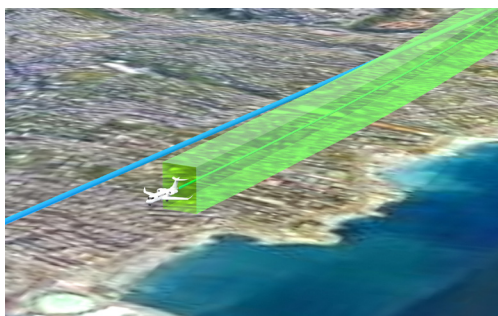


Figure 3.50. The tunnel with a continuous profile.

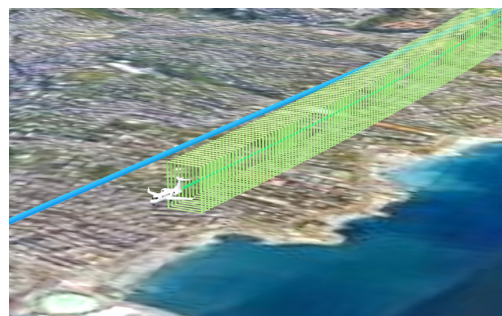


Figure 3.51. The tunnel with discrete sections.



Figure 3.52. Ideal path (blue), reference path (green), and navigation aid path (yellow).

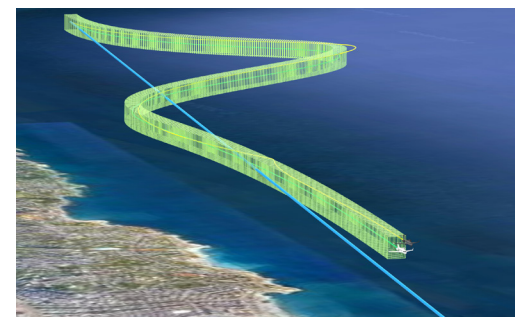


Figure 3.53. When the error is more than the tolerance, the yellow trail goes out of the tunnel.



Figure 3.54. The error is not obvious enough to be noticed.

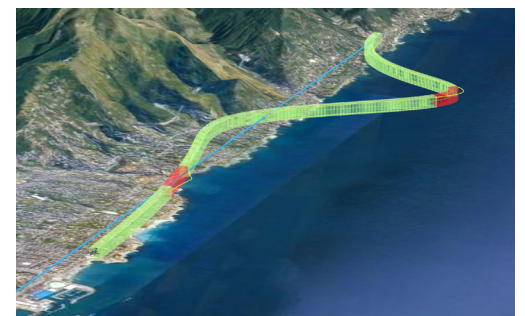


Figure 3.55. The red parts clearly show the error which is more than the tolerance.

To show the amount of error, a right triangle is drawn real-time between the real airplane and the ghost one. The purpose is to show the errors of localize and glideslope separately using the two legs of triangle. In addition, one input from the operator was that he wants to know how close the error is to the tolerance. To do so, two perpendicular lines are drawn from the ghost airplane to the boundary of the tunnel.

Because the tunnel is behind the aircraft, a front view of the aircraft is added to the concept. Toward this view, it is easier to compare the position of the ghost aircraft relative to the real one and the tunnel.

However, it should be pointed out that when the user wears HoloLens each view is tied to his head position and he can freely explore the world. The predefined views are only for making it easy for the operator to switch to his intended perspectives instead of moving/walking/turning in the real world.

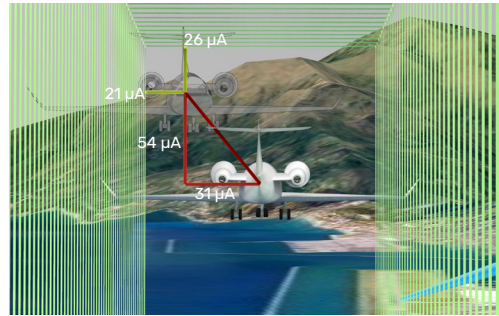


Figure 3.56. The red lines show the error and the yellow lines show how close the error is to the maximum .

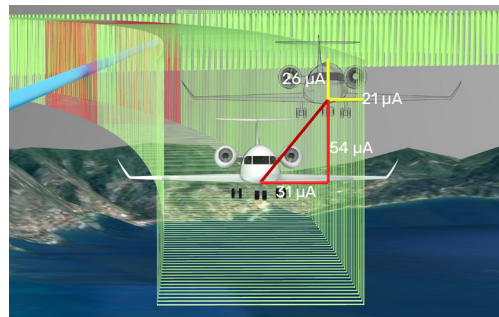


Figure 3.57. The front view is suitable to compare the error with the tolerance.

