UiA University of Agder

Master

Design of a VR application for pilots as a complementary tool for procedure training of Abnormal Operations

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Abstract

The aviation industry has been amongst the early adopters of VR for educational purposes, even since the very beginning of VR's technology establishment and throughout its further development. Flight simulators are invaluable as they let pilots and instructors replicate any situation for learning full control over the plane and improve situational awareness without paying the price of life-safety if using an actual aircraft.

Abnormal operations and their procedures are a key subject of safety training, where pilots have to understand and memorize particular orders of actions in order to solve a dangerous situation on board. A typical flight simulator emulating a pilot's cockpit might reach the price of 4.5 million $ or more. This Master's thesis investigates the feasibility of implementing a procedure trainer of abnormal operations for commercial pilots as a complement using low-cost VR equipment such as the Oculus Quest 2 with the Airbus A320neo cockpit as a reference.

The virtual learning environment has been developed in cooperation with Applica Training Systems AS and been tested on pilots and pilots' training manager for its usefulness, acceptance, and usability

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The subjects and projects I took part in at the university challenged me to push my own boundaries for new achievements that I could not think of before. With the stable base of such important knowledge and skills that I got here, I plan to continue learning and improving.

Nicole Shevchenko
Grimstad, 2021

Contents

List of Abbreviations

VR - Virtual Reality
HMD - Head-mounted display
VRLE - Virtual Reality Learning Environment
VE - Virtual Environment
ATS - Applica Training Systems AS
NAS - Norwegian Air Shuttle
APC - Abnormal Procedures Checklists
NNPC - Non-normal Procedures Checklists
CBT - Computer-based training
HCD - Human-centred design

1. Introduction

The aviation industry has been amongst the early adopters of VR for educational purposes, even since the very beginning of VR's technology establishment and throughout its further development. For over 80 years, VR features allowed the implementation of full-motion flight simulators that have become indispensable useful tools in pilots' education. (Lee, 2005) Flight simulators are invaluable elements in the aviation industry as they let the pilots and instructors replicate any situation for learning full control over the plane and improve situational awareness without paying the price of life-safety if using an actual aircraft. (European Helicopter Safety Team, 2015)

Nevertheless, there are challenges related to getting, maintaining and exploiting the flight simulators. For example, one unit of a flight simulator, representing a pilot's cockpit, might reach the price of 4.5 million $ or more. In comparison, a VR unit with artificial intelligence and advanced biometrics requires an investment of only $1,000 (Prokopovič, 2019).

There have been numerous discussions about the advantages of using VR Head-mounted displays (HMD) with controllers in workforce education and training. In addition to the cost efficiency, VR is not less immersive than the flight simulators, it provides opportunities for ubiquitous learning and it is easily accessible for training. (Carruth, 2017), (Vora et al., 2002).

This Master thesis investigates the feasibility of implementing a procedure trainer of abnormal operations for commercial pilots developing the solution and its instructional design in a virtual reality learning environment (VRLE), using the Airbus A320neo as a reference. It also discusses the efficiency of combining specific principles of cognitivism and connectivism learning theories, enhancing pilots' memorizing process and contributing to the safety studies in aviation. It proposes the advantages of using the VR application as a complementary tool for procedure training of abnormal operations.

1.1. Background

This Master thesis is a research project in collaboration with the company "Applica Training Systems AS", located in Kristiansand, Norway. The main focus of the company is to deliver affordable competence and e-learning solutions, websites, presentations-, 3D modelling- and animations for different industries. (Applica Training Systems, 2019)

This Master's thesis is a combination of practical experience of project development for the company's clients and academic research on VR utilization in pilots' procedure training. The idea of developing a VR solution for providing the pilots with the training of abnormal operations' procedures comes from an already existing 2D version of the trainer used by Norwegian Air Shuttle (NAS) Academy. The current 2D trainer is relevant to the Boeing 787 Dreamliner, one of the aircraft models belonging to NAS. The 2D visualization of the cockpit

is available for pilots to go through the non-normal procedures checklists and reinforce their knowledge using PCs or tablets. The VR platform is considered to be an innovative and engaging solution, providing a full immersion and presence in the cockpit, changing the experience of pilots' training. It might have a useful potential for this particular aircraft and other aircraft with suitable non-normal procedure checklists too.

1.2. Problem Statement

According to the International Aviation Safety Association (IATA), nowadays aviation is as safe as it has never been before and each day it is getting safer (IATA, 2019). Research shows that flying is the safest form of long-distance transport in the world (Massachusetts Institute of Technology, 2020).

Safety on the plane is maximized, when the crew is coordinated with the main standards and follows certain procedures. (U.S. Department of Transportation, 2017) Such procedures are usually organized into checklists in order to clarify and structurize required manipulations for particular situations during the flight.

As stated in Boeing Technical Journal (Higgins, 2016): "*Boeing pilots and other aviators in flight operations have used checklists for more than 75 years. ... Incorporating checklists in high hazard environments has been one of the most influential innovations to enhance safety. Using critical checklists, ..., could provide a safety interface between high hazard processes and potentially devastating results.*"

The checklists that are meant to be followed during the emergency situations are called Abnormal procedures checklists (APC) or Non-normal procedures checklists (NNPC). Nowadays, APC for civil aviation is usually represented in paper or electronic formats. They might be also represented as a part of the exploration of a dangerous situation replicated in a flight simulator, however, without an opportunity for a pilot to go over it again and with multiple tries, due to the limited accessibility of a flight simulator and instructor's time (Nählinder, 2009)

Commercial pilot licensing requires a minimum of 250 flight hours, including up to 30 hours in a flight simulator in order to advance pilots' practical skills (European Aviation Safety Agency, 2016). Nevertheless, these hours are aimed at various practical subjects, not only abnormal procedures. Even though emergency situations do not occur during every flight, it is vital to make sure that the pilot keeps the memory items of APC up to date, which also requires regular training. Current learning sources such as handbooks, paper simulators or 2D trainers on a tablet or PC screen are useful tools, though these are missing the experience that VR platforms might provide. VRLE lets the students involve their body memory, to acquire or reinforce the knowledge, improve their psychomotor skills. It might be beneficial when in critical dangerous cases and under stress conditions, the pilot has to recognize the abnormal case or a combination of abnormal cases and accomplish the required solution faster. In this case, it is important to give the pilots an easily accessible training platform that would let

them recall the memory items and provide them with an improved training process of APC at any time it is needed.

VRLE that would focus just on APC memorizing and training would presumably benefit pilots safety studies, however, it requires research and experiment to prove that.

1.3. Research Questions and Hypothesis

Based on the provided problem statement the research questions and hypothesis are the following:

Research questions

- What is the design solution for developing a VR learning environment for training pilots abnormal operations' procedures?
- How to design effective instruction of abnormal operations' procedures for the Airbus A320neo cockpit on a VR platform?
- Which advantages does VR imply for procedure training of abnormal operations?

Hypothesis

A standalone VR provides an engaging learning environment for more efficient and practical knowledge reinforcement of abnormal operations' procedures for pilots.

1.4. Scope

This Master's thesis is aimed to develop a VR solution for effective abnormal operations procedure training. Therefore, the cockpit of an aeroplane will be implemented in 3D and placed onto a VR platform. Based on the previously developed 2D procedure trainer by ATS, the plane's model Boeing 787 Dreamliner will be used as one of the references, however, due to the changes in NAS (Berglund, 2021), an alternative plane will be in the main focus too - Airbus A320neo. Due to a variety of procedure checklists' length and complexity, only one procedure checklist will be chosen for implementation within the time limits, personal capacity and availability of pilots for usability-testing: "A320 Engine failure during cruise" (Airbus Industrie, 2015). The project will let a pilot, using a VR headset, be immersed in the cockpit and interact with relevant procedure elements on the cockpit's panels. The idea is to develop an intuitive learning environment, applying selected aspects of cognitivism and connectivism theories, in order to improve memorizing processes for pilots.

At the beginning of the research, the main focus was aimed at developing a smartphone-based VR, in addition, using Bluetooth controllers for interaction opportunities. However, due to the sufficient loss of popularity of smartphone-based VR (Robertson, 2019), the research and project development have been redirected to a standalone VR solution with the controllers included in the package. Even though a smartphone-based VR has such advantages as cheaper availability and a simple setting-up process (vr-innovations.nl, 2021), a standalone VR provides a more advanced and higher-quality experience without a need to

explore the Bluetooth controllers' market and experimenting with various devices compatibility.

1.5. Thesis goals

This thesis investigates the feasibility of placing abnormal operations' procedure training into a VR learning environment (VRLE), using a standalone VR platform, as well as its practical potential for future use as an additional tool for pilots' knowledge reinforcement. Therefore, one of the goals of the project is to develop clear design guidelines for standalone VR application implementation, considering user and technical requirements. Furthermore, the intended design guidelines should be flexible for application on other aircraft models' cockpits, as procedures are different for each plane type. The developed design guidelines should enhance memorizing processes and correspond to several key elements of selected learning theories.

Besides, the developed VR solution should be intuitively easy to set up for future users and it should consider an additional pedagogical approach providing a tutorial about how to navigate in the VR application.

Finally, the VR solution for abnormal operations' procedure training should approve its usefulness potential, by collecting the positive results and feedback from the conducted research.

1.6. Constraints and Limitations

Considering that this Master's thesis is developed in collaboration with ATS, there is a confidentiality agreement that has been signed by both sides. The agreement protects data provided by ATS, and the same data has been previously received from NAS, meaning that the researcher should not share it with any third parties further, as well as not publish any information from that data, including this Master's thesis too. In this report, there are mentions of NAS academy as a reference for some of the procedure trainer elements' development, due to the confidentiality agreement the link to the source or visual examples can not be provided.

The researcher has agreed with ATS and supervisors on keeping a balance between deployment and academic research during this Master's thesis development, as the VR solution is aimed to satisfy particular customers' needs, which might affect the work's direction on the thesis' research.

COVID-19 pandemic has affected society and employment, causing various challenges and crises. The aviation industry is amongst those who have gotten into a hard crisis state, cancelling up to 85% of their commercial flights and laying off up to 7300 employers of all kinds of positions (Solsvik, 2020). As a consequence, the reduced amount of HR makes it

very challenging to reach the target audience that is needed for interviews, usability testing and as general sources of information.

In addition, COVID-19 requires following careful hygiene rules and social distancing, which makes it challenging to conduct testing of VR solutions, using a VR HMD on a wide target audience. Not everyone has a personal standalone VR HMD, so these challenges shorten the number of participants available for providing the highly accurate results of testing possible.

1.7. Thesis outline

Following the introduction part, the literature review presents state-of-the-art VR's educational advantages and its utilization in the aviation industry. The 2nd chapter presents learning theories that apply to this project's instructional design, as well as introduces the readers to the potential contribution of VR's technology in abnormal operations' procedure training. The next chapter discusses the methodology chosen for solving the problem statement, considering the target audience's requirements, limitations and availability. The 3rd chapter describes the process of planning the project's solution development applying the Human-centred design approach. Further, the thesis provides an insight into the production phase, usability testing settings and progress. It investigates the usability of VR solutions from different perspectives, before the 5th chapter analyzing results and forming the findings into conclusions. The last chapter of the thesis summarizes the conducted research and veracity of the hypothesis, adding the recommendations for further VR pilots' trainer development, based on gained experience.

Figure 1.1. "Cockpit of the Airbus A320neo", 2021, CSG aerospace a.s (https://csgaerospace.cz/job-air-technic-started-type-training-for-airbus-a320-neo)

2. State-of-the-art

2.1. VR for training pilots

Virtual Reality (VR) is a computer-generated digital environment that lets its users experience and interact as if it was a real environment, creating an immersive experience. (Jerald, 2015) It is a 3D artificial world operated through devices, sensible to the effects of sight, touch, movement, and hearing (Ki, 2011). The VR device adapts and reacts to any changes according to the user's location and performing activity (Viseu, 2003), (Bower, 2015)

The exploration of VR development started in the first part of the 20th century, with the advent of electronics and computer technologies. People kept on advancing the illusion of presence, initially meant for entertainment and understanding the sense of depth using the stereoscopic approach (Virtual Reality Society, 2017). Nevertheless, the scope of VR utilization has been continuously increasing (Ki, 2011). Nowadays, VR technologies have been successfully deployed in various industries such as oil and gas exploration, scientific visualization, architecture, therapy, flight simulation and many others (Jerald, 2015)

One of the early breakthroughs of VR technology development is considered to be the first flight simulator, developed in 1928, by Edwin A. Link. It is also shown in Figure 2.1.

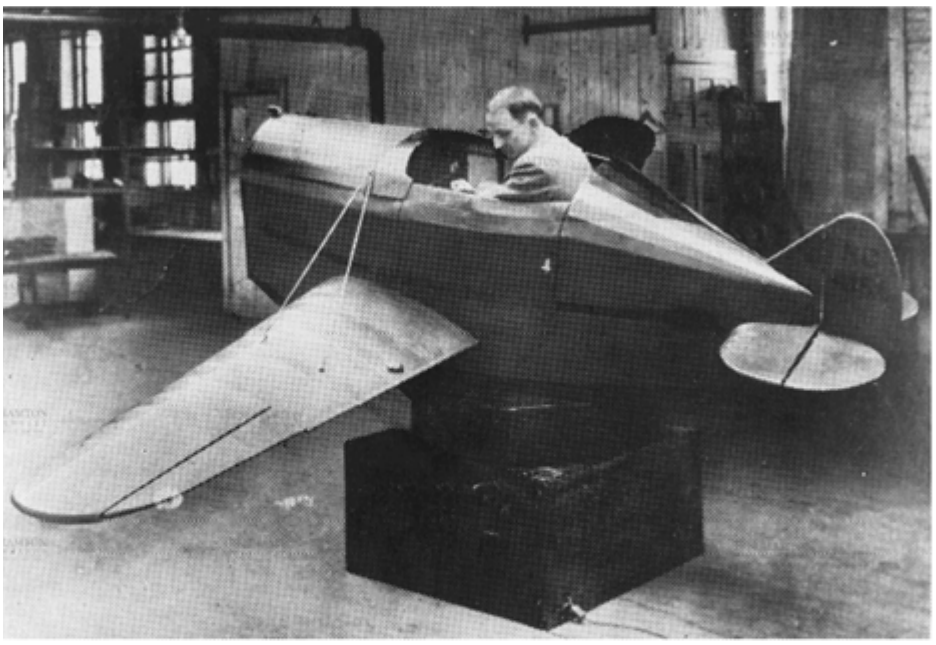

Figure 2.1. "Edwin A. Link and the first flight simulator", 2015, Jerald.

Even though it is not fully immersive, in comparison with modern times, the first flight simulator included the cockpit with controls that produced the motions of flying. In the period between 1935 and the end of World War II, there were around 10 000 such systems sold to the Army Air Corps (Jerald, 2015).

In 1968, the first VR Head-mounted display (HMD) that was connected to the computer was invented by I.Sutherland (Virtual Reality Society, 2017). Further on, from around the 1980's, with the rapid growth of computer power, the flight simulators' development started to progress significantly, improving the virtual environments and involving innovative approaches for the pilots' training (Lee, 2005). For example, the computer-based training (CBT) enhanced the use of VR HMD's and other devices, bringing new changes and standards to the aviation industry (Wen, 2014).

In the 21st century, the flight simulators employ the VR HMD's as complementary tools for training particular subjects (Weirauch, 2020). Nevertheless, there are discussions ongoing that the VR has even more potential and not all of its functionality is yet used (Ellis, 2019). Traditional civil aviation training is lacking in both media and tools, so the application of modern CBT promises to become more popular in the civil aviation industry (Wen, 2014)

Below is a brief overview of VR utilization's examples in the commercial pilots and cabin crew training:

- Lufthansa Aviation Training and its first VR Training for cabin crew practicing the safety-related state-of-the-art virtual courses. It is planned to expand the general VR training to other areas of cabin crew training too. (Lufthansa Aviation Training, 2019)
- KLM Cityhopper's VR training for pilots flying Embraer 175 and 190 aircraft that includes three applications: Virtual cockpit, Instruction video and Virtual walkaround (DFLY.no, 2021).
- The European Union Aviation Safety Agency (EASA), as of April 2021, has granted the first certificate for a VR based Flight Simulation Training Device with an application that lets the pilots train and conduct high-risk training operations and manoeuvres, critical training scenarios (European Union Aviation Safety Agency, 2021).
- Center Air Pilot Academy (CAPA) accepted the VR based procedure trainer by VRflow for the Boeing 737 in February 2021 (Andersen, 2021). The use of the trainer is presented on Figure 2.2..

There are more VR simulators, available for public access, marked with their realism and technology of a good quality, such as AeroFly2, X Plane 11, Microsoft Flight Simulator X, however, these are not amongst the complimentary tools for pilots training (Ellis, 2019).

Even though aviation adopted the VR for attempts to include it in pilots' training almost at the beginning of VR technology development, according to the state-of-the-art, the VR HMD-based applications still have not been established as traditional tools for training.

The key benefits of VR in pilots training

There was multiple research conducted on the potential and benefits of using the VR technology in pilots training. Amongst the main advantages is that VR allows trainees to practice without any risks involved (Hussein, 2015). Pilots are getting ready to manage potentially dangerous manoeuvres of extreme conditions, while still remaining in a safe environment. The high sense of immersion that VR HMD's system provides, replicates real-life scenarios, which is very effective and the training can be conducted multiple times based on the pilots' needs (spinoff.nasa.gov, 2018). Besides the personal safety of pilots, the VR preserves from damaging an actual aircraft when the pilots or the cabin crew would attempt to detect certain issues, during the aircraft maintenance training (Velichko, 2019).

The Full-flight simulators (FFS) also provide a fully realistic immersive training, however, the equipment is very expensive and is not flexible for booking by the pilots' request. The training approach, involving VR, will generate cost savings - it cuts down on the number of external suppliers and makes pilot scheduling more accessible and convenient (DFLY.no, 2021). According to P.K. Arban & S.M. Doherty (Arban, 2006): *"Since it is not economic or realistic to allow airline pilot trainees to have access to study in actual airplanes, they must rely on simulators to show where switches and displays are located in the cockpit. Due to the fact that the simulators that many Airlines typically cost hundreds to thousands of dollars to run, it then becomes essential to have a simple, inexpensive alternative which can still have the effect required to ensure trainees learn the procedures required."* (Tobin, 2013).
As stated in (Grimshaw, 2013): *"Virtual worlds are a natural extension of the diverse and evolving family of simulators."* In addition, Europe's aviation regulator considers that the pilot instruction and operational safety could be improved by using devices less sophisticated than a full-flight simulator (Kaminski-Morrow, 2021).