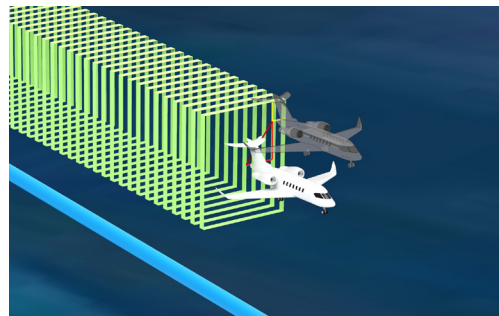


Figure 3.58. The operator can change the view freely.

3.4.4 Feedback session

The second feedback session was held with the same participants as the last time in the same setup. Here, comes the feedback:

1. The operator preferred the discrete view of the tunnel for two reasons: first, it is more consistent with the machine because the sensors have sample rates, so, the frequency of generating new section for the tunnel can be synchronized with the sample rates, second, he agreed on the better 3D perception of the discrete mode compared to the continuous one.
2. The method of showing the error and tolerance was so easy to understand that the operator realized it without any explanation.
3. He mentioned the change of color to red at the position when the error is more than the tolerance was a helpful way to draw his attention and make that event bold.
4. The new way of showing vertical and horizontal errors was satisfying to the operator and he pointed out that he does not need to switch between the top view and the side view to observe them separately. He does not need to calculate them based on the diagonal error either.

5. The director of flight inspection systems requested for two other parameters to be visually presented in the concept. They are called signal strength and alignment. These items are shown only using numeric values in their current software.

3.4.5 The third prototype

At the request of the product director, signal strength and alignment would be added to the solution in a sensory manner instead of numeric values.

Signal strength is a number that represents the quality of received signals from facilities, for example from a localizer or a glideslope. Although this parameter does not necessarily affect the measured deviation and error, being aware of its weakness would be useful for the operator to interpret the data. Signal strength should be normally more than a minimum value. The operator needs to make sure about the signal coverage along the flight path.

To represent signal weakness, the tunnel wall becomes purple in the area where this issue occurs.

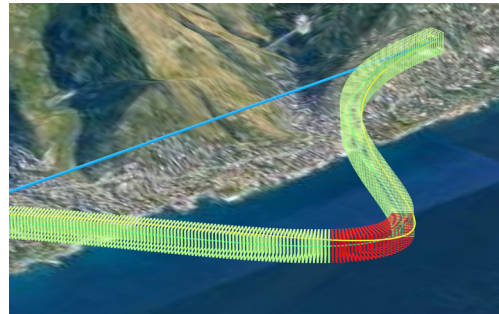


Figure 3.59. Only the nav error is shown.



Figure 3.60. The signal weakness is shown in purple.

Alignment is the amount of change that should be applied to a facility to calibrate it. This value is calculated based on the error in a specific range of the flight path, so, it can be calculated when the measurement is completely done. The alignment area varies in different aviation standards.

After completing a mission, alignment can be visualized as offsets of the

ideal path in an area. Since there are two facilities (localizer and glideslope) to define the ideal path, there will be two alignment values. The alignment of localizer is shown with a horizontal offset and the alignment of glideslope is depicted as a vertical offset of the ideal path. In addition, the area in which alignment values are calculated are shown with two planer surfaces along the path.

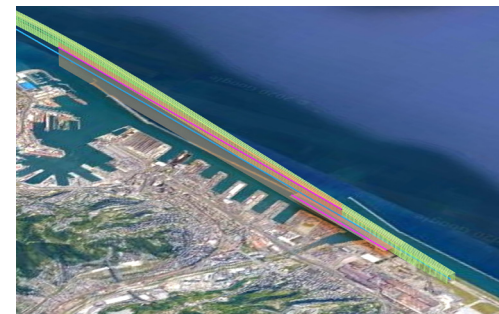


Figure 3.61. Alignment can be calculated when the measurement is finished.

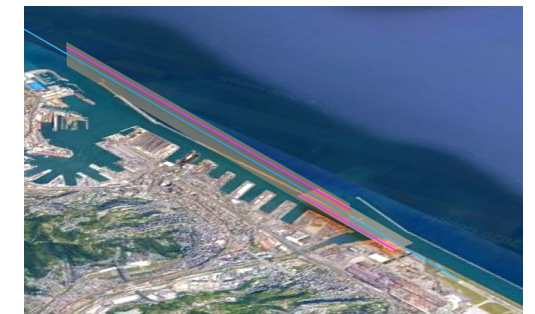


Figure 3.62. Alignment values are depicted as purple lines on the orange planes.

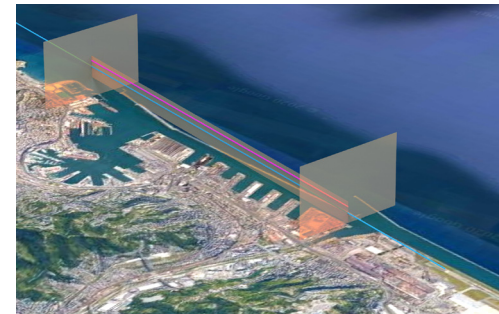


Figure 3.63. The area of measuring glideslope alignment.