Figure 2.2. "Pilots training in VR, using VRflow trainer", 2021, Andersen. (https://vrpilot.aero/vrpilot-delivers-virtual-reality-based-procedure-trainer-for-b737-to-center-air-pilot-academy/)

One more benefit in VR learning is considered to be a high degree of personalization of the learning process, which enhances the motivation and engagement in achieving the educational goals. According to Cordova, Lepper & Rieber, it arises from the ability of learners to make their own choices within the environment (Cordova, 1996) (Rieber, 2005)

Exploring the training in VR lets the trainees also learn more about the aircraft systems, the processes that happen in the background and are not visible directly in real life. For example, in the training context, it might allow the individuals to "see" structures inside a fuel system. Trainees could learn more about the function of an aircraft fuel system via HMD, which would potentially increase an individual's knowledge (O'Neil, 2000).

Abnormal operations

In the aviation vocabulary, there are multiple terms applicable as synonyms to define the unplanned cases, happening on board. However, some of them have differences:

- Abnormal operations & Non-normal operations - also, emergency situations; *"An abnormal situation is one in which it is no longer possible to continue the flight using normal procedures but the safety of the aircraft or persons on board or on the ground is not in danger."* (skybary.aero, 2019).
- Abnormal procedures & Non-normal procedures - the order of actions that is needed to be undertaken to solve the abnormal situation;
- Abnormal procedures checklists & Non-normal procedures checklists - *"A handbook containing checklists of actions which are the initial response element of Emergency and Abnormal procedures."* (skybary.aero, 2019).

According to the European Union Aviation Safety Agency (EASA): *"Each flight crew member shall be periodically checked to demonstrate competence in carrying out normal, abnormal and emergency procedures."* (baatraining.com, 2020).

Traditionally, the procedure of the abnormal operations studies can be described as following:

- During the simulator training, in a particular amount of time, the abnormal operations or malfunctions of the aircraft are presented to a pilot in series. However, the flight crews don't get to practice all of them, only the most critical ones, that require memory items or the very common ones (Civil Aviation Authorit, 2014). *"The crews are often not allowed to see a situation through to its completion before the simulator is reset and the next system malfunction is presented, thus, the degree to which training truly reflects real life emergency and abnormal situations, with all of their real-world demands, is often limited."* (Burian, 2005).

2.2. Learning theories in VR

According to (Fussell, 2020), VR is beneficial for training on repetitive tasks to positively enhance and involve visual-spatial skills, psychomotor skills, cognition, memory, and

emotional responses. Actively participating in an action, making concepts intuitive, encouraging motivation through engaging experiences, and the thoughts inside one's head all contribute to a better understanding of the learning materials (Jerald, 2015).

Further the learning theories relevant to VR, their main principles that will be applied to this project research are described.

Cognitivism

Cognitivism is a learning theory that emphasizes the active involvement of the student in the learning process and the importance of the environmental conditions (Ertmer, 2013). The focus is aimed at the inner mental activities, such as thinking, memory, knowing, and problem-solving (learning-theories.com, 2020). The active involvement of the learner implies the learner's own control over the process: self-planning, monitoring and applying revising techniques (Ertmer, 2013).

Cognitivism enhances the development of meaningful learning. It means that the learner is capable of acquiring new information and relating it to past experiences. The cognitive learning approach teaches to build transferable problem-solving skills that can be applied in other areas (valamis.com, 2020).

In order to develop a cognitivism-supported learning environment, it is practical to include instructional explanations, demonstrations, illustrative examples and matched non-examples for guiding the student's learning (Ertmer, 2013).

With modern technologies' development, another cognitivism-related theory might be applicable to the research: the principle known as the "multimedia principle", which states that *"People learn more deeply from words and pictures than from words alone"* (Mayer, 2009). The cognitive theory of multimedia learning is described by R.Mayer, it explains that the brain does not interpret a multimedia presentation of only words, pictures, and auditory information, it selects and organizes the information dynamically to produce logical mental constructs (learning-theories.com, 2020).

Bloom's taxonomy and Psychomotor domain

Bloom's taxonomy is a classification of learning outcomes and objectives in the hierarchical pyramid, as on Figure 2.3.. (bloomstaxonomy.net, 2021). However, the pyramid might be explored further and each of the levels can be divided into three domains: cognitive, affective and psychomotor (University of Waterloo, 2021).

The research is focused on VR technology, where the application of physical motion is one of the core aspects and purposes for the whole experience, therefore the psychomotor domain is reviewed.

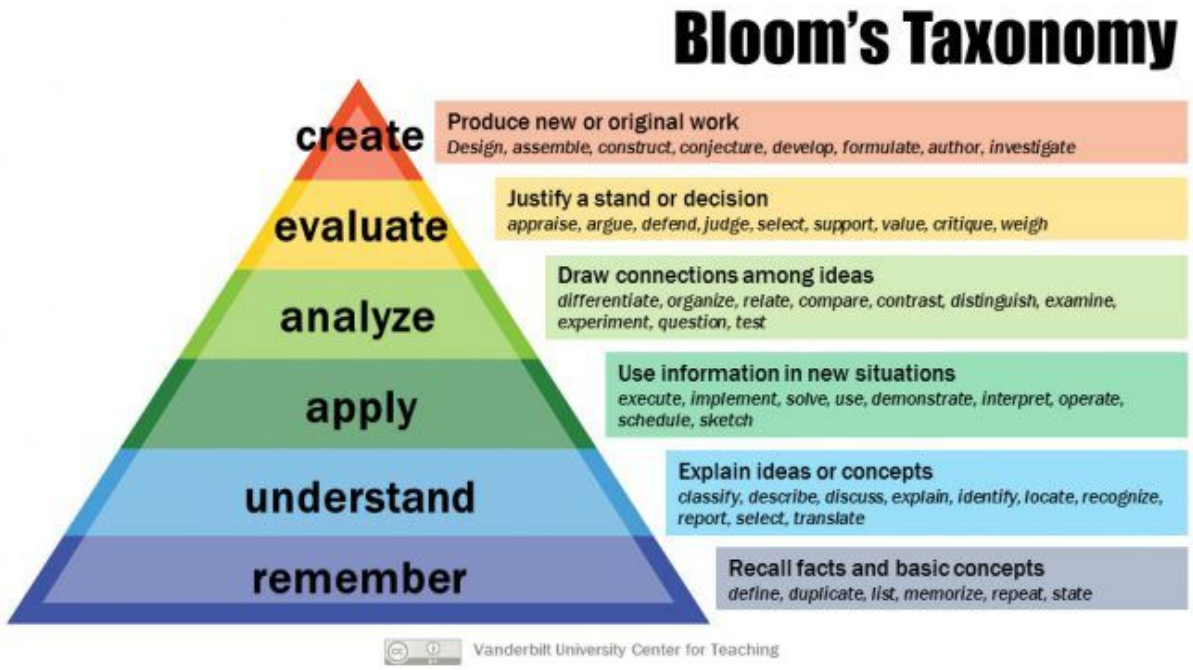

Figure 2.3. "Bloom's taxonomy", 2021, bloomstaxonomy.net. (https://www.bloomstaxonomy.net/)

The psychomotor domain has been first mentioned by Simpson in 1972: "*It includes physical movement, coordination, and use of the motor-skill areas. Development of these skills requires practice and is measured in terms of speed, precision, distance, procedures, or techniques in execution.*" (Clark, 2015).

Connectivism

The main principle of the connectivism learning theory is encouraging the student to research the needed learning information through the establishment of a network, using the technology and online platforms (learning-theories.com, 2020). The connectivism theory has been introduced by George Siemens & Stephen Downes and sometimes it is also called "A knowledge learning theory for a digital age" as it drives to involve modern learning technologies, learning management systems (LMS) and tools (Goldie, 2016) (Growth Engineering, 2021).

It is considered that in connectivist learning theory the learners also gain the knowledge from the established network with other learners. The knowledge gets assimilated subjectively, producing new ideas from the current knowledge (Siemens, 2021).

3. Methodology

Virtual Reality is not just about replicating an environment into the digital world, it is about the communication that users establish with its content while interacting. VR focuses on the experience more than on the technology itself and is concerned with the harmony between the human, software and hardware, and how all of it works together. A well-designed VR should always be intuitive and bring a balance into this communication. The VR development process is based on this element and it is also the most essential part of it (Jerald, 2015).

This chapter presents the methods and structure for the process of the VR solution development. It explains the choice of a Human-centred design (HCD) approach for the implementation, describes the techniques used for data gathering, analysis, development of the solution and for planning the usability testing.

3.1. Human-centred design approach

Based on the stated problem and research questions, the Human-centred design (HCD) approach has been chosen as the main guideline for the efficient implementation of instructions and design solution for pilot procedure training in VR. HCD is one of the well-known approaches for developing solutions relevant to intuitive human-computer interaction, including VR technologies. This method specifies a deep understanding of users requirements, needs and their expectations from a system (interaction-design.org, 2021).

Retrieving from (General Services Administration, 2016): "*HCD is a design and management framework that develops solutions to problems by involving the human perspective in all steps of the problem-solving process".* This is an iterative process, meaning that the development should be split into cyclic phases, continuously improving each stage of the cycle and placing the users' evaluation results as the main requirement for the next design iterations.

A human perspective implies the involvement of selected users who are representative for the characteristics, capabilities and experience of the system under design. Their feedback is crucial for accomplishing goals of efficient and intuitive usability, it also minimizes risks of missing out on the users' organizational needs in the system (ISO 9241-210:2019).

The HCD process requires detailed and thoughtful planning considering a continuous evaluation for each of the phases, as well as strategic recruitment of test-users for it in order to accomplish successful results. It consists of a mixture of different investigation methods, for reaching the intuitiveness and balance in communication between the users and the system (interaction-design.org, 2021).

According to the (ISO 9241-210:2019) the HCD approach consists of planning and implementing the following phases:

- Phase 1: Understanding and specifying the context of use;
- Phase 2: Specifying the user requirements;
- Phase 3: Producing design solutions to meet these requirements;
- Phase 4: Evaluating the designs against requirements

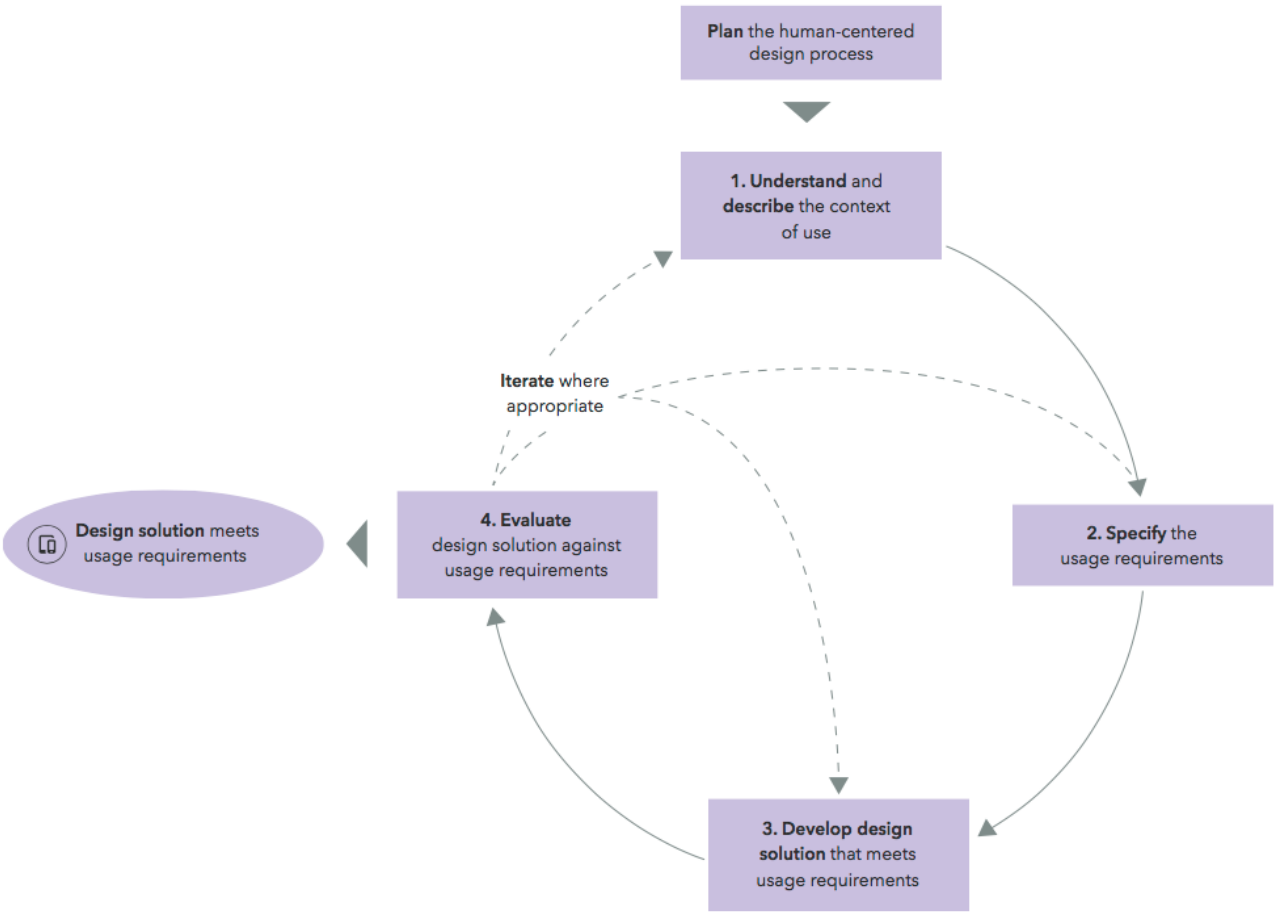

Figure 3.1.: "Human-centered design process for interactive systems", 2018, uxbooth.com, (https://www.uxbooth.com/articles/designing-usability-standards)

Figure 3.1. represents the cycle of iterative phases using the HCD approach and their interdependence of each other.

The project is developed in cooperation with Applica Training Systems AS (ATS), meaning that the practical part of it will be offered to the potential customers. In order to benefit from the project production it is very significant to be able to understand the future users' needs and requirements, to let them interact with a simple, yet very useful application and define what advantages it will bring them.

It is planned that the VR solution will be distributed to the VR platforms in other companies that would purchase this application from ATS. The system should be ready for a wide audience of different backgrounds and experiences. It should provide the users with the

guidelines on how to use the procedure training, being independent from ATS. Moreover, one of the main goals of the VR application is to enhance the memorizing process and reinforce the knowledge of a particular subject in pilots' training. The VR technology should not distract the users from the learning process, whereas the student-centred learning theories will be applied. In addition to understanding the needs and goals of the users, the project requires the understanding of cognitive processes that will happen during the procedure training in VR. One of the efficient ways to get this understanding, is directly involving the users in the solution development, asking the users their opinions, exploring their perception, reactions and thoughts about the system.

For a VR designer and researcher it is important to be able to imagine themselves in the user's place and look at the system from their perspective. Reviewing the definition of the HCD approach, it is one of the most suitable ways to carry out the whole production process.

The next chapters will describe the planning and implementation of each phase of the project in detail and explicit the match of using the HCD approach for such a project.

3.2. Context of use specification

Figure 3.2. compares the Context of use specification phase as a "Discovery" step of the project, where it helps to build a problem frame for the future solution.

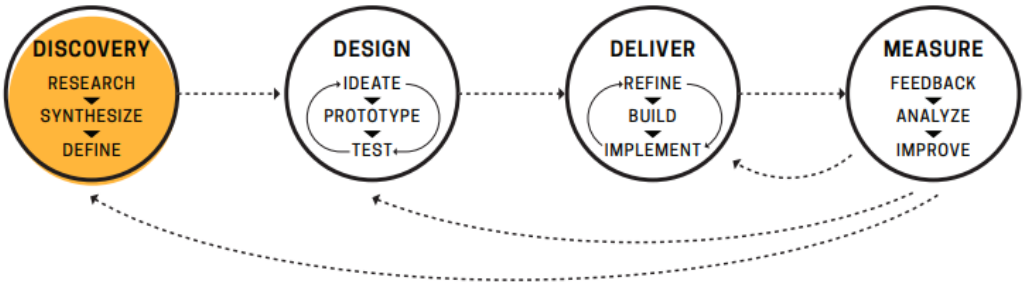

Figure 3.2.: "The cyclical process of HCD approach", 2016, General Services Administration.
(https://www.gsa.gov/cdnstatic/HCD-Discovery-Guide-Interagency-v12-1.pdf)

The first phase of the HCD approach starts with defining and analysing multiple sets of characteristics such as:

- Users and stakeholders

People who are included in the target group that the system is meant for and their relevant personal attributes such as *Roles* (concerning the system, e.g. operational, supporting, mentoring, etc.), *Experience*, *Education* (including their tech-literacy), *Physical* and *Cognitive characteristics*, *Attitude to the system* (Alonso-Rios, 2010).

- Tasks

This is an analysis of the work or activities that the users should carry out while interacting with the system. The task description determines the overall goals of the users that influence the usability of the system. Their description might be subdivided into categories (Jokela, 2003).

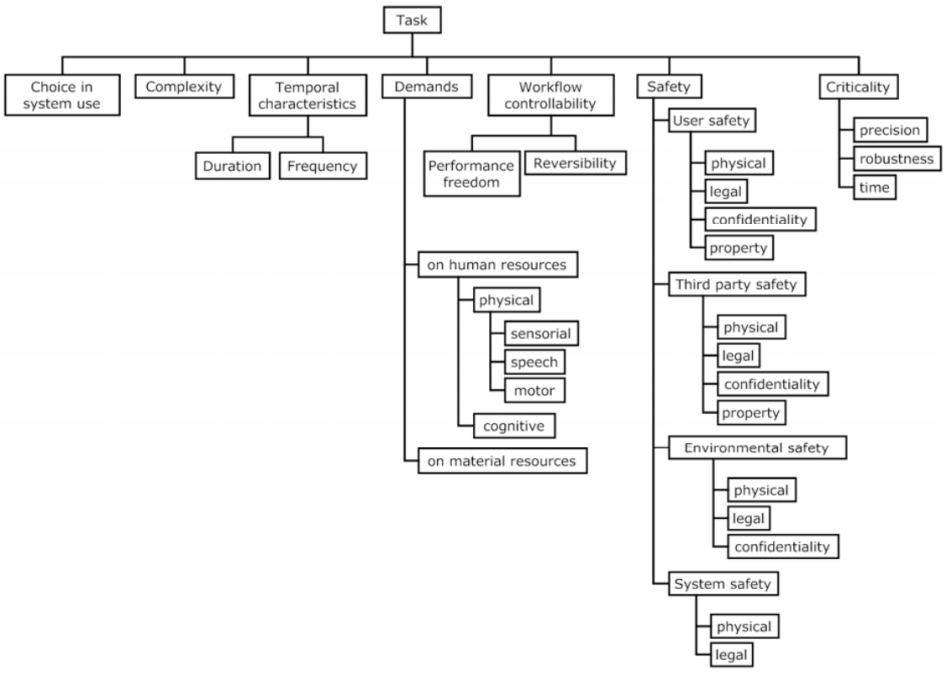

Figure 3.3.: "Task sub-attributes", 2010, Alonso-Rios.

- Environment

This is a description of the conditions where the interaction between the users and the system takes place. It is divided into four sub-categories:

- Physical environment: Spatial-, atmospheric-, tactile-, audiovisual conditions and safety;
- Technical environment: Hardware, software, equipment and their suitability to the usability;
- Social environment: Work relations (amongst the users), assistance, attitudes, job characteristics; (Alonso-Rios, 2010)
- Organizational environment: System use policy, interruptions, management and communication structure; (Maguire, 2001)

A clear understanding and definition of this phase's elements directly affect the quality of use of a system and its usability. It is recommended to start with this phase as early as possible in the general project's development. (Maguire, 2001)

To provide a piece of sufficient information for the specification of the context of use, the following activities have been carried out:

- People, Activities, Context, Technology (PACT) analysis

- Interviews with the experts relevant to the field of research
- User stories and personas' description

3.2.1. PACT analysis

PACT is an acronym for People, Activities, Contexts and Technologies, for the framework that lets the designers understand the future users of the system and help with the context of use specification (Benyon, 2019).

Considering the criteria and characteristics for Users, Tasks and Environments, mentioned previously, the relevant description has been organized following the framework.

	Description
People	The target users of the VR procedure trainer are pilots with different professional experience: from the beginner pilots who have not flown the aircraft with the whole crew and passengers before to the pilots with the experience of many years both as captains and co-pilots. The VR procedure trainer is meant for the pilots studying for or holding a commercial pilot license, thus another kind of the stakeholders are various airlines too. The stakeholders are also educational institutions for pilots, pilots' training managers, organizations that provide the educational institutions and airlines with the equipment for training. The users will have an operational role in the interaction with the application, meaning that the users will perform the tasks in the system to achieve their goals and complete the training. The users are expected to have minimal tech-literacy skills that would let them understand how to start the procedure training on the VR goggles and how to conduct the interaction with the hand controllers. The users should have the same theoretical and practical knowledge as required by the aviation educational institutions before getting introduced to the abnormal operations in the traditional learning approach. The physical and cognitive characteristics of the users should also correspond to the aviation educational institutions and training organizations' criteria to the pilots going through the training. The VR procedure trainer provides the learning environment in the cockpit of Airbus A320neo and uses its instructions for abnormal operations. Therefore the users such as pilots or pilots' training managers should be either flying, providing the training for this aircraft or be in a process of transferring from one model of the aircraft to the Airbus A320neo.
Activities	The procedure training in VR is a single-user experience that will

	require users' full attention and immersion in the VRLE. The menu of the training in VR will provide the users with options to adjust the settings for the training's environment which will affect the complexity of the tasks' accomplishment. The VR procedure trainer is meant to be a complementary tool to the traditional approach, therefore the user will decide himself/herself how frequent and how long should every session in VR last. It is possible to consider that setting up the VR goggles might take some additional time before and after the training sessions. The training itself can be interrupted by the user at any time. Based on the concept idea, one of the VR procedure trainer's main goals is to enhance the memorization process of the abnormal operations' checklists. Therefore, the task completion requires the users to be able to self-reflect on their own progress, evaluate their own skills and knowledge, and repeat the tasks until reaching the needed result. In order to complete the tasks of the procedure training, the pilots should involve their motor skills, sight, hands and head movements. The activities in the provided VRLE do not require the users to walk in the physical space, nevertheless when moving the hands to reach different cockpit elements in VR, the users might accidentally hit an object or another person located closely. Therefore it is required that for safety reasons, the users should train in a spacious location where they will not be surrounded by any obstacles in the radius of the straight arm.
Contexts	**Physical Environment:** The activities of the VR procedure trainer should be carried out in a spacious physical environment, without any external disturbing factors, e.g., surrounding noise, bad weather conditions (if the user is outdoors), disturbing air temperature, etc.. The training is happening in a sitting position, therefore a suitable location for that is required. Based on the users' personal preferences there should be convenient time settings for conducting the training session. **Social Environment:** If the user does not have any prior experience with VR technology, it is recommended to have a person who would be able to help setting up the training session and explaining how to use the VR HMD, otherwise the user should look into tutorials provided by the VR platform. In the application itself, the instructions will be always available describing how to interact in it. This project's concept implies individual training. **Organizational Environment:** Specific terms and conditions,

	including the confidential aspects of the product, should be discussed and developed by ATS as owners of the VR procedure trainer, selling it to their stakeholders. Since the VR procedure trainer is meant to be a complementary tool to reinforce the knowledge, the absence of the regular training sessions in this VRLE should not affect the loss of skills of pilots.
Technology	For accessing and conducting the training, the users need a standalone VR HMD, two hand controllers for the VR HMD, VR procedure training application itself. It is required to have an Internet connection and options for charging the VR device to get ready for accessing the procedure training. The concept of the VR application considers to implement accompanying voice guidelines and sound feedback, therefore the VR platform should also provide audio support. **Input:** The interaction input happens through the hand controllers by the users pressing buttons on them and moving their hands. The HMD also tracks the position and rotation of the users' head. **Output:** VR HMD outputs the VR environment and the interaction patterns of the user. The system should provide the fastest response possible to avoid the latency, which might cause motion sickness.

Table 3.1. PACT analysis for the VR procedure trainer of abnormal operations

3.2.2. Interviews with the experts relevant to the field of research

Three representatives of the VR procedure trainer's target audience were invited to participate in the interview: two pilots and the pilots' training manager. There were multiple goals and purposes of the interview with the participants:

- **Terminology**

It was needed to clarify some of the terminology and its correct definition, which is widely used in the aviation's industry and in the pilot's training. In addition, it was important to understand the context of using some of the terms to name the UI elements in the VR application appropriately. For example, whether there is the difference between abnormal operations and non-normal procedures, what are the non-normal procedures checklists, etc.

- **The learning process**

To investigate the potential advantages of using such a VR application, it was necessary to gather the information about the traditional ways of studying for forming their comparison. Furthermore, to plan an efficient instructional strategy and design for a VR application, it was needed to understand the potential users' attitude to a traditional learning approach, their preferred methods to study the abnormal operations.

- **Experience with VR and any possible VR utilization in modern pilots' training**

For this purpose, it was important to clarify the tech-literacy of the potential users for developing a user-friendly and intuitive VR solution.

The full content of the in-depth interviews are provided in the following Appendixes:

- Appendix B: The interview questions prepared for pilots
- Appendix C: The interview audio-recording transformed into the written form with pilot 1
- Appendix D: The interview audio-recording transformed into the written form with pilot 2
- Appendix E: The interview questions prepared for the pilots training manager
- Appendix F: The interview audio-recording transformed into the written form with the pilots training manager

There is a difference between the planned interview with the list of questions and the interview that actually took place because the idea was to conduct a semi-structured interview. The approach, purpose and advantage of such an interviewing technique is explained in chapter ***3.5.1. Qualitative research***.

3.2.3. User stories and personas

To emphasize the importance of the user's presence in the context of use specification and definition of user requirements in the next step, two other methods were conducted. Both user stories and personas describe concrete types of people that the system is designed for. (Benyon, 2019).

User stories description makes the solution designer place themselves in the users' perspective. It is needed to state a formulation of a request from a user to the system, and following, e.g., one of the well-known formats for it:

- "*As (a type of user), I want (a goal), [so that]*." - this structure has been popularized by M.Cohn (Cohn, 2004), (Lucassen, 2015) .
- Example: "*As a pilot, I want to involve my motor memory in training and feel more present in the cockpit, so that I could better memorize the location of the switches on the cockpit's panel".*

Personas are small stories of the users, including their personal characteristics, who would need to use the proposed system in a concrete scenario. This method enhances the understanding of users' emotions and impressions (Benyon, 2019).

Personas example for the project	
Henrik Olsen (the name is fictitious)	Henrik is 47 years old, he has been a pilot for around 25 years and has experience of flying as both a captain and a co-pilot. Henrik is a pilot of Boeing 787 Dreamliner.

	The COVID-19 pandemic has caused a lot of changes in the airline he has been working for. Currently the airline considers exploiting the Airbus A320neo aircraft instead of Boeing 787, therefore pilots like Henrik will have to complete the Type Rating - a pilot's qualification to fly a particular aircraft (baatraining.com, 2019). Nevertheless, the restrictions related to the pandemic change a lot, causing a lot of challenges for pilots to manage the process. Henrik lives in Trondheim, while the airline's training center with the required equipment is located at Gardermoen. It is very problematic to travel down to the airline's hub and in addition, the restrictions do not allow people to gather in small spaces. One of the Type Rating phases requires training in a flight simulator with the crew and with the instructor, yet it is not possible to conduct. Henrik reads the manuals of the Airbus A320neo, however it is not enough to get used to the new cockpit, memorize how and where to reach needed switches on the panel in case of an abnormal situation.

The rest of examples of the user stories and personas for the project are provided in Appendix A.

3.3. User requirements

Summarizing the conducted PACT analysis, interviews, user stories and personas descriptions, it is possible to structure specific user requirements, hence recommendations for design solution production. The user requirements are the statements that specify what the system will offer, perform and what to expect from it from the users' position (Sharp, 2019).

3.3.1. 7 Product Dimensions model

The information gathered during the context of use specification has been organized following the 7 Product Dimensions model, developed by Ellen Gottesdiener and Mary Gorman (Gottesdiener , 2012).

This model allows the developer to discover and improve own product concept by first stating the questions to the product's dimensions and then through reflection and evaluation, provide the most relevant answers to those. This model is also used as a framework for delivering high-value products to the partners and customers by various organizations (Idris, 2020).

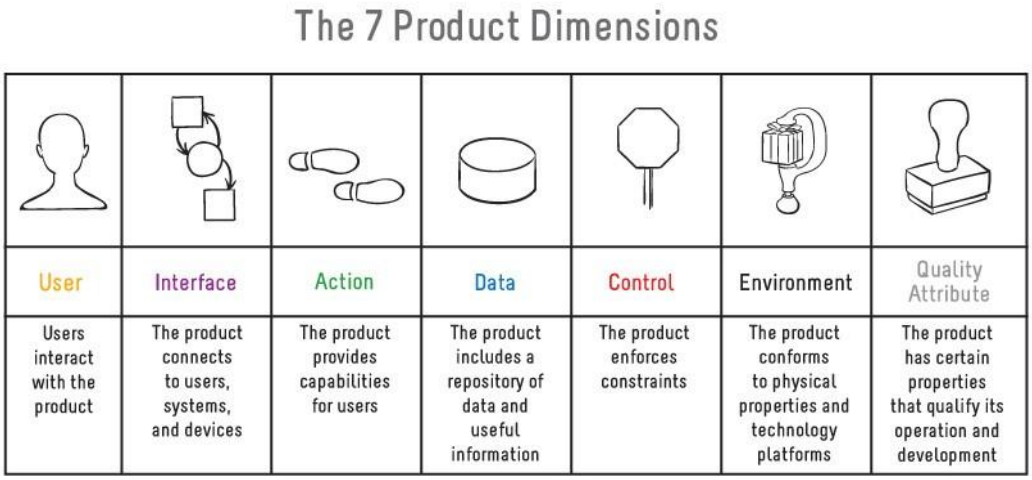

Figure 3.4. "The 7 Product Dimensions", 2012, Gottesdiener.

In order to plan the next step, designing a solution meeting user requirements, the statements have been also categorized following the Minimum Marketable Product (MMP) principle (Idris, 2020). It makes the developer select the most valuable elements of the planned system that would make it function and start receiving feedback from the potential users or customers sooner. Such approach helps not only start testing the solution at early design phases but also prove or disprove the assumptions about the functionality and usability, check whether the system works (Idris, 2020). It suits the HCD approach because starting to test the solution at early stages, then continuously improving it based on the target users' feedback, supports this approach's main idea.

Based on the provided problem statement and the results of conducted activities for the context of use specification, the whole VR procedure trainer seems to be a big and complex application with a lot of various functions and settings. Nevertheless, one of the main goals of this research is to investigate first the feasibility and sense of implementing such an application. It will help to use the time in an efficient way, by selecting the most valuable elements from general user requirements, functional requirements and other aspects of the application. Thus it will be able to present the potential advantages and enhance the interest of customers of ATS, as well as develop the guidelines for the VRLE design solution and instructional design of abnormal operations procedures' training.

The full overview of the user requirements are presented in Appendix G.

3.3.2. Usability and User experience goals

In addition to the 7 Dimensions model description, a special attention has been paid to the usability and user experience goals. The usability goals are ensuring the system lets the users complete their tasks and intended outcomes during the interaction. According to H. Sharp et al. (Sharp, 2019), usability has six goals:

1. Effectiveness
2. Efficiency
3. Safety
4. Good utility
5. Easy to learn
6. Easy to remember how to use

These are not only the goals but also a criteria for an interactive system that would define how usable it is. Same as most of the specification activities of the HCD approach, the usability goals for a particular system are operated by questioning each of the goals, e.g. Would it take a long time for a user to get used to the system? (= Easy to learn) Will the system provide a user with a high level of productivity? (= Efficient), etc. (Sharp, 2019)

Figure 3.5. "Usability and UX goals", 2015, Adikari.

Based on the information retrieved from (ISO 9241-210:2019), the term "Usability" implies an *extent to which a product can be used by specified users to achieve specific goals with effectiveness, efficiency and satisfaction in a specified context of use.*

On Figure 3.5. the usability goals are placed in the middle of the circle, as a core element, the outer circle represents examples of user experience goals. User experience goals are usually described with adjectives and define the emotions and experiences that the user has obtained as a result of interaction. These might be divided into both desirable and undesirable aspects (Sharp, 2019).

3.4. Design solution meeting user requirements

The third phase of the HCD approach, requires the developer to plan the design solution based on the information and conclusions made from the previous steps.

There are multiple techniques that would let start developing a solution while continuing following a HCD approach. First of all, there is a need to map out the formulated requirements to the system and represent the input-output relation between the user and a

system in one structure. Creating a conceptual model is one of the ways to outline what users can do with the system and which concepts are needed to understand it (Sharp, 2019)

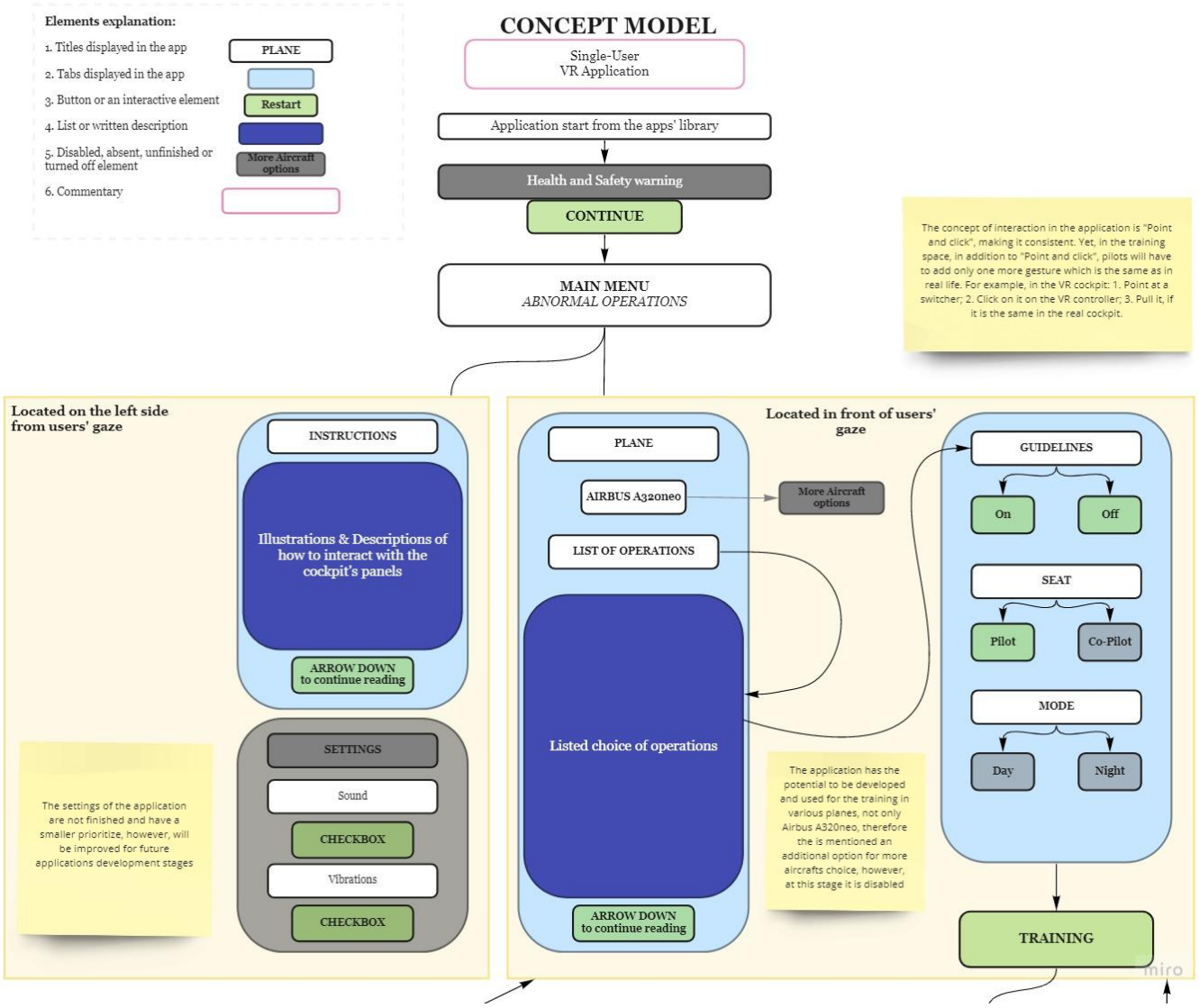

Figure 3.6. Conceptual Model 1 "Main Menu"