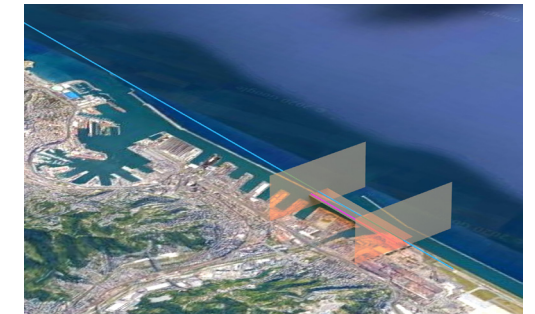


Figure 3.64. The area of measuring localizer alignment.

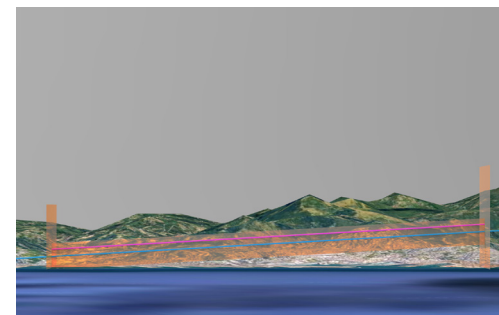


Figure 3.65. The alignment of glideslope is a vertical offset of the ideal path.



Figure 3.66. The alignment of localizer is a horizontal offset of the ideal path.

3.4.6 Expansion for airborne surveillance

Based on the structure of the solution for flight inspection, a mockup was formed for airborne surveillance missions. This model contains different features of the ideas for airborne surveillance that were discussed in the ideation chapter.

When the system starts, the operator has a tethered perspective of the area where they are flying. A key finding from the observation phase was that a mission timeline is missing in the current software. So, a mission path with checkpoints are shown over the map. During a mission, the pilot follows the path and pass through checkpoints.

The color of the rectangle indicates the types of the vessels, for example, cargo, passenger, or offshore ships.

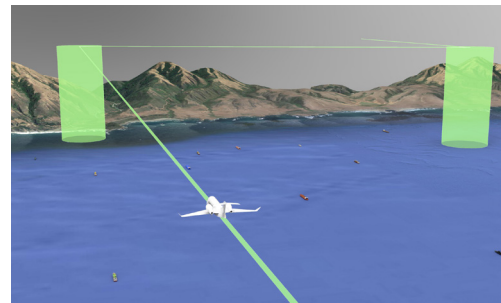


Figure 3.67. The exocentric view of the area and the flight path.

The position of the operator relative to the ocean is retrieved from the position of the aircraft in the air. When the observation begins, the operator is provided with a bird's eye view of the area where the aircraft is flying over. He can observe his surrounding by turning his head. In fact, the orientation of the camera of the aircraft is synchronized with the orientation of user's head.

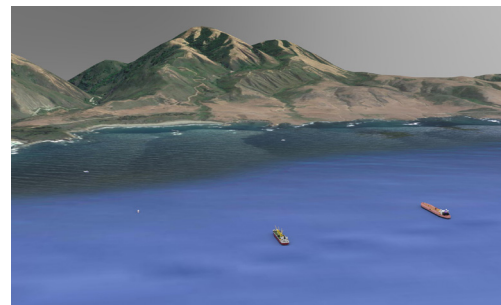


Figure 3.68. Bird's eye view.

During the flight, vessels are recognized using radar and image processing and their position and other relevant data can be captured in real-time using AIS. This technology is already being used by NSM. In the holographic view, each vessel is marked with a rectangle.



Figure 3.69. The vessels are marked based on their types.

To give operators a better perception of orientation, a 2D indicator shows the heading of aircraft and the operator's field of view relative to the orientation of the aircraft. This indicator has a north-up plan view. Choosing this orientation is based on the observation of the operator and how he is used to have this information. Also, according to Ware (2012), north-up view provides users with a reliable frame of reference for geographical data analysis and sharing this data over phone or radio link. Communication with the pilot or the technicians on the ground is a key activity of the operator. So, this

view is suitable for communication purposes as well.

To focus on a target in the current system, the operator needs to control the camera manually and zoom on it. He should do this for every target. In this concept, the only needed activity to focus on a target is to gaze at it. The gaze point is shown with a transparent circle. Since the ships' location is recognized in advance, the system recognizes when the operator is looking at a target. Moreover, the target will be marked with a contour on the indicator.

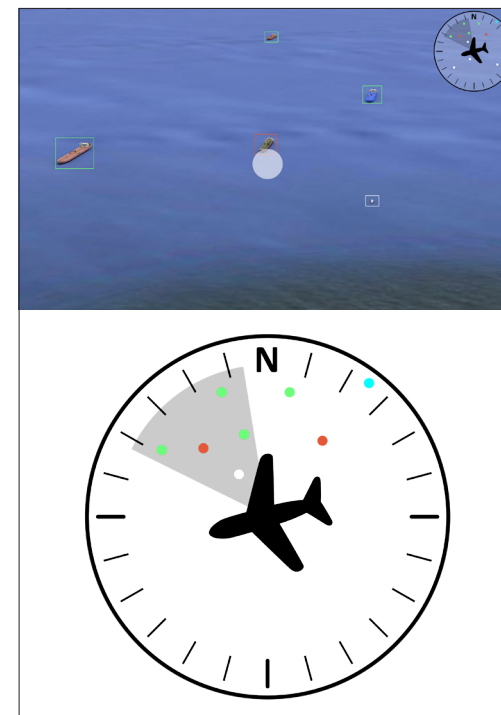


Figure 3.70. The indicator shows the orientation of the aircraft, targets, and the direction of looking.

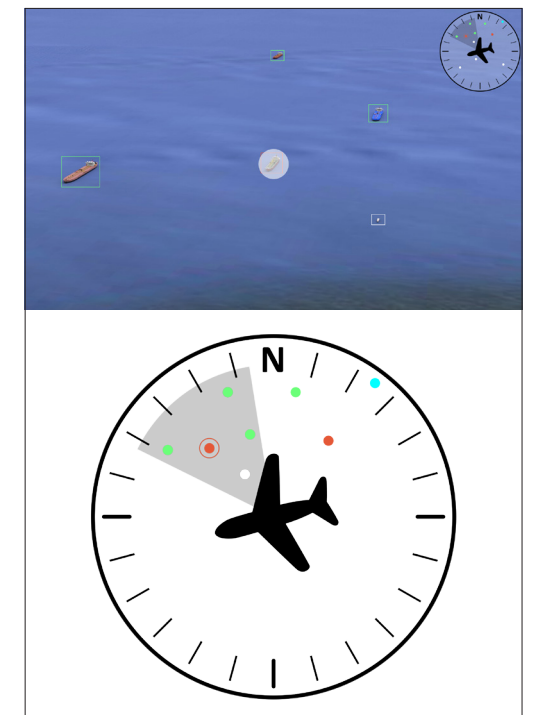


Figure 3.71. When a target is in gazed, it is marked in the indicator.

3.5 Further development

When the operator looks at a ship and selects it, a window pops up that contains detailed information and the camera view of that target. The user can switch the camera view to other lenses, such as FLIR or SLAR, and capture the photo/video of the ship. If needed, he can contact the target, as well.

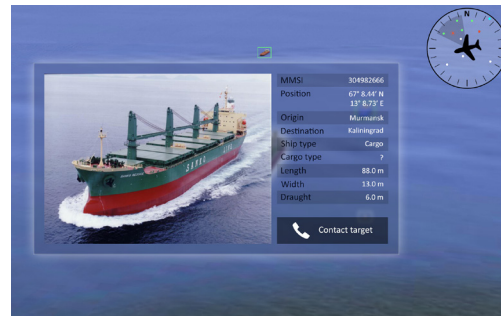


Figure 3.72. Inspection menu of the target, image of the ship by Sanko Line (2007).

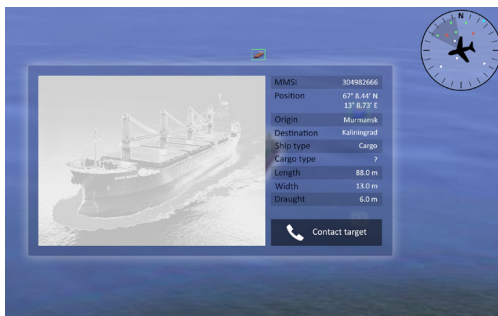


Figure 3.73. SLAR view of the target.

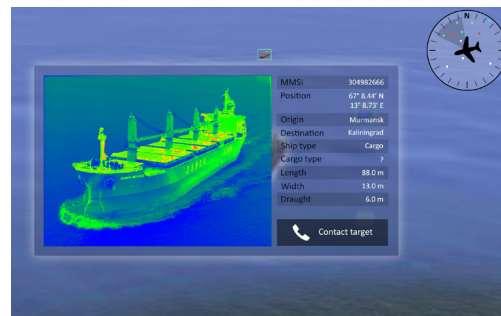


Figure 3.74. FLIR view of the target.



Figure 3.75. Capturing a photo of the target.



Figure 3.76. Recording a video of the target.

In this part, three ideas will be proposed for further development. They include an idea for communication using 3D avatars, a layout for the menus, and an input device. These proposals are based on the user research and theoretical studies done in this project, however, each of them is a large topic of its own and should be investigated and designed in detail in separate projects.

3.5.1 Communication avatars

One of the main activities of the operators in both airborne surveillance and fight inspection missions is communication using radio. They may want to switch channels, mute one voice, or increase the volume of another one multiple times during a flight.