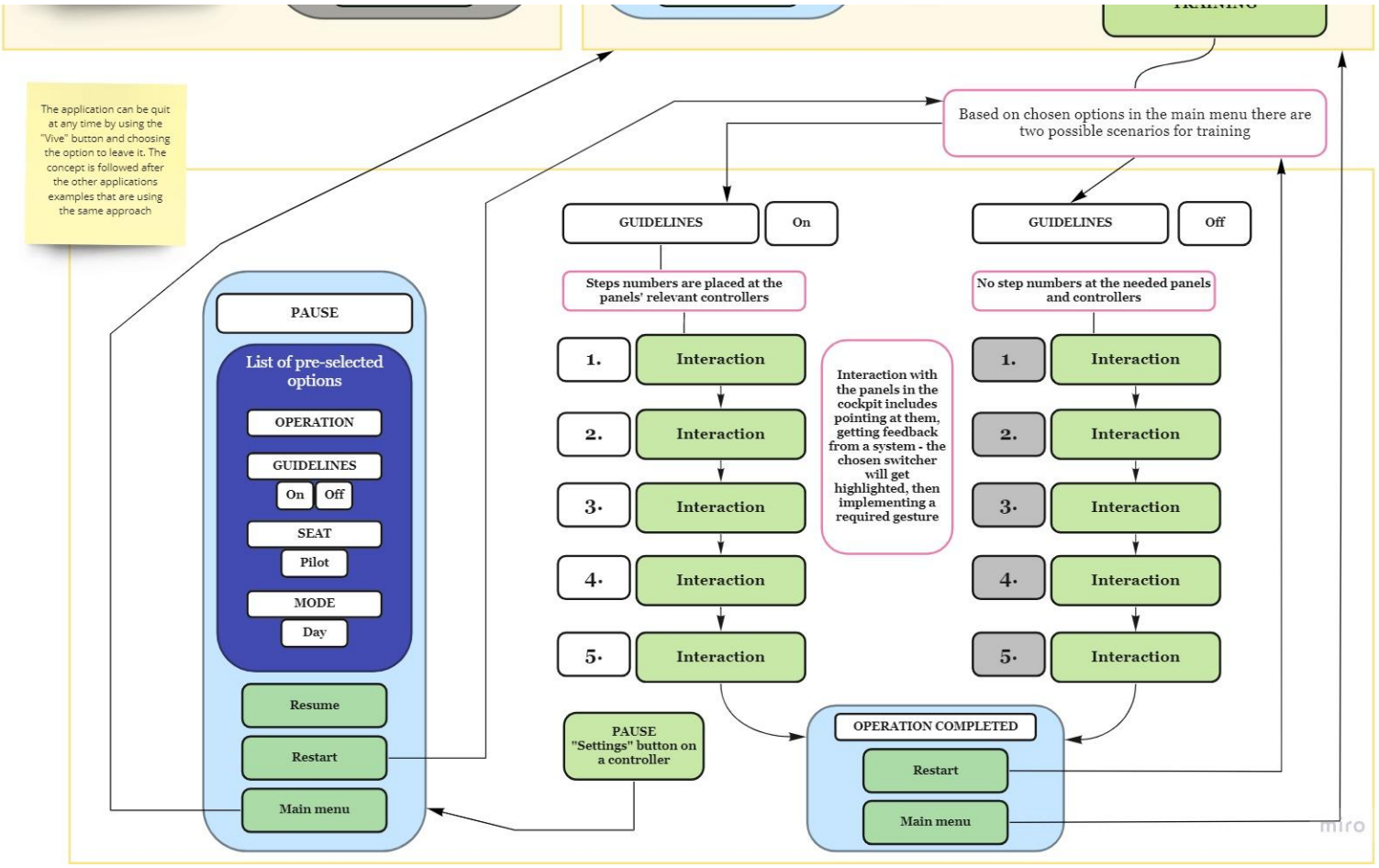

Figure 3.7. Conceptual Model 2 "Training Space"

Provided conceptual model on the Figure 3.6. and 3.7. represents the overview of interaction paths that the target users would experience during their procedure training from the moment they would start the application and until they would be ready to finish. The conceptual model shows that the application is divided into two parts: the menu and the training space. It helps to visualise that according to the user requirements, there will be opportunities for preparing the necessary settings for the training and then move on to the procedure training itself.

This phase of the HCD approach and the next one - Planning the UX evaluation, both were worked out in a narrow period of time, completing some of the activities together, for example, the conceptual model has been developed in a way that would complement the efficient planning of the UX evaluation. For instance, after the selection of the most valuable requirements, the conceptual model shows some of the elements in grey color, which means that these functions will not be included in the upcoming usability testing. For example, "Health and Safety warning" - it is a requirement for the VR applications, as VR experiences have risk of personal injury, discomfort or property damage (ancientandrecent.com, 2021), therefore there is some information that should be shown before starting the app to protect the

users from undesired consequences (Facebook Technologies, 2021). Nevertheless, it might be more practical to include a fully defined “Health and Safety warning” at later design iterations because at the first iteration’s usability testing the users will be directly observed and guided. The process is described in chapter ***3.5.1. Qualitative research*** and ***4.3. Testing and Evaluation***.

The second part of the solution design is proceeding to the physical design implementation. Physical design is concerned with structuring the interactions into logical sequences, detailing the way the product will look like (Benyon, 2019).
According to D.Benyon (Benyon, 2019), there are three components of the physical design:

- Operational design

A specification of how the elements of the product will work, stored and structured;

- Representational design

A design of the product’s aesthetics and style, e.g. its colors, layouts, shapes, etc.;

- Interaction design

A sequence of interactions and allocations of functions for the users and the technology;

In order to continue visualising the product, there were two techniques chosen for this part: low-fidelity prototyping and high-fidelity prototyping.

- Low-fidelity prototyping lets the developers try their early design visualisation using cheap and fast-in-development materials and methods, e.g. creating paper prototypes, drawing storyboards, without implementing actual user interactions (usability.gov, 2021).

For this project a digital mockup has been produced as a starting point for the VR app’s prototyping. A mockup simulates the static user interface of the application in development, letting the users and customers get a realistic impression (designthinking-methods.com, 2021).

A screenshot of the 3D model of the Airbus A320neo’s cockpit, that has been purchased for the project development by ATS, has been used as the base, and the concepts of the UI elements with commentaries were arranged on top of it.

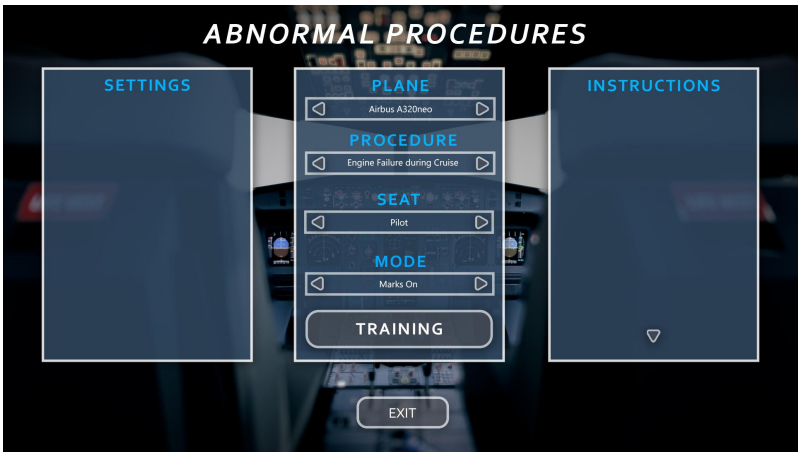

Figure 3.8. Early design of the VR app's main menu

Figure 3.9. Example of various UI elements arrangement

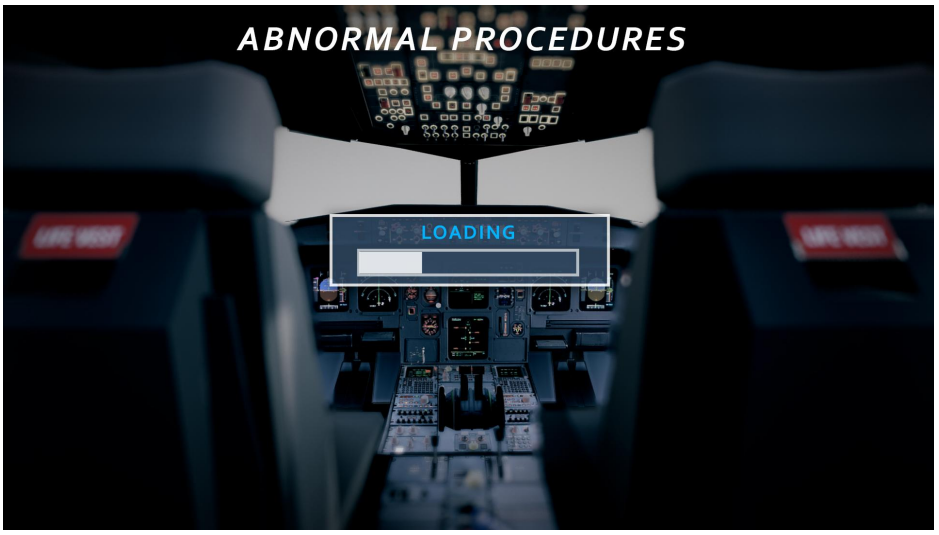

Figure 3.10. Example of the "Loading" UI element between the scenes

Figure 3.11. Alternative example of the Pause menu

Figures 3.8. - 3.11. represent early design examples of the VR procedure training application. These UI elements were developed in Adobe Photoshop. The early design examples were discussed amongst the project participants at ATS. As a result, the style of the UI elements and most of their arrangements were approved.

One of the advantages of low-fidelity prototyping is that it allows multiple approaches for changing the design without a big amount of effort. For instance, the early design of the Main menu went through a few iterations until it got to the variant implemented in the high-fidelity prototype afterwards. In addition, with the consultancy of the pilots, who are a part of the target audience group, it was possible to edit the terminology mentioned on the UI elements, so that it is represented correctly. On the *Figure* 3.8. and 3.10. the headline over the tabs is “Abnormal procedures”, which is relevant to the context, however, it is more correct to name it “Abnormal operations” - what has been changed in the mockup.

The arrangement of tabs has been updated multiple times: it has been agreed that in order to choose a procedure for training it might be more convenient to see the full list of procedures at once, then clicking on the arrows on the sides to switch the choice, as visible on the Figure 3.12. and 3.13. .

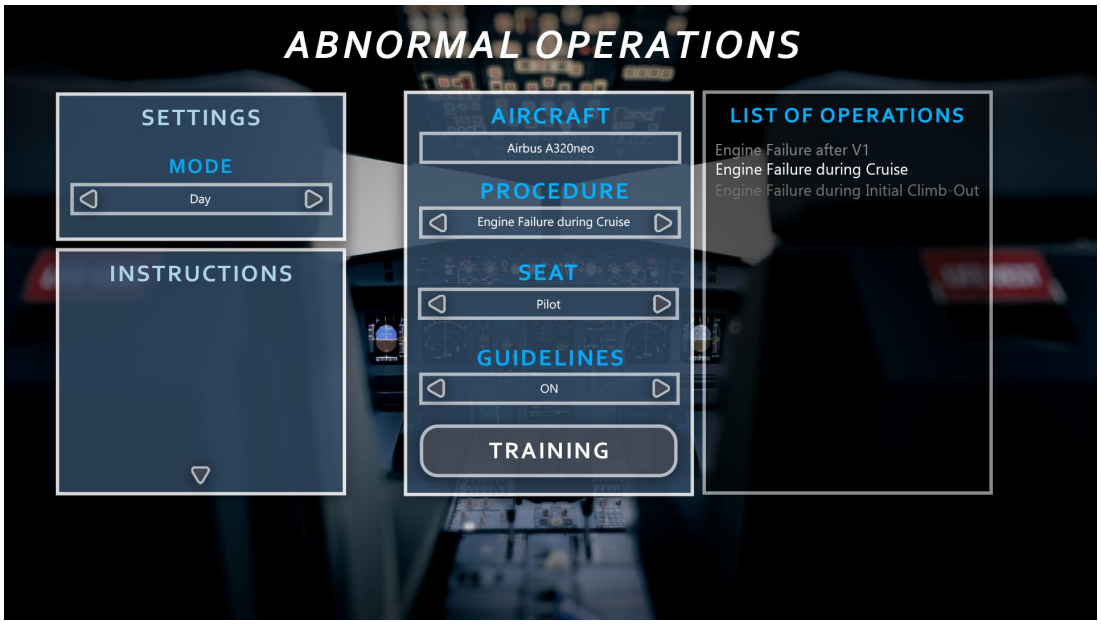

Figure 3.12. Second design of the VR app's main menu

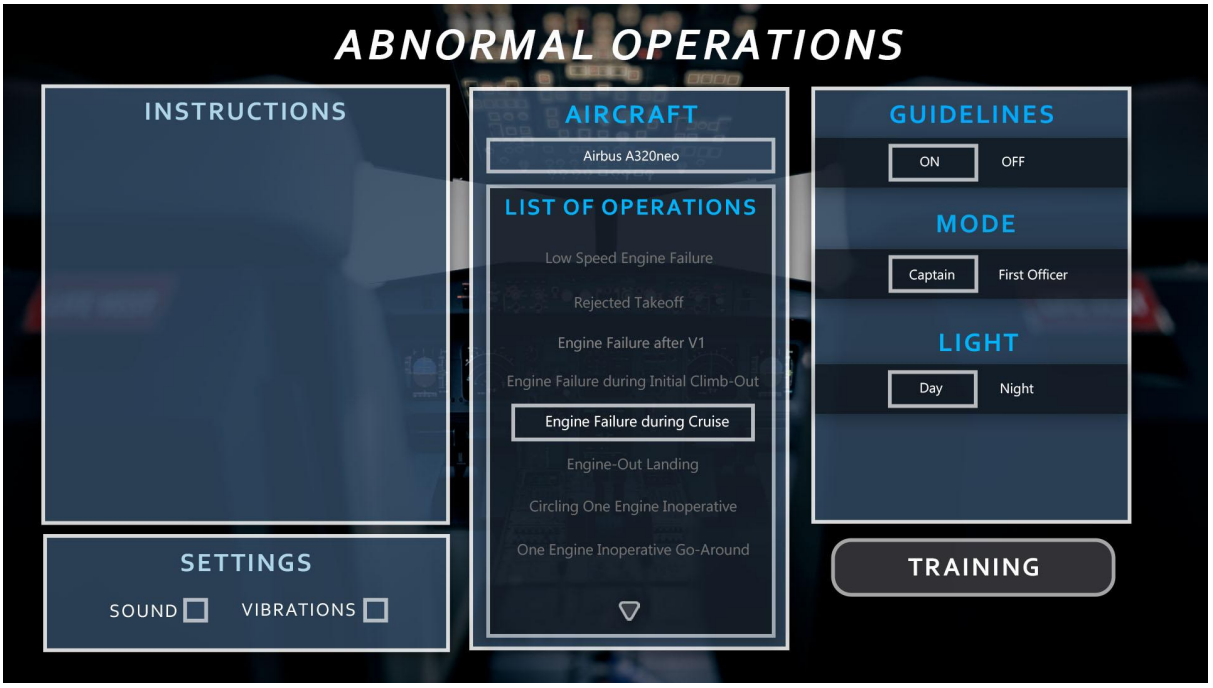

Figure 3.13. Third design of the VR app's main menu with correct terminology

- High-fidelity prototype is a computer-based representation of the realistic user interface, which looks as close to the intended final product as possible. It includes the interactions between the users and the system and is assumed to be more effective in usability evaluation, providing insightful data (usability.gov, 2021).

The high-fidelity prototyping for the VR procedure trainer of abnormal operations has been developed using the 3D software such as Maya, Unity, using the IDE such as Visual Studio and using the UI elements developed in Adobe Photoshop. The detailed description of the high-fidelity prototype is provided in chapter ***4. Development & Testing*** because the design process of the VRLE is related to the investigation of one of the research questions.

3.4.2. Instructional strategy

In order to develop an effective instructional design in the VR, it is needed to plan the instructional strategy, according to the learning theories mentioned in chapter ***2.2. Learning theories in VR***.

The main learning theories and the aspects to consider:

- Cognitivism
- Bloom's taxonomy/Psychomotor domain
- Connectivism

Analyzing the user requirements, the interviews with the target users' representatives and the principles typical for the learning theories, it has been decided that the key elements of the instructional strategy in the application will be following:

- To involve the cognitive processes, the numbers of steps for the procedure sequence that are needed to be completed will be placed next to the elements of the panel. Repeating the steps in particular order, will presumably enhance the memorizing process.
    - Besides, the guidelines that would explain the steps to the users are needed to create a learning pattern.
- To involve the psychomotor domain and combine it with the cognitive processes, the users will have to conduct physical movement towards the elements of the cockpit's panel to solve the operation.
- The VR technology using a modern VR HMD and hand controllers will work as an additional component to the network of knowledge, built by the pilots from before. The utilization of VR as a complementary tool to the traditional approach will involve the connectivism learning theory.