In flight inspection, as mentioned before, the operator hears from the cockpit, tower, radar station, and technician at a facility. He can also talk to the cockpit and technicians. It was mentioned in the interview that the operator usually mutes the voice of tower and radar station in order to focus on the measurement and the communication with the technician to do the required calibration on a facility.

To make communication-related task easier and more intuitive, a new model is proposed for this AR system. People and places that can be reached out by the operator are represented as 3D models and avatars. He can find them around him as holograms at different distances. To communicate with a target, the user should pull its avatar and place it close to him. In the same way, a target is muted and disconnected when it is pushed away. In fact, the distance of the avatars to the operator is proportional to the volume of their voice. Also, the hats of avatars indicate their role. There are four different hats to represent the pilot, the technician, the coast guard, and the sailor.

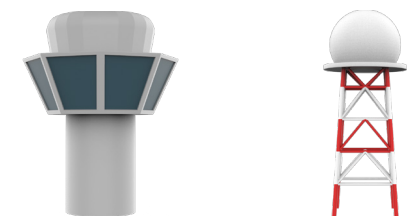


Figure 3.77. The 3D icons of ATC tower and radar station.

In airborne surveillance, the operator may need to contact a ship if he observes a questionable case or pollution around the target. He may also need to contact coast guard in order to report a target. He is always connected with the pilot, as well.



Figure 3.78. From left to right: pilot, sailor, coast guard, technician.

In a flight inspection mission, the operator finds four items floating in the air around his head. These items contain the pilot, the technician at a facility, the ATC tower, and the radar station. It was mentioned before that the operator is only able to talk with the pilot and the technician. This is the reason for representing these two items by man's head while the other ones are objects.

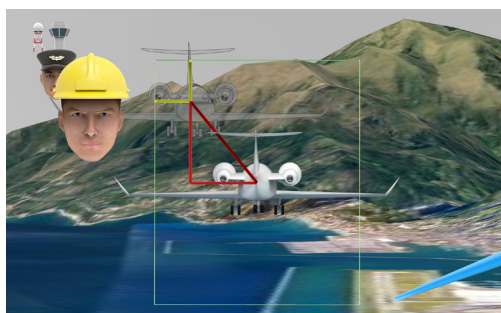


Figure 3.79. The operator is talking with the technician.

In airborne surveillance, the operator always has the pilot's avatar. In addition, an avatar for coast guard is available but at a distance. If he wants to contact the coast guard, he should select that avatar to call, then, it comes closer. Also, if the user contacts a ship, a sailor avatar will appear.



Figure 3.80. The operator has contacted the vessel.

3.5.2 Menu

For this concept, like any other user interface, it is required to have menus for functions including system setup, mission planning, etc. Here, there will be some ideas inspired by the available AR and VR software and games. Then, a model will be recommended for further investigation.

The first group of ideas are about mapping menus on the user's hand:

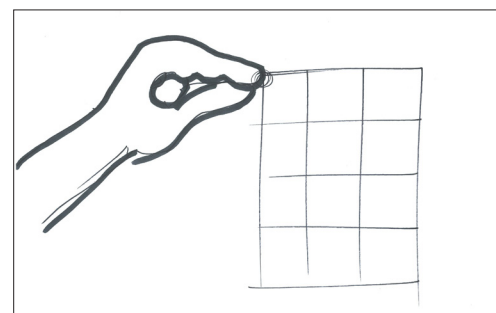


Figure 3.81. To open the menu, the user should do a gesture like in the sketch.

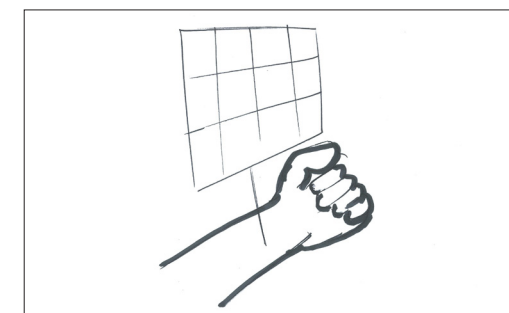


Figure 3.82. The menu will appear if the user looks at his left wrist, similar to the start menu in HoloLens 2.

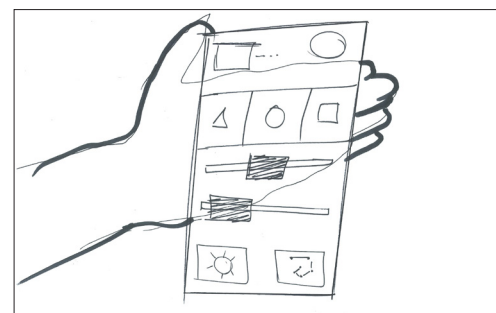


Figure 3.83. The menu is visible when the user gazes at his left hand.

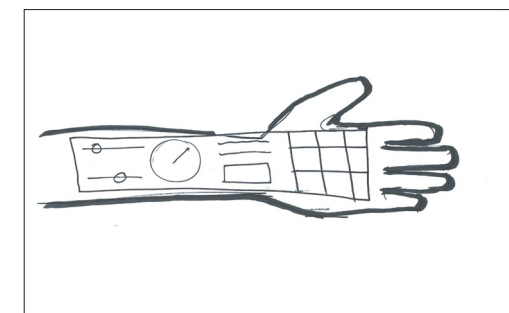


Figure 3.84. The main menus are on the palm and the sub-menus are shown on the forearm.

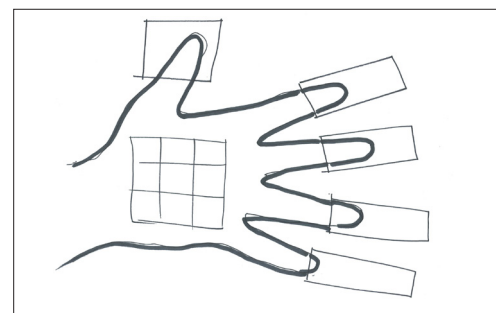


Figure 3.85. The main menus are mapped on the fingers. Tapping each finger opens its sub-menus on the palm.

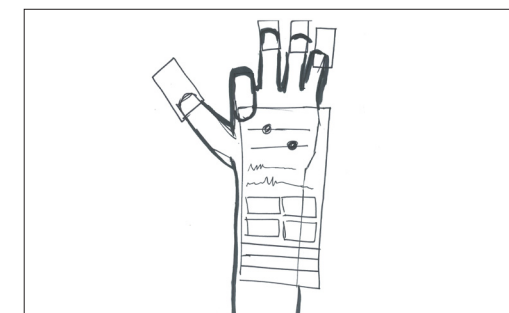


Figure 3.86. The main menus are mapped on the fingers. Bending the fingers open the sub-menus.

These ideas will be different shapes of menus floating in the air:

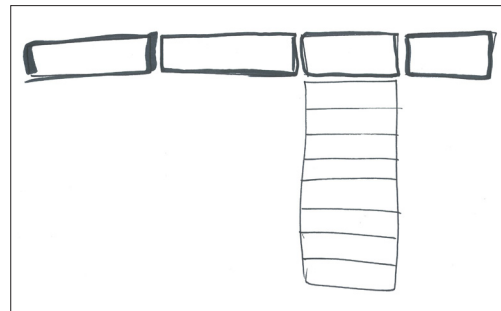


Figure 3.87. The main menus are in a row. They work like drop-down menus.

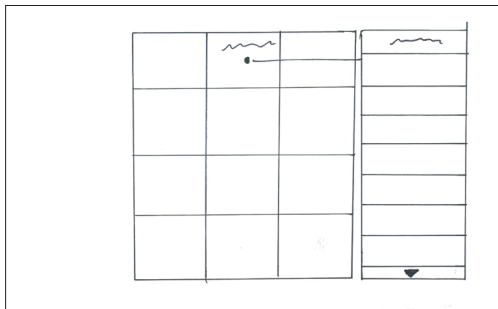


Figure 3.88. The main menu is like a matrix. The sub-menus are shown as a list.

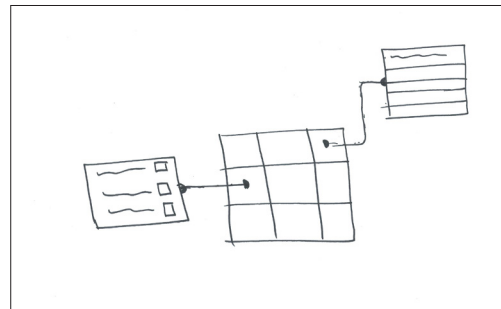


Figure 3.89. The main menu is like a matrix. The sub-menus are shown with a line connected to their parent.

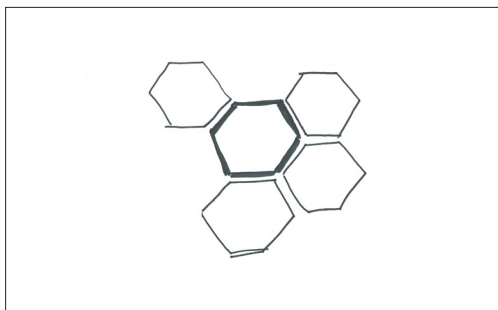


Figure 3.90. The sub-menus are shown on the sides of each cell.

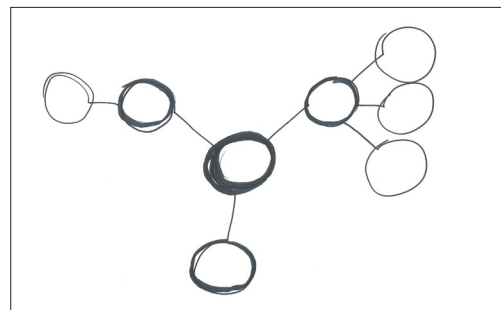


Figure 3.91. The sub-menus are shown as branches of the main menus.