3.4.3. Technology

According to the technology requirements, the following VR goggles were chosen:

- HTC Vive Focus Plus (HTC Corporation, 2021)

This VR HMD has been released in 2019 focusing on enterprise as its target audience (Porter, 2019). HTC Vive Focus Plus is a standalone headset, including two controllers in its pack. It provides a 110-degree field of view, which enhances the feeling of immersion in VR. It is easily portable and has a comfortable, ergonomic design, which helps avoid fatigue from interaction. (HTC Corporation, 2021)

Another alternative has been reviewed - Oculus Quest 2 (Facebook Technologies, 2021), the standalone HMD which is amongst the most popular and leading in the VR goggles' market. However, it has been placed only as an alternative because of the requirement of having a Facebook account. Even though it states that Facebook collects only "relevant data", it has been considered that the attachment to a social media might not be attractive for future customers of the VR application. In the future perspective, it has been announced that from 2023 to get the full functionality of Oculus Quest 2, the Facebook account will be the obligate requirement (Baker, 2021).

3.5. Planning the design evaluation

The fourth phase of the HCD approach lets the developer collect the needed data to reveal any issues with the accomplished stage of the design solution, determine the next iteration targets and get the feedback from users about the strong and weak sides of the interactive system, learn whether it has been produced corresponding to their needs. In this research, this phase implies the usability testing of the solution, which consists of particular sets of activities and it is followed by a thorough analysis and summary of the evaluation results (ISO 9241-210:2019).

There are multiple variants of methods for conducting usability testing, UX evaluation and data analytics. The choice of the methods depends on the system's characteristics, purpose, usability testing goals and previously defined context of use with user requirements (Adikari, 2015).

According to (Rubin, 2008) , the planning process of the testing is divided into 8 steps, each requiring own preparations:

1. Develop a test plan
2. Set up a testing environment
3. Find and select participants
4. Prepare test materials
5. Conduct the test sessions
6. Debrief the participant and observers
7. Analyze data and observations
8. Report findings and recommendation

(Rubin, 2008).

3.5.1. Qualitative research

To begin with, it is important to define the user research method that will influence the selection of further techniques and gathering a specific type of data process for usability testing.

Based on the fact that the VR application is being developed for ATS, the amount of available users/customers for testing is narrowed, therefore the qualitative research has been chosen against the quantitative.

The qualitative research allows the developer to observe the users evaluating the interactive system directly and it helps answer such questions as *"Why might there be a challenge in using the VR procedure trainer?"* and then it proposes the options for answering *"How to fix any challenges?"*, what is very useful at the early iteration stages (Rohrer, 2014). Qualitative data analysis helps to define users' attitude, interpretations and categorize the received feedback (Sharp, 2019). Furthermore, the qualitative research provides more detailed insights on the user needs, feelings, motivation and opinions regarding the interactive system (prwd.co.uk, 2019). This kind of research supports the inductive approach, meaning that when analysing the interviews and observations of the users, the developer might extract the need for further investigation concepts from the general information (Sharp, 2019).

Figure 3.14. "Qualitative & Quantitative dimensions' types of questions", 2014, Christian Rohrer. (https://www.nngroup.com/articles/which-ux-research-methods/)

(Virzi, 1992) states that five users is sufficient enough to explore problems in the user interface and this number of participants might help to discover up to 80% of challenges if there are any, even though this statement is often disproved in various research discussions (Lazar, 2017).

Initially, it was planned to recruit 5 participants suiting the target users descriptions for the usability testing. However, due to the circumstances of COVID19, there were only 4 participants available. All of the participants were provided with the consent form describing the usability testing activities' purposes, users' rights and confidentiality agreement. It has also been decided to protect the participants' personal identification, therefore there is no personal data mentioned in this report. The consent form is provided in the Appendix H .

The goals of the usability testing are divided into sub-topics, stated as questions and are the following:

Usability testing goals	
● **The intuitiveness of the VR procedure trainer** *These statements also imply a test of particular usability goals:* ○ *Ease of use* ○ *Ease of learning* ○ *Memorability*	● How clear are the instructions in the application? ● Is it easy for the user to select the needed features for the training and proceed to the training space? ● Whether the pilot can navigate in the app without any challenges or obstacles?
● **The functionality of the app** *Usability goals:* ○ *Efficiency* ○ *Effectiveness*	● Are there any issues related to latency or any other software issues? ● How precise are the interactions with the elements in the VR cockpit? ● Whether the VR technology distracts the pilots from the learning process?
● **The advantage of this type of training** *Usability goals:* ○ *Utility* ○ *Efficiency*	● Whether the pilots would find it practical to use such a tool for memorizing the abnormal operations? ● Whether the virtual space enhances the knowledge reinforcement and memorizing process? ● Whether involving VR controllers for physical movements helps to memorize the steps too? ● Whether it has the potential to be included in traditional methods of training the abnormal operations? ● Whether the application has good instructional design? ● Whether the guidelines in the cockpit were helpful?

Table 3.2. Usability testing goals

Interviews

As qualitative research focuses more on users' opinions, feelings and motivation regarding the interactive system, one of the ways to get more of such kind of information, is to conduct interviews with the users of the target group. Interviewing the future users is also considered as one of the most common formats of data collection in qualitative research and one of the most effective ways to figure out what they need and expect from the system (Pharm, 2014) (Benyon, 2019).

There are different types of interviews: unstructured, semi-structured and structured interviews (Sharp, 2019).

During the context of use specification phase of the HCD approach in this project, semi-structured interviews were taken with three representatives of the target users: two pilots and the pilots' training manager.

- In order to take a semi-structured interview, it is needed to have a script or a guidance of topics and questions that should be discussed in the conversation. The questions might be both opened and closed. Nevertheless, the interviewer is free to reword the questions and explore more of the topics if any additional, yet useful for the research information arises (Benyon, 2019).

The main topics for discussion in the semi-structured interview were the terminology, learning process and experience with VR technology, as it described in chapter ***3.2.2. Interviews with the experts relevant to the field of research.*** The participants of the interview have also given their consent to record the audio of the conversation and use it for this research. The recorded interviews have been written down, keeping the style of users' expressions, but with minor edits such as excluding the repetitive words and a few grammar edits. The structure of the interviews and the written conversations are presented in Appendix D to H.

To analyze the information collected from the interview, it is important to avoid subjective interpretations. To provide a reliable qualitative data analysis, one of the methods is to look and focus on the key elements such as objectives, words and sentences that describe actions, phrases, that for example, would provide information about which functions the users use the most, etc. (Lazar, 2017). Below, is an example of how the needed statements could look like.

Statement	Examples
Objectives	Use computers for educational purposes
Actions	Enter a password, chat online
Outcomes	Success or failure, whether the objective is achieved
Consequences	Files unintentionally deleted, a specific application abandoned
Causes	Limited memory, dated equipment
Contexts	User is computer savvy, user works with classified information
Strategies	Avoid specific tasks, multimodal interaction

Figure 3.15. "Examples of statements to look for while analysing the content", 2017, Lazaer.

Observation

Observation, in comparison with interviews, is a dynamic activity which captures the evidence of the interaction process with the developed system (Mulhall, 2003). It is a method to explore how the users react and exploit the system in different settings, how the physical

and social environments can affect their interactions and whether there is any difference between what users say during the interview and how they actually act (Mulhall, 2003) (Sharp, 2019).

Observation is also one of the qualitative research methods and according to (ISO 9241-210:2019) can be carried out by both or one of the two widely used approaches:

- User-based testing
- Inspection-based evaluation using usability and accessibility guidelines or requirements

For the user-based testing, the same participants as for the interviews were invited: two pilots and one pilots' training manager. It has been decided to conduct the observation in a controlled environment, which means that the users had to complete concrete tasks within the VR application prototype to let the researcher test the hypothesis (Sharp, 2019). To collect the feedback and information about the users' opinions, thoughts and reactions to their user experience, a think aloud technique has been applied. It requires the users to comment on the actions they undertake, the reactions or problems they get while completing the tasks (Lewis, 1993).

Considering the defined usability goals to explore and accomplish, the following tasks were planned for the usability test participants:

● The testing administrator will start the application and let the pilots explore around, get familiar with the application, get used to the hand controllers, read the instructions (approx. 5 minutes)

1. Start the training with Guidelines "ON" mode
2. Complete the procedure following the guidelines
  a. Pause the procedure and resume
3. Start the training with Guidelines "OFF" mode
4. Complete the abnormal procedure without the guidelines
  a. Skip one of the procedure steps
  b. Restart the procedure before finishing
5. Exit the training
 	
After completing these tasks, the users will be asked to return first to the training in the Guidelines "ON" mode, then:
1. Skip one of the procedure steps during the completion
2. Restart before finishing
3. Explore the training mode as they would like for around 2 minutes
In the Guidelines "OFF" mode:
1. Pause the procedure and resume
2. Leave the procedure before finishing

3. Explore the training mode as they would like for around 2 minutes After these steps, the users will be given around 5 minutes of free time to explore the application as they would like and continue to accompany this time with their opinions about the VRLE, UI elements, and provided functions.
● The application will be quit by the testing administrator

Table 3.3. User tasks for observation

Survey

A survey has been conducted with the users after the usability testing in order to evaluate their experience and the usability of the system. Since the chosen research method is qualitative, this survey does not focus on collecting the numerical results, instead it gathers the opinions for further improvements of user requirements, new targets for the next iterations, and reveals whether the system reaches the usability goals.

There are different standartionalized questionnaires (that might be also used as questionnaire-based surveys), these are utilized in order to evaluate UX and the usability of the system. To develop an efficient and structured survey, a few of the standartionalized questionnaires examples have been reviewed:

- QUIS - Questionnaire of User Interface Satisfaction (Agency for Healthcare Research and Quality, 2021).
- UMUX - Usability Metric for User Experience (Gibson, 2017).
- SUS - The System Usability Scale (Gibson, 2017) (usability.gov, 2021).
- SUMI - Software Usability Measurement Inventory (sumi.uxp.ie, 2021).
- PSSUQ - Post-Study Usability Questionnaire (Garcia, 2013).

It has been decided to develop a customized survey, due to the smaller number of participants than it is required for the reviewed options, yet following some of the same principles of formulating the statements for the evaluation. The main goal of the survey is to analyse the effectiveness, efficiency, ease of use, ease of learning, memorability and general users' satisfaction with the VR prototype.

The survey has been divided into three parts. The Table 3.4. shows the examples of the questions, statements and categories. The full survey is provided in the Appendix L.

Categories of the survey	Examples of the survey's questions and statements
Gathering the opinions for further requirements'	Open and closed questions: ● What is your overall impression of the VR

improvements, UX evaluation	application? ● In your opinion, what is the biggest advantage of such a training approach? ● Would you personally use such a tool? ● ...
Usability goals evaluation	The statements with “Agree”, “Slightly agree”, “Slightly disagree” or “Disagree” answering choice: ● **The overall impression from the application** ○ It is easy to use and navigate in the VR application ○ The application design looks pleasant ○ The instructions in the main menu were helpful ○ … ● **The interaction within the application** ○ I felt full control over the process ○ VR controllers let you interact with the elements in the cockpit without any latency ○ The VR technology distracted me from the learning process ○ … ● **The educational aspect of the application** ○ VR application would help to memorize abnormal operations ○ VR application provides more opportunities for better training of abnormal operations than traditional methods ○ I enjoyed the opportunity to do the physical activity in the training ○ ...
Targets for the next iterations	The statements with “Yes” or “No” answering choice: ● Having a choice between the “Captain” mode and “First officer” mode is useful ● Having a choice between the Guidelines “on” and “off” modes is useful ● Having a choice between the daylight and the night light in the cockpit is useful ● ...

Table 3.4. Examples of the questions and statements included in the survey

Heuristic Evaluation

The fourth participant of the usability testing of the VR prototype is an employee of ATS, who has a background in developing VR solutions and UX in general. It is useful to evaluate the product from an expert's perspective, therefore a heuristic evaluation has been conducted.

It is a technique that lets identifying potential problems with the system and what recommendations for further improvements there could be (Maguire, 2001).

Traditionally, there are 10 usability heuristics used for user interface design, introduced by (Nielsen, 1994), presented on Figure 3.16 .

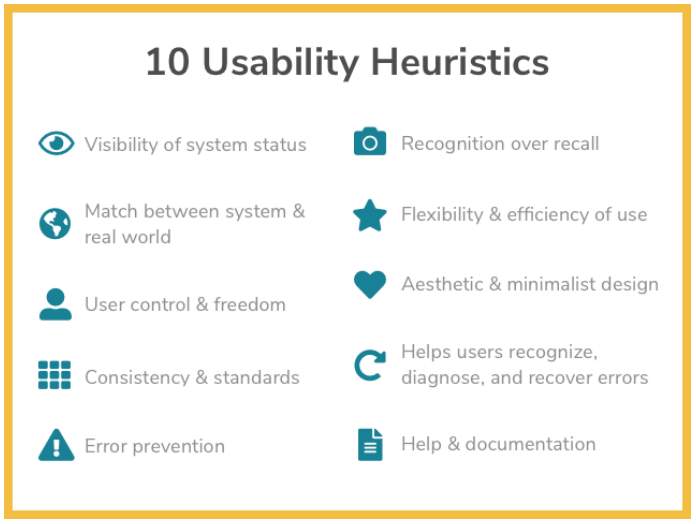

Figure 3.16. "10 Usability Heuristics", 2020, by Useagility Team. (https://useagility.com/blog/how-and-why-to-use-a-heuristic-evaluation/)

Nevertheless, based on the J.Nielsen heuristics, there have been heuristics specific for the VR applications developed by (Sutcliffe, 2014). This method proposes 12 heuristics, more relevant to investigating the problems that might occur in the virtual worlds:

1. Natural engagement
2. Compatibility with the user's task and domain
3. Natural expression of action
4. Close coordination of action and representation
5. Realistic feedback
6. Faithful viewpoints
7. Navigation and orientation support
8. Clear entry and exit points
9. Consistent departures
10. Support for learning
11. Clear turn-taking
12. Sense of presence

It has been chosen to evaluate 10 out of 12 heuristics, excluding *8. Clear entry and exit points* and *11. Clear turn-taking*. The reason for the 8th heuristic exclusion is the absence of the interaction pattern for entering or exiting the virtual world by users, which is also not included in the usability testing plan. The VR prototype will be launched and quited by the usability testing administrator. The 11th heuristic is more relevant to the VE with audio

feedback (Sutcliffe, 2014). The audio guidelines are considered to be included in the VR application but in later iterations.

The heuristic evaluation for this iteration phase started with a brief interview for the expert's self-introduction, followed by completing the same set of tasks as for the target users' representatives, and concluded by answering questions relevant to the mentioned heuristics and system's issues.

Following the method by (Sutcliffe, 2014), a set of classified problems have been discussed with the ATS employee:

- Graphic display (3D depth or perspective distortion, poor resolution of image)
- Moving and manipulating the user presence, sub-divided into the hardware device being used and the representation of the user in the VE
- Interaction with objects and tools in the VE
- Environmental features
- Interaction with other controls, such as floating menus and palettes
- Other hardware problems

If one of the problems has been identified during the usability testing, the expert had to evaluate the type of the problems either as "Severe", "Annoying" or "Distracting", otherwise, if there were no such problem - "Satisfying" (Sutcliffe, 2014). The Heuristic evaluation description is provided in the Appendix K .

Summarizing the preparations and continuing to follow the plan by (Rubin, 2008), the four first steps have been completed:

1. Develop a test plan	The usability testing of this project will be operated by qualitative research, that will include the following methods to collect the data for testing analysis: interviews, observation, survey, heuristic evaluation. The sequence of methods is the same. The design solution production will be finished in the period between the interviews and observation. It is planned to get the information from the interviews that would help the production.
2. Set up a testing environment	The consent form describing the activities, intentions of the research and users' rights has been provided **Interviews** ● Individual interviews with two pilots at the ATS office in Kristiansand ● Online interview via Microsoft Teams platform with the pilots' training manager

	● Individual interview with the ATS employee/expert at the University of Agder group room All of the interviews were audio-recorded using iPhone 11pro. There were no specific requirements for the environment, except approximately 30 minutes of participants' free time. **Observation** ● Individual direct observations with two pilots at the ATS office in Kristiansand ● Individual direct observation of the pilots' training manager at the office in Oslo ● Individual direct observation of the ATS employee/expert at the University of Agder group room VR HMD and hand controllers, the PC for setting up the test have been provided. The requirements for the controlled environment of the observation such as spacious quiet place with a seat for the user and Internet connection have been met. **Survey & Heuristic evaluation** ● Individual survey sessions with two pilots at the ATS office in Kristiansand ● Individual survey session with the pilots' training manager in the office in Oslo ● Individual heuristic evaluation with the ATS employee/expert at the University of Agder group room The PC for taking the notes has been provided and a survey form has been developed online.
3. Find and select participants	**Representatives of the target users' group:** two pilots, one pilots' training manager **Expert:** One employee of ATS/VR designer One more pilot has been invited to the usability testing, however, the participation did not happen.
4. Prepare test materials	● Consent form ● Interview questions for the pilots ● Interview questions for the pilots' training manager ● Interview questions for the ATS employee ● Audio recording device ● VR application prototype ● VR HMD and hand controllers ● PC ● List of the tasks for the test

	• Survey • Heuristic evaluation with the ATS employee

Table 3.5. Planning the design evaluation

In the following chapters the next four steps and the VR procedure trainer of abnormal operations development are described:

5. Conduct the test sessions
6. Debrief the participant and observers
7. Analyze data and observations
8. Report findings and recommendations.

4. Development & Testing

4.1. VR application development

Based on the conducted analysis of the user requirements and according to the described methodology, a VR procedure trainer of abnormal operations high-fidelity prototype has been developed. The following chapters describe the framework, attempts and the development process in order to address the research questions.

In cooperation with ATS, it has been decided that for the first prototype iteration the following abnormal operation will be implemented and tested:

- Abnormal Operation “Engine Failure during cruise” (Airbus Industrie, 2015).

“"Cruise" is the phase of flight that occurs between climb and descent. The largest percentage of total flight time typically occurs in cruise. An engine is rarely producing its maximum rated thrust during cruise and failures during the cruise phase are rare. However, they can, and do, occur due to mechanical failure, inappropriate maintenance practices or certain atmospheric conditions such as high level ice crystal icing.” (SKYbrary, 2020).

4.1.1. Technology and system requirements

VR headset and controllers

Initially, it has been planned to develop a VR procedure trainer prototype for the HTC Vive Focus Plus, however, during the development process the challenges with launching the application on the VR HMD have occured. To project the screen or run the applications that are in the development process, it is needed to have installed particular applications and plugins both on the PC and in the development software. The following options were tested in order to connect the VR HMD with the PC:

- Viveport (with “Infinity” subscription) (HTC Corporation, 2021).
- Steam VR (Valve Corporation, 2021).

- Virtual Desktop (Virtual Desktop, Inc. 2020).
- Unity plugins:
    - Vive Wave SDK Packages (HTC Corporation, 2021).
    - Vive Open XR (HTC Corporation, 2021) (The Khronos Group Inc, 2021).

Even though the HTC Vive Focus Plus has been set in "USB debugging"[1] mode and multiple tutorials were overviewed, the connection between the VR HMD and the PC did not succeed to get established: in some cases it would show errors, in others - full absence of connection. Therefore it has been decided to change the platform for VR prototype development.

Nevertheless, the HTC Vive Focus Plus has been put aside only for this iteration stage. It is planned to try researching another approach and solutions to the described challenge again.

The second alternative - Oculus Quest 2 has been used for the application's further development and usability testing instead.

Both of the VR HMD run on the Android OS, therefore by solving the challenges with the HTC Vive Focus Plus, it might potentially provide an additional opportunity to continue developing a prototype that would suit different VR platforms, hence involving more stakeholders.

The specifications of the selected VR HMD for the prototype of the VR procedure trainer of abnormal operations are following:

Oculus Quest 2 (Facebook Technologies, 2021)

- Panel Type: Single Fast-Switch LCD, 1832×1920px per eye
- Supported Refresh Rate: 72Hz
- Default SDK Color Space: Rec.2020 gamut, 2.2 gamma, D65 white point
- USB Connector: 1x USB-C
- Tracking: Inside out, 6DOF
- Audio: Integrated, in-strap
- CPU: Qualcomm® Snapdragon XR2 Platform
- CPU Notes: Developers have access to 3 gold cores
- Memory: 6GB total
- Lens Distance: Adjustable - 3 preset IPD adjustments
- Two controllers that require 2AA batteries each (Graham, 2021)

PC

The VR procedure trainer of abnormal operations has been developed on the PC with the following specifications:
Predator Helios 300 (Acer Inc., 2021)

[1] The "USB debugging" mode allows the developers to create and upload their own applications on Android devices.

- Device name: Predator 15 (G3 - 572)
- Processor: Intel(R) Core(TM) i7-7700HQ 2.80 GHz
- Memory: 16.0 GB DDR4 SDRAM
- GPU: NVIDIA(R) GeForce® GTX 1060
- Video memory: 6 GB GDDR5
- Operation system: Windows 10

Software

The process of designing the VR procedure trainer has been split into four different steps based on the tasks required to be completed in different kinds of software:

1. **Adobe Photoshop**

Adobe Photoshop is a photo, image and design editing software that lets artists develop various creative works (Adobe, 2021). The development of the VR application has started with a brainstorm creating an approximate visual concept using Adobe Photoshop 2021 as a platform. The static mockup has been implemented first, representing the design concept of the UI elements (examples provided in the chapter ***3.4. Design solution meeting user requirements***).

Further, the rest of the UI elements were created there too and exported in the PNG and JPEG format in order to be transferred to Unity afterwards. Based on the conceptual model, mockup and instructional strategy the rest of the UI elements were listed and produced: buttons, tabs, texts, numbers, frames, symbols, selection frames. The arrangement of the UI elements has been planned according to the instructional strategy and has been partly inspired by the NAS academy 2D procedure trainer of NNPC.

Figure 4.1. UI elements for the VR prototype's procedure steps

2. Autodesk Maya

Autodesk Maya is a software for 3D computer animation, modeling, simulation, and rendering (Autodesk Inc., 2021). A 3D model of the Airbus A320neo's cockpit has been purchased for the procedure trainer implementation (AirStudios, 2019). In the package of the purchase the 3D model with subparts such as panels, switches, seats etc. were included, as well as textures for the 3D model. The textures showcase the colors and the surface features of the cockpit and in some places, the realistic textures imitate the buttons too. However, the textures were not assigned to the needed places and on some switches and controllers they were missing.

In Maya 2020, all of the textures were re-assigned, some of the model's parts' UV-maps were reorganized and the missing textures were produced. Besides, initially the 3D model parts were named and listed chaotically in the hierarchy, therefore it has also been fixed in order to simplify further iterations. The 3D model has been purchased, edited and transferred to Unity in FBX file format.

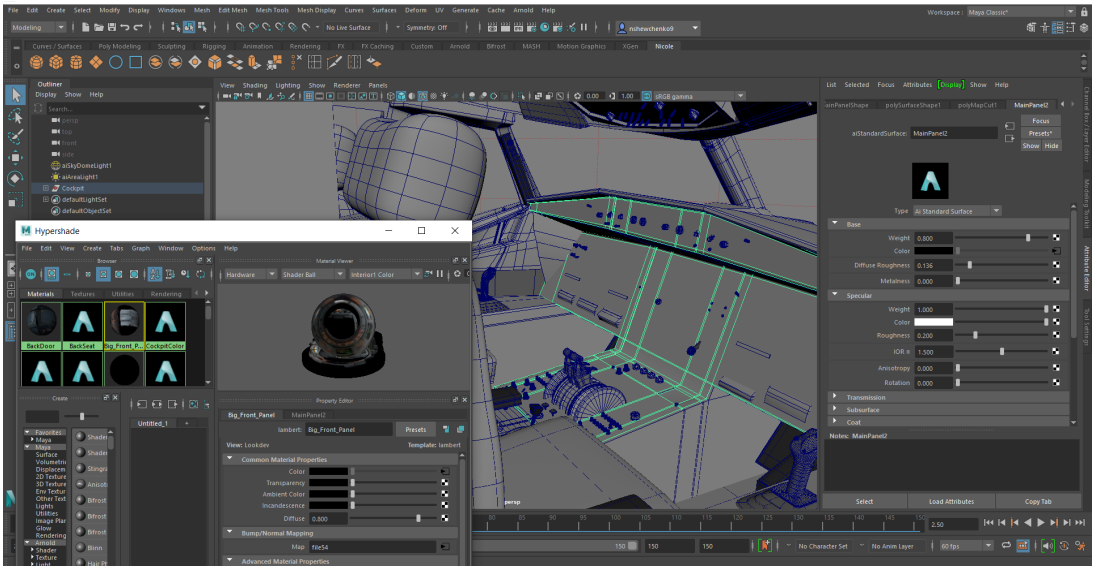

Figure 4.2. Screenshot of the workspace in Maya; Organization of textures on the model's elements

Figure 4.3. The Airbus A320neo cockpit's 3D model rendered in Maya; The textures are applied on correct objects in the cockpit, the 3D model is prepared to be transferred to Unity

3. Unity

For the third step of the VR procedure trainer development, Unity 2020.2.6f1 has been used. Unity is amongst the leading software for developing creative and interactive solutions such as 2D, 3D games and VR & AR experiences (Unity Technologies, 2021). Unity uses C# programming language for the applications' development.

In order to develop a VR application in a time-efficient way, a structure of tasks has been created:

VR prototype's scenes: Main Menu, Training Space: Guidelines "On" + Guidelines "Off" scenes		
Pre-production	**Production**	**Post-production**
• Plugins and workspace setup • 3D model placement and setup • UI elements arrangement	• Hand controllers' settings management • Scripts development and application	• Lighting and rendering • Export settings management

Table 4.1. Phases of the project development in Unity

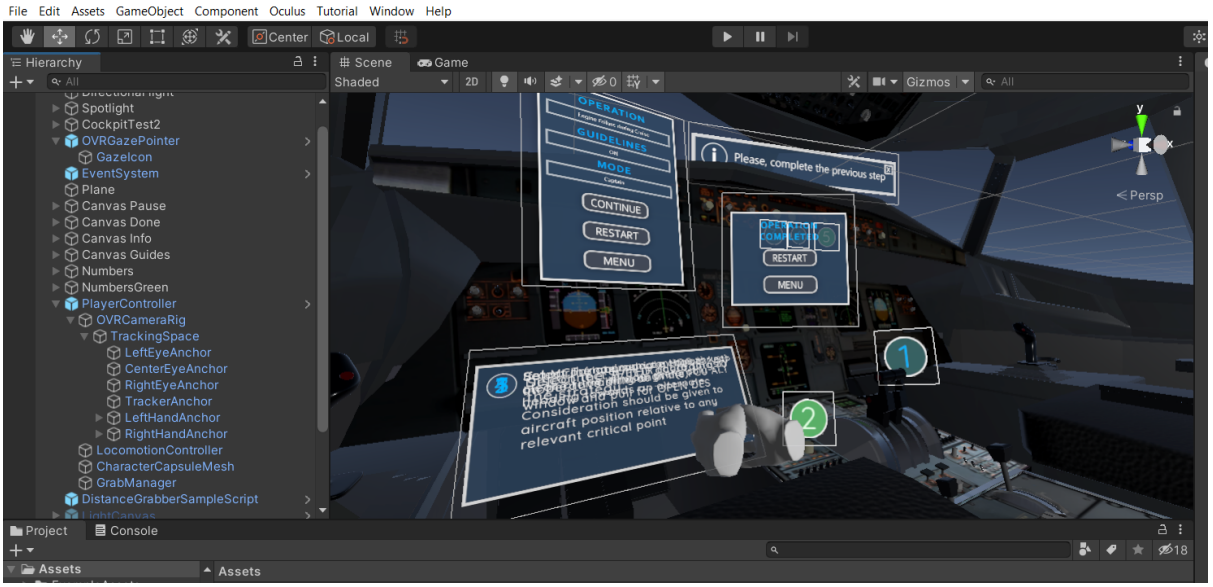

Figure 4.4. Screenshot of the workspace in Unity; Organization of the UI elements and hand controllers: Pre-Production and Production phases

Each of the production phases implied multiple subtasks and exploration of the most efficient ways of implementation. In the production phase, focusing on only selected requirements for the application, the overview of the scripts that will make the interactions real has been created.

Planning the scripts and functions	
Switching scenes	The "Main menu" is the first scene when the app starts.

	If the Guidelines “ON” is toggled - Guidelines “On” scene runs	If the Guidelines “OFF” is toggled - Guidelines “Off” scene runs
	Returning back to the main menu: - Through the Pause menu - After completing the procedure Restarting the training scenes: - Through the Pause menu - After completing the procedure	
Main Menu	Provides functions: - To set a toggle for the needed mode of training - “On hover” colour change of the elements before their selection	
Pause Menu	The “Pause menu” can be active only in Guidelines “On” & “Off” scenes - To pause: the “Start” button on the left controller - To resume: the “Start” button on the left controller or by the “Continue” button in the Pause menu + Provides options to restart the procedure or return back to the Main menu	
Completion menu	Sets active if all of the procedure steps are completed, provides options: - To restart the procedure - To return back to the menu	
Wrong action / Information message	Can be active only in Guidelines “On” & “Off” scenes. Sets active if the user tries to skip the step of the procedure/if the previous logical step is not marked as “completed” - Can be closed by the “X” button	
Guidelines tab	Can be active only in Guidelines “On” scene. - Updates whenever a step is completed: the text in the tab changes to the currently required step - Is empty when the whole procedure is completed	
Numbers of the procedure’s	- The blue colour is default at the start of the training	

steps	- The blue colour stands for not completed steps - Updates to green colour whenever the user has reached the needed controller/switch/element on the cockpit's panel - Does not get green if the user skips the step of the logical order

Table 4.2. The overview of the scripts for the VR prototype

3.1. Visual Studio

Visual Studio is an IDE by Microsoft. (Microsoft, 2021), the version used for the development: Visual Studio 2019 [16.7.1].

3.2. Plugins and settings

Unity plugins for developing the VR procedure trainer play one of the key roles in the development, as they support the consistency of different application's development and structure: if the user had already had some experience in VR, he/she would probably seek for similar kinds of manipulations in order to interact in VE.

- Oculus Integration package

"OculusIntegration.unitypackage, is a collection of core VR features, components, scripts, and plugins to ease and enhance the Oculus app development process in Unity". (Facebook Technologies, 2021). This package lets the developers create applications that would run on such Oculus devices as: Oculus Quest, Oculus Quest 2 and Oculus Rift S. Therefore, even though the application has been tested only on Oculus Quest 2, it is expected that it will also be suitable for the rest of the mentioned devices.

The Oculus Integration package includes the following prefabs that have been used in the VR prototype development:

- "OVRCameraRig: *A custom VR camera that optimizes rendering for a stereoscopic display on the Oculus device. It provides access to OVRManager, which is an interface to the VR hardware.*"(Facebook Technologies, 2021).

This prefab has been used in the "Main Menu" scene, it lets the users observe the cockpit 360 degrees around, yet remaining static as there is no need to walk in the space. It includes the scripts that let the users have a "Pointer" on the UI elements in order to choose the needed settings in the menu, as well as on other UI elements in the training scenes. As visible on Figure 4.5. , the pointer is a blue circle. The UI tabs are arranged according to previously presented digital mockup.

Figure 4.5. Screenshot of the VR procedure trainer of abnormal operations prototype: Main Menu

- "OVRPlayerController: *Allows the player to move around in the virtual environment. It includes components and child objects that are necessary for 3D control. It includes OVRCameraRig prefab to serve as the VR camera and is attached to a character controller.*" (Facebook Technologies, 2021).

This prefab has been used so that the users have the opportunity to see the controllers as their hands, which would make it more natural when training. The prefab also includes the realistic input functions: whenever the user presses on various buttons on the controllers - the projected hands in the VE move and bend fingers accordingly.

On Figure 4.6. the camera position for the initial placement of the users in any of the training's modes is selected. The advantage of the prefab lets the users choose a more convenient position in space by using the joysticks on the hand controllers. During the VR prototype development, there was no chance to visit a real cockpit, therefore, there is no information about the correct proportions between the height of the pilot and distance to the elements on the cockpit's panel. Hence the joysticks would help to move the user a bit closer to the cockpit panels if it is needed.

Figure 4.6. Screenshot of the hand controllers in the VRLE

When developing a script for implementing the interaction between the hands and the elements on the panel, it was needed to know how do pilots interact with different switches in real life, how does each of the required buttons look like when it is pressed, what position of the lever should be before interacting and how far it is possible to pull it.

To solve this issue an additional investigation has been made by asking one of the pilots specific questions in written form. The questions have been reviewed by one more pilot, however, due to the different aircraft specialization, it was not possible to fully clarify all of the interactions. It has been decided that in the future iterations, the connections with pilots through ATS will be expanded and more consultants will be found to provide the needed information. At the current stage, an alternative has been implemented: to complete the required step of the procedure and activate the next steps on the panels, the user has to reach/touch a correct element by hand in VRLE.

The questions are placed in the Appendix J . In addition, the letter has a brief introduction to the project that has let the pilot get acknowledged with the concept better.

The realistic rendering settings were not amongst the main priorities of this iteration of VR prototype, they were set in a way that would save time on rendering and proceed to the usability testing stage earlier.

4. SideQuest

SideQuest is a tool that enables additional functions on the Oculus Quest HMD that are usually not accessible on the goggles directly. (UVR Media LLC, 2021), (sidequestvr.com, 2021). In this project, SideQuest was needed to launch the VR procedure trainer on the goggles. It has been decided to keep the application in the development format to have an

opportunity, if needed, to add any minor edits, before, during or right after the usability testing.

SideQuest functions by a simple principle: it is only needed to connect the Oculus Quest 2 to the PC with the USB cable, allowing the file transfer between the VR HMD and the PC. Then it provides an option to first install the application on the goggles (one time procedure), afterwards it enables an option to launch the app on the goggles. Whenever the application is running on the Oculus Quest, it is possible to disconnect the USB from the PC and continue the experience.

SideQuest provides a convenient framework for organizing and side-loading the applications for Oculus Quest 2 goggles.

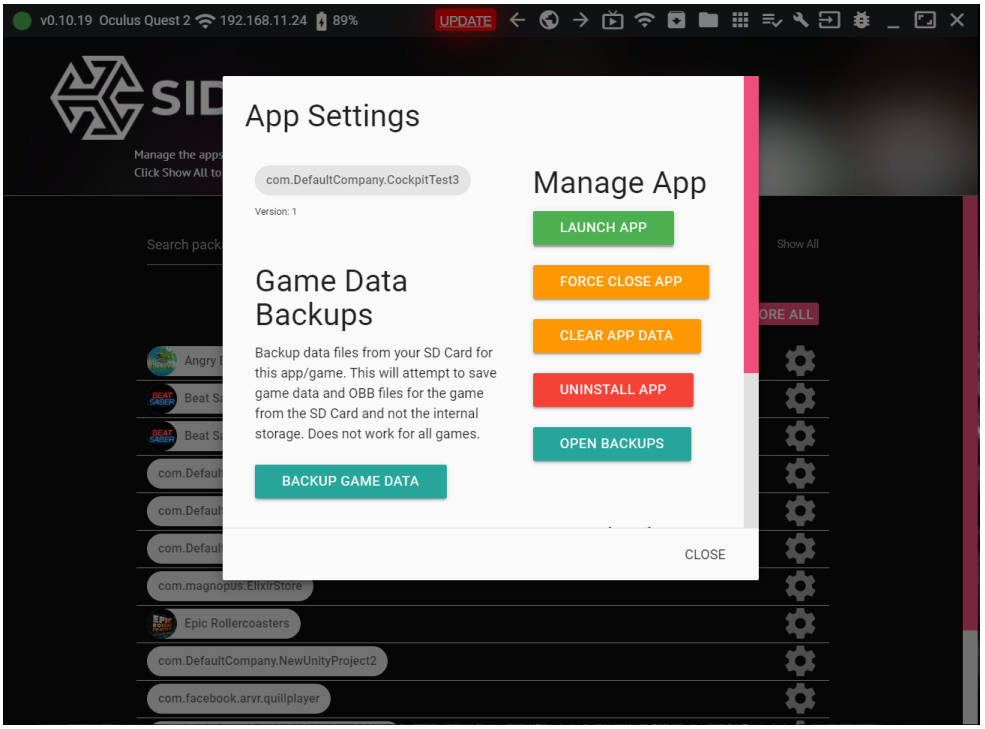

Figure 4.7. Screenshot of the application's launching procedure

4.1.2. VR procedure trainer

As a result of the development phase the VR prototype has reached the following progress and specifications:

- VR procedure trainer of abnormal operations, made for pilots to reinforce the knowledge and involve psychomotor skills in the memorization process, while being immersed in the virtual cockpit of an Airbus A320neo. The presented VR application includes training for one of the abnormal operations for this aircraft: "Engine failure during cruise". This procedure can be trained in one of the two modes:

- Guidelines “ON”
  This mode lets users complete the procedure following the guidelines that explain each step of the procedure. In addition to informative guidelines, the numbers of the steps are placed next to the relevant cockpit’s elements such as lever, buttons, switches, etc. They indicate the progress of the procedure's completion and turn green when the pilot completes every step. In order to enhance the memorization process of the correct sequence, it is not possible to skip any of the steps.
- Guidelines “OFF”
  This mode is made for self-assessment, as there are no guidelines provided to explain the meaning and sequence of the steps. The users are only able to see the amount of steps that are ought to be completed. It is also not allowed to skip any of the steps in this mode.