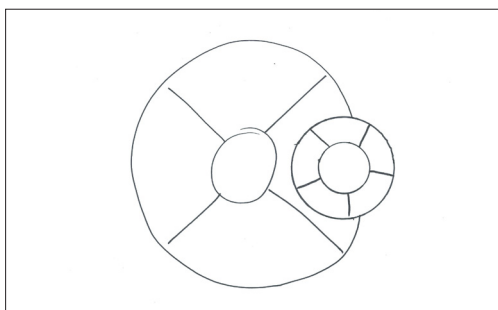


Figure 3.92. The main menu has a radial design and sub-menus are mapped on the sectors.

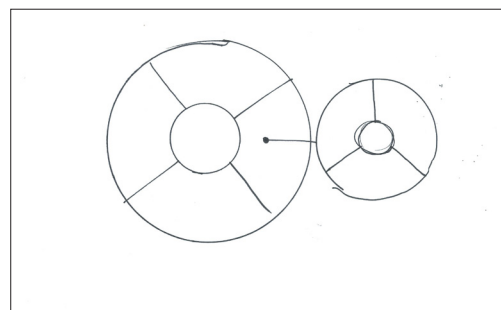


Figure 3.93. The main menu has a radial design and sub-menus are linked to their parent.

According to Spillers (2020), radial menus are suitable options for many immersive UIs. They have been used in various AR and VR systems. These menus are usually located in the center of view so that the users can focus on all items. Besides, an important consideration in the design of menus is Fitts's law and the required time to reach an element. Based on this criteria, radial menus are better choices than lists and matrixes.

Furthermore, radial menus make less probability of error in selecting an item, because each item has only two adjacent elements while in a matrix each cell is surrounded by at most eight other cells.

On the other hand, gesture-based menu systems may cause fatigue in the muscles. Also, the user loses his attention to the mission data while he looks at his hand.

Based on mentioned criteria, the radial structure would be proposed for this concept. However, as said before, this needs to be developed further and evaluated by the users.

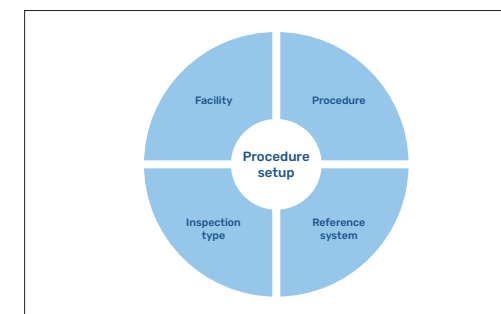


Figure 3.94. An example of pie menu for procedure setup in flight inspection.

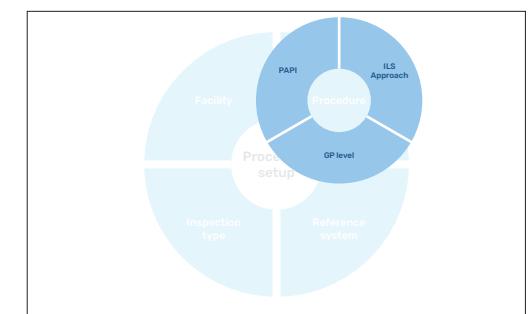


Figure 3.95. Sub-menus are centered to their parent menu.

3.5.3 Input method

With virtual and augmented reality devices, it is possible to have new methods of giving input to computers, for instance, gaze and gestures. However, AR/VR devices still come with a sort of hand-held input device. Microsoft HoloLens is paired with a clicker; Oculus devices are delivered with a touch controller; HP Reverb has its controllers; and Magic Leap comes with a space controller. So, why do the major manufacturers still use physical input devices? There are studies that answer this question.

According to Attwenger (2017), gestures create problems that are not relevant to typical input methods, namely, the need of learning and memorizing them. This also results in a need of manuals to increase discoverability and memorability of these gestures and deal with input and recognition errors. In addition, gestures cause fatigue since more muscles are involved in executing them. Therefore, gestures themselves become an object of design that should be quick and comfortable to perform.

Technology limitation is another reason for inefficiency of gesture interactions. The limited working area and the inaccuracy of hand tracking systems affect the user experience and do not allow them to interact as naturally as they do with traditional input methods (Alkemade et al., 2017).

This issue was also visible in the testing phase of the AR concept that I developed for NSM in the summer of 2020. To interact with the AR content, the test users had to tap on them in the air. This task was difficult for all participants at first because the gesture must be done exactly in the way that was defined to the system. Also, the users had to hold their hands in a specific area in front of the headset sensors. As a result, I had to explain and train the interaction to them and they could not do it intuitively.

In another study by Van Beurden et al. (2012), it was observed although embodied interactions bring higher hedonic quality and fun in comparison to device-based interactions, they increase body fatigue. As well, they score lower in perceived performance and pragmatic quality.