In order to complete the step in any of the modes, the users should touch the needed element in VRLE. There is also an option to pause the training, restart it, or leave it and return back to the main menu. In the main menu it is possible to get acknowledged with the instructions on how to use the application. The figures 4.8. to 4.11. showcase how the VR application looks like. The grey tabs in the upper corner indicate where and what is captured and are not parts of the VE design.

Figure 4.8. Screenshot of the VR procedure trainer of abnormal operations prototype: Main Menu

Figure 4.9. Screenshot of the VR procedure trainer of abnormal operations prototype: Guidelines “On”

Figure 4.10. Screenshot of the VR procedure trainer of abnormal operations prototype: Guidelines “Off”

Figure 4.11. Screenshot of the VR procedure trainer of abnormal operations prototype: UI elements

The VR application is meant for Oculus Quest 2 VR HMD and requires to use both of the hand controllers.

The following chapter describes the procedure of testing the usability of the provided VR prototype.

4.2. Testing and Evaluation

The usability testing took place following the time and location agreement between the researcher, ATS and participants.

The interviews, observations and surveys with two pilots took place at the ATS office in Kristiansand. Both of the pilots took part in the test on the same day, but at different times. On the figure 4.12., the setup is represented. Before the start, the pilots had to read and sign the consent form, then they were also introduced to all of the tasks of the usability testing. None of the pilots minded to be audio-recorded during the whole usability testing. They were also aware that at any moment of the usability testing they are free to leave, if they feel uncomfortable or request withdrawing the consent form and deleting the audio recording.

The whole usability testing with each of the pilots, including the interview, observation and survey took around 1 hour 15 minutes.

Figure 4.12. Usability testing setup at ATS office: Oculus Quest 2 with hand controllers and USB cable to launch the app, the PC, consent form; The chair on the left side for the participants

During the interviews, both of the pilots confirmed that they don't have much experience with VR technologies, VR HMD and controllers. Therefore, before the application's test, both of the pilots got a quick but detailed instruction:

- The overview of hand controllers buttons' and their functions
- The VR HMD adjustment to their heads
- Defining the boundaries for interaction, before start[2]

As it has been also mentioned on Table 3.3. *User tasks for observation* in chapter ***Observation***, before completing the tasks, the pilots were given a few minutes to get used to VR, controllers, feel more comfortable moving hands, turning head, etc.

[2] When turning on the Oculus Quest 2 goggles, the first thing it asks the users to do is define the boundaries of interaction: the user has to point where the floor is and how big is the "Play" area. There is also a choice for stationary experience, which means that the user will be sitting during the VR experience.

According to hygiene requirements, before and after each application's testing, the VR goggles and hand controllers were thoroughly sprayed with antiseptic spray and wiped with antibacterial napkins. There has also been a sufficient distance between the researcher and participant during the whole session.

Before the completion tasks, the Oculus Quest 2 has been set in cast mode, so that the researcher could see the stream of everything that was happening in the VR on the PC. The screen of the PC has been recorded during the sessions for an opportunity to analyze it more if needed later.

After the application's testing, the pilots took part in a survey. The pilots could see the questions and statements of the survey, yet the fields were filled out by the researcher due to the hygiene requirements. In addition to the survey, the pilots were commenting their thoughts and expressions from the VR experience - the notes were written down.

The usability testing with the pilots' training manager has been conducted following absolutely the same structure. The only difference was location: the interview has been taken during the online meeting using Microsoft Teams platform. The usability testing took place in Oslo at the pilots' training manager office of work. The office had all of the needed requirements for conducting the observation and survey.

The heuristic evaluation with the ATS employee also followed the same structure, yet the interview, observation and evaluation took place at the group room at the University of Agder in Grimstad. It was not needed to conduct a detailed instruction on how to use the VR HMD and controllers, therefore the whole session took less time.

After the usability testing, all of the collected data has been analyzed following the described methodology. The recordings of the interviews with the participants have been written down, the notes from the observations organized and the information from surveys represented in charts.

Summarizing the testing and continuing to follow the plan by (Rubin, 2008), the three other steps have been completed:

5. Conduct the test sessions
6. Debrief the participant and observers
7. Analyze data and observations

In the following chapter the last step is described:

8. Report findings and recommendations

5. Findings and Results

5.1. Design of VR learning environment for training abnormal operations procedures for pilots

RQ1: What is the design solution for developing a VR learning environment for training pilots abnormal operations' procedures?

To address the first research question a thorough investigation on HCI field has been done and different methodology approaches have been reviewed. The HCD approach has been chosen and tested in order to develop the design solution, which has led to satisfying results: the VR application prototype runs smoothly, without major distracting system issues even at its early design iteration and has received positive feedback from target users.

The development of the VR design solution requires a careful procedure of preparing the materials and purposes for its implementation. A deep analysis of user requirements and possible contexts of application's use, choice of hardware and software provide a stable base for the design production. All of the techniques applied for this project have sufficiently moved the progress forward: the PACT analysis, User stories and personas, interviews with the target users' representatives have helped to understand the most important things: Why do the users need this product and what do they expect to see in this solution? This information led to forming the strategy for VRLE development and confirmed that the developers should keep in mind users' perspective of perceiving the VR application during all of the progress stages.

When designing a VR learning environment it is very important to consider specific features of the technology, that also led to even more questions for investigation: How to implement intuitive communication for users who, for example, might not have had much experience with VR technology before? How to develop an environment that would not distract the users from the main purpose of learning? To answer these questions, the usability testing procedure might be one of the most efficient and useful ways to conduct because the target users' are the main sources for the system's intuitiveness and effectiveness evaluation.

The framework used during this VR prototype development has produced solid results, therefore it is possible to say that the design solution is a whole from combining specific techniques that contribute to reaching these results:

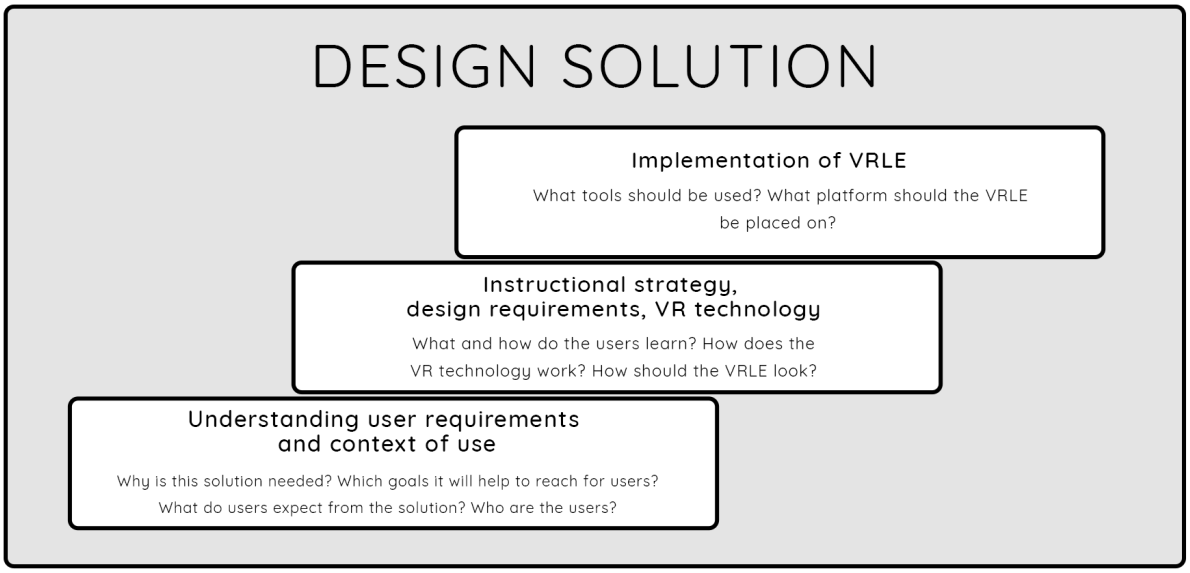

Figure 5.1. What is a design solution?

Figure 5.1. shows that the design solution is defined by all of the progress stages that have been done for this project. Each of the steps has equal value and cannot be removed. It also cannot be replaced as the design solution should keep a logical order for the needed information research. Each of the stages is meant to solve a particular set of challenges and questions, therefore qualitative research and its methods have been chosen to find a design solution as well.

Design solution for developing a VR learning environment for training pilots abnormal operations' procedures is a full completion of HCD approach techniques described in chapter ***3. Methodology*** and structured production phases proposed in chapter ***4. Development & Testing***.

5.2. Design of effective instruction of abnormal operations procedures for pilots

RQ2: How to design an effective instruction of abnormal operations' procedures for the Airbus A320neo cockpit on a VR platform?

In order to understand how to design an effective instruction of abnormal operations' procedures on a VR platform, first of all, it was needed to investigate the learning theories that VR might be good for. It was also needed to review similar VR solutions that have been developed for educational purposes and succeeded in the aviation industry. The collected information and proposed problem statement helped to develop an instructional strategy and set the priorities for implementing the needed elements for training in VRLE.

In this project, the main focus for implementing effective instruction is aimed at enhancing one of the cognitive processes - memory. In order to enhance the memorization process for users, the VR technology advantages were used: an opportunity to involve motor skills in the learning process and full-immersion in the learning environment.

The interviews with the target user representatives helped to compare the traditional methods of training the abnormal operations and the proposed VR concept. It revealed what is missing in their current learning approach and whether it is possible to implement it in VR.

Proposing the VR technology as a complementary tool to the traditional approach corresponds to the connectivism learning theory principles and it expands the educational opportunities for pilots, adding them more choices on how to memorize the abnormal operations' procedures.

The analysis of the target users, their requirements and context of use, helped to formulate additional requirements that would enhance the effective learning process in VR. For example, the design of the application should be quite minimalistic so that the crowded user interface does not distract the users from their educational goals. It is needed to have feedback on the current progress of the training, therefore the numbers on the cockpit panels turn green whenever the step is completed and the guidelines for the next step update accordingly. The training is straight-forward, meaning that it makes the pilots memorize only the correct sequence of the steps, without an opportunity to skip any.

The effectiveness of the implemented learning environment in VR has been evaluated by the target users and the results are presented further.

5.3. Usability testing results and data analysis

RQ3: Which advantages does VR imply for procedure training of abnormal operations?

To address the third research question, the usability testing has been conducted, including three different methods: interview, observation and survey.

5.3.1. Findings from interview

Besides figuring out the correct terminology to be used in the prototype and getting to know the target users, the interviews were meant to get a better understanding of how the pilots study, what is the structure, time settings and tools that pilots use not only for abnormal operations, but in general too. The interviews present the information for wider understanding of what the abnormal operations are and how pilots manage them. Nevertheless, it is also possible to highlight some particular findings from the conversation that address the RQ3.

- **The traditional approach to study the abnormal operations and the contexts of use for a VR procedure trainer**

According to the information provided by the pilots, it is typical to study abnormal operations for a particular aircraft during the Type Rating, which is a course that makes a pilot to be specialized on the aircraft that he/she will fly. The pilots train only the most critical abnormal operations in the simulators during their course. Each of the abnormal operations has a lot of nuances, therefore it is not possible to cover all of them during the training. There are also some of the less critical abnormal operations, for example, sensor failures or failures with the radio altimeter callouts, which pilots might also experience.

The most common way to study the abnormal operations, including the less critical ones, is by reading the Quick Reference Handbook and aircraft manuals, learning to understand how the systems in the aircraft work. In order to add the practical part to the training, the pilots have an option to use a paper prototype, called "Paper tiger". It is basically a combination of cockpit's panel posters folded and placed as if it was a real cockpit. However, one of the pilots said that these are usually located at the training centres and there might be, for example, just two paper tigers, but 20 students in the class who might need it to train. What do the pilots miss about the paper tigers is, of course, the systems' feedback, the realistic interactions with the systems. All of the interview participants see the potential of implementing the procedure training in VR and using it as an alternative to the paper tigers, Here are some quotes from the interviews:

- *"Yes, and that was also what I was hoping for because what I personally miss about the paper tiger is* ***having feedback*** *because it is easy to do it in the aircraft when you have that* ***system that responds to you****. So if you could have a training program which does that - that would be very very nice. And having, basically, a digitized paper tiger could be very very useful, to see how the system responds."*

- *"For Airbus, I know we have two paper tigers for SAS, and maybe 20 pilots are doing a course at the same time, and you have only two paper tigers.* ***It would be much better to have VR goggles for loan.*** *You don't have to own them, but the company could have 5 or 10 sets of VR goggles that you could bring home. Now you have to be, for paper tigers, at Gardermoen to use them and maybe there is somebody else already, you don't get time to book it. So* ***I really see the potential with VR goggles****."*

- "*I would say that the* ***VR would be a very good substitute for the paper tigers*** *because they are cheap and they require a lot of room (paper tigers)*, so *you actually have to go to the training centres and most of the training centres have one or two paper tigers and a class of maybe 10 students.* ***If you had a VR - you're free.****"*

- *"And it actually is still that way, we have our computer-based training on our iPads, and we do a combination of reading manuals and CBT (computer-based training). We don't have very much classroom teaching, it is mostly self-study."*

- ➢ *"QRH (Quick Reference Handbook) which describes all of the failures, so you cannot cover all of them in the course. Some of them are just like: "The system has failed; and how to deal with the system", so what you train is actually, how to read from the handbook and how to properly use QRH, how would you handle the emergency situation.*"

The last two quotes also confirm that applying a student-centred learning theory might be appropriate because the pilots already conduct a self-study, interpreting and memorizing the learning materials in their own way. Offering one more learning tool, such as a VR procedure trainer, might expand their learning approaches.

- **Challenges whereas the VR procedure trainer can be use as an alternative tool**

Besides the paper tigers there is a full flight simulator or a 2D computer-based procedure trainer, where the pilots can complete the procedures', however, for example, the flight simulators are very expensive and pilots do not have access to them whenever they need.

- ❖ *"No, they are extremely expensive and bookable only by the company, so that's why we came up with a paper tiger. ... They are expensive, maybe 3000-4000 NOK per hour. As a pilot, you can't afford it, as a captain - they don't pay you to do it. That's why we had paper tigers since the beginning because it has been a cheap tool... "*

- ❖ *"It's mandatory for Boeing, I guess it's mandatory for Airbus (briefing the abnormal operations). For example, I would also brief what to do during the engine fire or an engine failure, or a wind-share (the change of wind direction, a speed during the take off, that could be critical for the flight) - these things we talk about before the first departure, so we know what to do. And it's the same every time: hand grips, the throttles and the speed - it's the same brief before each flight, but anyway it is important.* ***That's just to get motorics, motor skills.****"*

- ❖ *"Now in SAS a lot of guys are transferring from 737 to 320 (Boeing 737 and Airbus A320 - author's note). So having an opportunity to just go into a simulator and* ***just having an idea of how it looks and how it feels like.****"*

One of the pilots has also said that the simulators that the airlines owe or rent are located only in a few locations, therefore it is a kind of a challenge to physically access them.

An interesting finding is that the pilots' training manager has proposed the content for the VR procedure trainer and some of his proposals coincided with the prototype which by that moment had already been developed. The difference is that the design solution for this iteration did not consider implementing exploratory mode and test.

- ❖ *"My idea, how I would like to have it is that, two or three ways to use it. First, brand new pilots, never been there before, then you can put all your glasses on or do it on screen, and then you're prompted to highlight the switches in a sequence you should*

use. So it guides you where to do it (procedures). Then you can have a "free play", so you can do it on your own. Then for the problem check, I would like to have… Let's say you have 10 steps in the procedure, then you have to do 8 or 9 steps correctly, depending on how you put it, to pass that check. ***So you can have three races: guided, free-play and test.****"*

5.3.2. Findings from observation

The observation helped to understand the behaviour of users with the VR prototype and whether they see the advantages of a procedure trainer.

Even though the users were asked to comment on their VR experience, sometimes they got too focused on exploring VR, therefore some additional reminders and questions were asked during the process too. Nevertheless, during the users' completion of the tasks, several notes were still taken down.

- The common behaviour

All of the participants were new to the VR technology, none of them had an opportunity to fully experience and interact within the VE before. Therefore, all of the participants were very careful at the beginning of the test. It has been expressed by a bit of slow movements and actions, when, for example, clicking a button or selecting an option. However, the process of getting used to the VR environment and controllers did not take the users longer than 2-3 minutes. As it was mentioned in chapter ***4.2. Testing and Evaluation***, the users also got an introduction on how to use the controllers, how to select elements in VR.

All of the participants have experience with Boeing aircraft, but not with the Airbus that was represented in VR. However, there were no signs of pilots and the pilots' training manager being too confused with the navigation within the cockpit of the Airbus.

- Interaction with the UI elements and the cockpit panel

The participants quickly learned how to select the needed settings for the training mode, how to click on the buttons in the pause and completion menus. Exception was the information tab that asked the participants not to skip the steps: since it was during the procedure completion, the participants intuitively tried to close the tab by touching it the same way as the cockpit's elements. In reality, they needed to manipulate the pointer and click on the button on the controller to close the tab.