Based on the studies, my own test, and the fact that the pioneers in this industry like Microsoft, Facebook (Oculus), HP, and Magic Leap deliver their solution with a type of physical controller, It is decided to have a physical controller to interact with this AR solution. The design of this controller is based on Microsoft Clicker, but changes have been made to improve it for this specific solution.

Clicker has a single click function that can be used instead of air tapping with index finger. So, users should look at an object and keep the gaze on it, then, they can click. After recognizing the required functions for flight inspection and airborne surveillance, it was understood that having only one button would not sufficient for this system. Therefore, it was decided to replace the click function with a joystick. A joystick provides us with six possible functions: up, down, right, left, click, and long click. These items will be used for different purposes in the two types of missions.

In flight inspection, to zoom in and zoom out in different views, the user should push the joystick down and up respectively. In addition, the right and left directions can be used for switching between different views. In airborne surveillance, the operator can select a target by clicking while he gazes at it. In the target window, he can zoom in and out by tilting the joystick down and up. To switch between different lenses, he should

push right or left. If he clicks on the camera view, a photo will be captured and if he clicks long, the system starts to record video.

In both systems, the user should gaze at the avatars to Control them. He can push or push them using the up and down directions of the joystick while gazing at them.

To open menus in both systems, the user can long click on any place in the view. Then, he can gaze at the items and select them by normal clicking. Also, when a sub-menu is open, pushing the joystick toward left closes the sub-menu.



Figure 3.96. Clicker for HoloLens.



Figure 3.97. Idea of the joystick based on Clicker.

CHAPTER FOUR

Reflection



4.1 Design process

In this project, the Delft innovation model was combined with a user-centered design approach. The Delft model was suitable to identify the position of the firm and define strategic plans for them. The business-related and strategic considerations of this model helped with concluding a design brief that complied with the company's capabilities and the market situation.

When it comes to designing the solution, the user-centered model is a necessity, because the solution should answer the users' demand. Involving the users, in this project the engineers and the operator, in the ideation and creation process resulted in a clearer insight into their mental model, and finally, an idea that was desirable to them. Furthermore, iteration, which is a key characteristic of this model, was effective to improve the solution to an optimal level that fulfills the users' expectations in the best possible way.

4.2 Solution

Although the solution may look incompatible with today's aviation standards, it can still be beneficial for NSM in different aspects. In combination with their current mission system, this concept lets them shrink the size of the system, because the displays can be removed, so, the whole system takes less space in an aircraft. Moreover, it was mentioned by the R&D director that even if the concept is not implemented in operations in the near future, it is still useful for the operators to review and analyze the mission data after a flight.

Furthermore, the concept will be definitely advantageous for the future drone-based mission system. AR lets the user get an immersive sense of being in the air even though he is on the ground. The immersion provides him with better control over the drone and more awareness about the causes of the changes in the signals.

This solution would also be fruitful for implementing the ADA service-based business. The customers can rent and get control over a drone using a holographic headset for a period of time.

However, there is still a lot to do to create a real functional software out of this concept. During the process, the activities were mostly focused on information visualization. This was not planned in advance, but a necessity

for developing a viable solution. To implement the concept, it is required that all elements of the concept, for example 2D menus and the input device, be precisely and independently designed in individual projects.

4.3 Visual quality of the prototype

The rendered scenes of the prototype may look similar to dated games. This is due to the limited computing power that I had access to. In fact, what I expect the solution looks like, is a realistic 3D space like what is done in the latest version of Microsoft Flight Simulator.

Given that HoloLens can work as an AR display for a normal Windows PC, the software can be run on the central computing unit of the mission system in the final solution. The main unit is powerful enough to render the high-quality scenes and stream it on the HoloLens. In this way, the limited graphical processing power of the HoloLens is overcome.

4.4 Test conditions

The testing phase was not performed as predicted in the planning phase. When, the project was planned in the summer of 2020, I did not expect COVID-19 restrictions to last as long as they have and prevent meeting the users in person. Unfortunately, the restrictions did not allow me to do real tests. So, the remote feedback sessions were the only possible ways to get their comments on the concept. Although every attempt was made to simulate and present the idea for them in the best setup, the results are not as reliable as the results of a real test. The ideas must still be tested with the operators when the restrictions are lifted. Besides, the usability of the proposed input device needs to be tested while testing the concept.

4.5 Collaboration with NSM

Working with NSM was an educational experience. It allowed me to test my theoretical knowledge in the real business environment and learn how to deal with multifaceted problems caused by multiple factors, including human needs, business context, and financial considerations. In addition, it was a great opportunity for me to expand my design knowledge to a field that may look too technical for designers.

Also, people at NSM have been really open to my ideas despite the conservative mindset imposed by aviation authorities, which is understandable given the dangerous nature of aviation and the strict regulations that are required to render it safe. They were always supportive and eager to participate in the process and their guidance was so helpful to me when I struggled with understanding the very-technical concepts of their job.

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