The participants had some challenges pressing the flat buttons on the hand controllers. There are two buttons on the Oculus controllers that are not meant for being involved in the application's process, but have such functions as, for example, interrupting the whole application to leave it or recentering the view, etc. The pilots needed one of such buttons on the controller to pause, but could not press it properly from first tries.

- The proportions of the cockpit

The pilots have emphasized that they get a feeling of being present in the cockpit. Nevertheless, the seat and the height of the view should be adjusted - the pilots used a joystick to get closer to some of the panel's switches.

Besides the main notes on the usability of the applications, the participants have mentioned a few more suggestions during their VR experience:

- Mentioned the audio guidelines as a good potential addition to the training
- Would like to have more functionality of all of the buttons in the cockpit to explore
- Implementing the operators manual on the panel of the cockpit

The observation has shown that the representatives of the target users enjoyed their experience, as they did not have any confusions. Even when the pilots had to go through the procedure without the guidelines, they succeeded to do that. In total, it took around 15 minutes with each participant to complete all of the tasks mentioned in chapter ***3.5.1. Observation, Table 3.3. User tasks for observation.*** When the participants had a few minutes after completing the tasks, all of them returned to the training modes, tested buttons a few times more and looked around the cockpit.

5.3.3. Findings from the survey

Analyzing the results collected from the survey answers, it is possible to say that the representatives of the target users have confirmed a practical potential in using a VR application for procedure training of abnormal operations.

The survey started with asking open questions and the answers were following:

- What is your overall impression of the VR application?
    - *"I like it, I definitely see the potential, even though it is a big challenge. Positively surprised that it is actually possible to visualize and implement."*
    - *"Will be useful for the young pilots, those who did not fly with aircrafts before, but for the senior pilots might be more challenging to get used to the technology (probably would prefer a traditional simulator). Predicting negative feedback regarding the time of getting used to the app. Can be good to try this application before they go into the simulator (for everyone)."*
    - *"It has a potential"*
- In your opinion, what is the biggest advantage of such a training approach?
    - *"Good focus on actual training, not on VR technology; opportunity to have action in training and interaction with the panel that would provide feedback."*
    - *"Definitely more advanced and useful than a paper tiger, especially for young pilots for understanding the flows in the aircraft."*

    - *"Response from the system and response to what happens in the cockpit; The cost of the tool."*
- Would you personally use such a tool?
    - *"Definitely - when it is a finalized product."*
    - *"If I would have to use it for training pilots - would use it mostly for Normal procedures and just the introduction to the Non-normal procedures."*
    - *"Absolutely, no doubt!"*

The pilots and pilots training manager have expressed a positive feedback to their user experience in developing VR procedure trainers. Based on the answers, it is possible to assume that some of the user requirements have been implemented in this solution in a way users would find them useful. In the next part of the survey, pilots had to evaluate the statements according to their experience from testing.

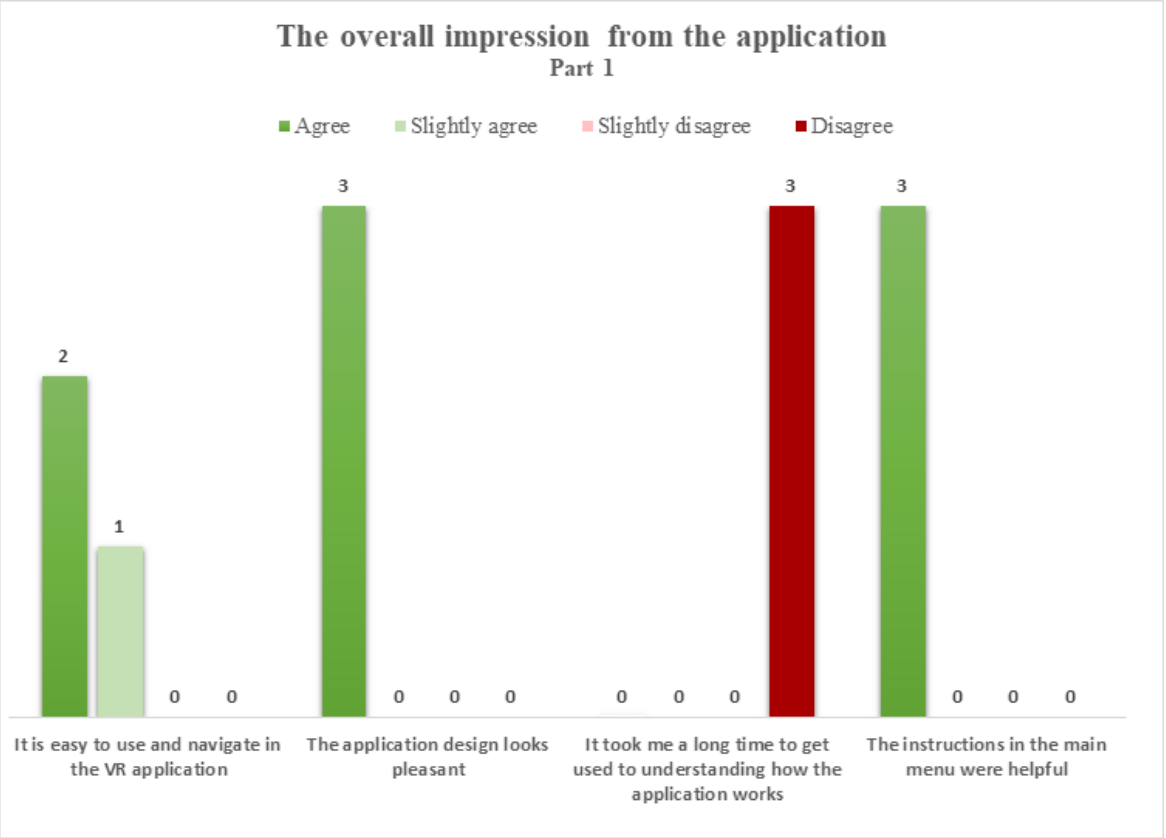

Figure 5.2. The results of the survey's section "The overall impression from the application" Part 1

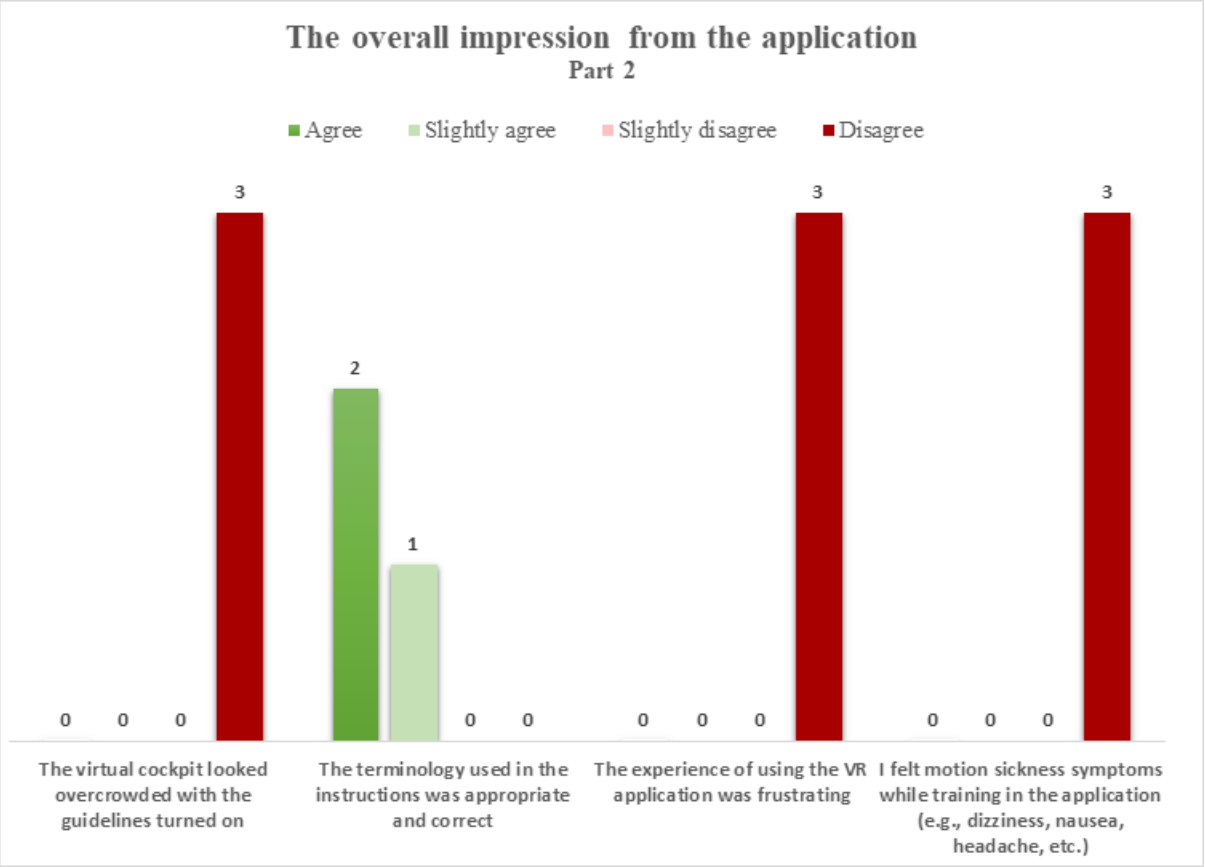

Figure 5.3. The results of the survey's section "The overall impression from the application" Part 2

The overall impression mostly provides positive feedback, confirming that the application suits the users of different VR tech-literacy levels and backgrounds. The users felt safe in the application as all of them disagreed with the statements about feeling motion sickness, or that it took them a long time to understand how to use the application, and that the experience was frustrating. All of the participants agreed that the design of the application is pleasant. The overall impression section has been meant to investigate whether it is safe to use the application, easy to learn how to use it and whether it is satisfying.

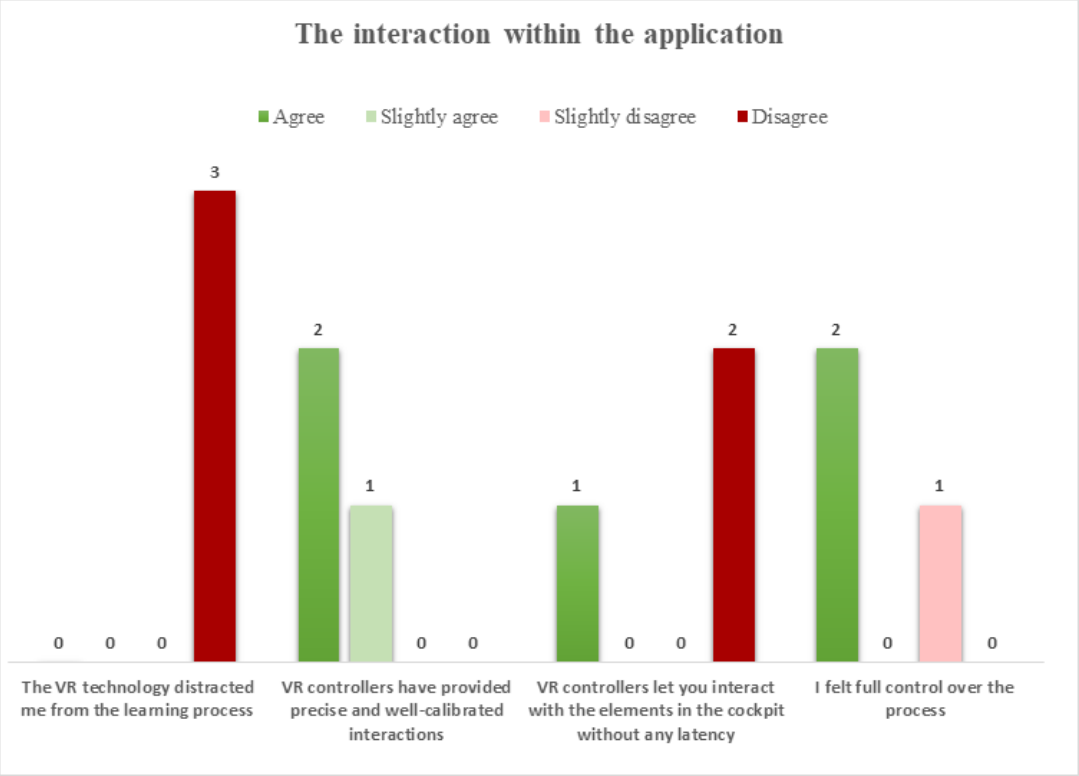

Figure 5.4. The results of the survey's section "The interaction with the application"

The second section of the survey shows the results of how efficient and effective the interaction with the VR application is. Answering to "I felt full control over the process", one of the participants slightly disagreed because of the lack of having an exploration mode, whereas the users could freely explore how the systems of the aircraft work, instead the application let the user follow only particular order of actions in the training.

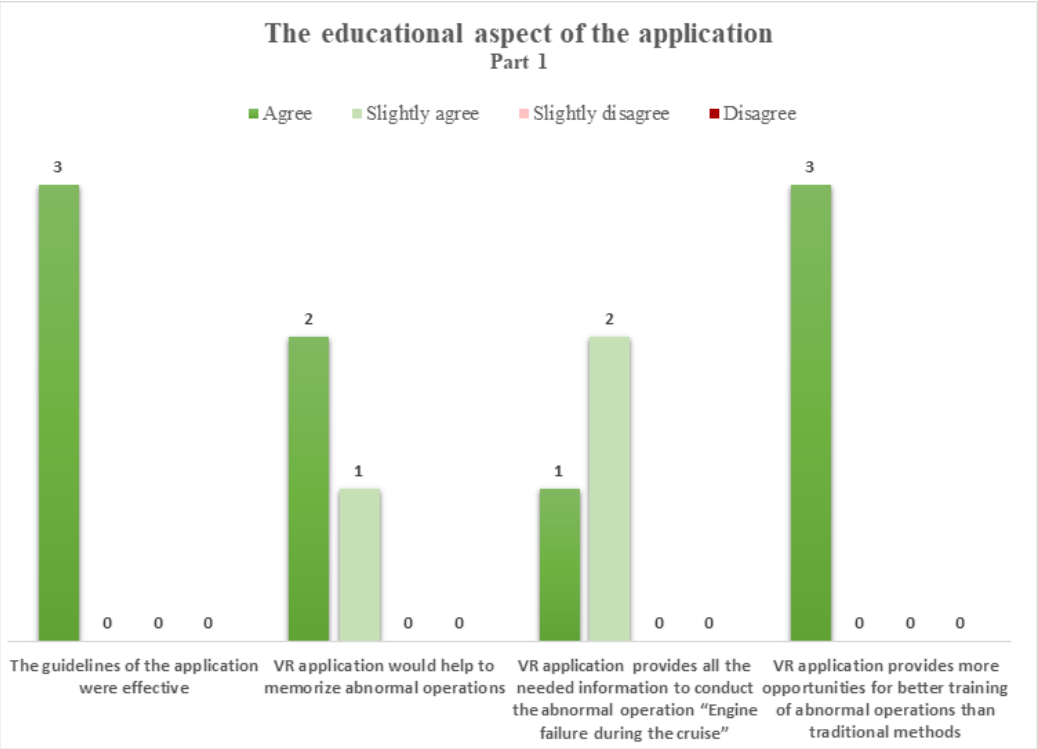

Figure 5.5. The results of the survey's section "The educational aspect of the application" Part 1

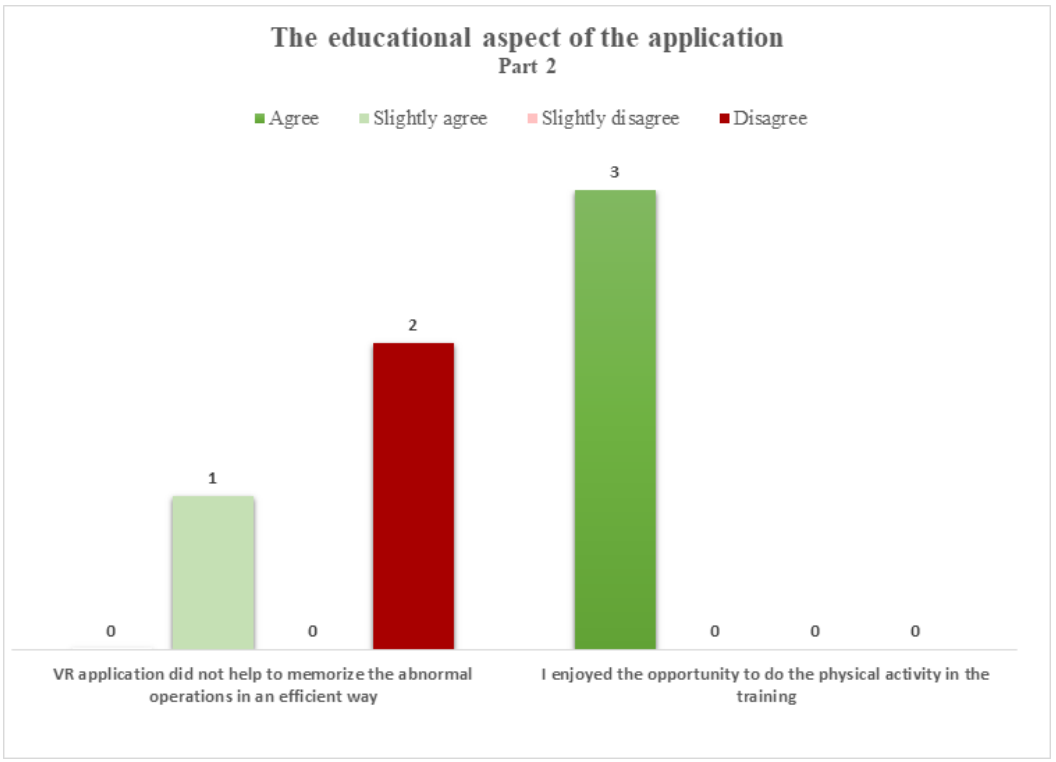

Figure 5.6. The results of the survey's section "The educational aspect of the application" Part 2

The third section of the survey shows the educational aspect of the application and whether the users consider it as efficient to use for training and usable for learning in general. The answers of participants confirm such a positive aspect of training in VR and that it is good to involve physical activity in training, the guidelines are effective, it provides more opportunities for better training of abnormal operations' procedures.

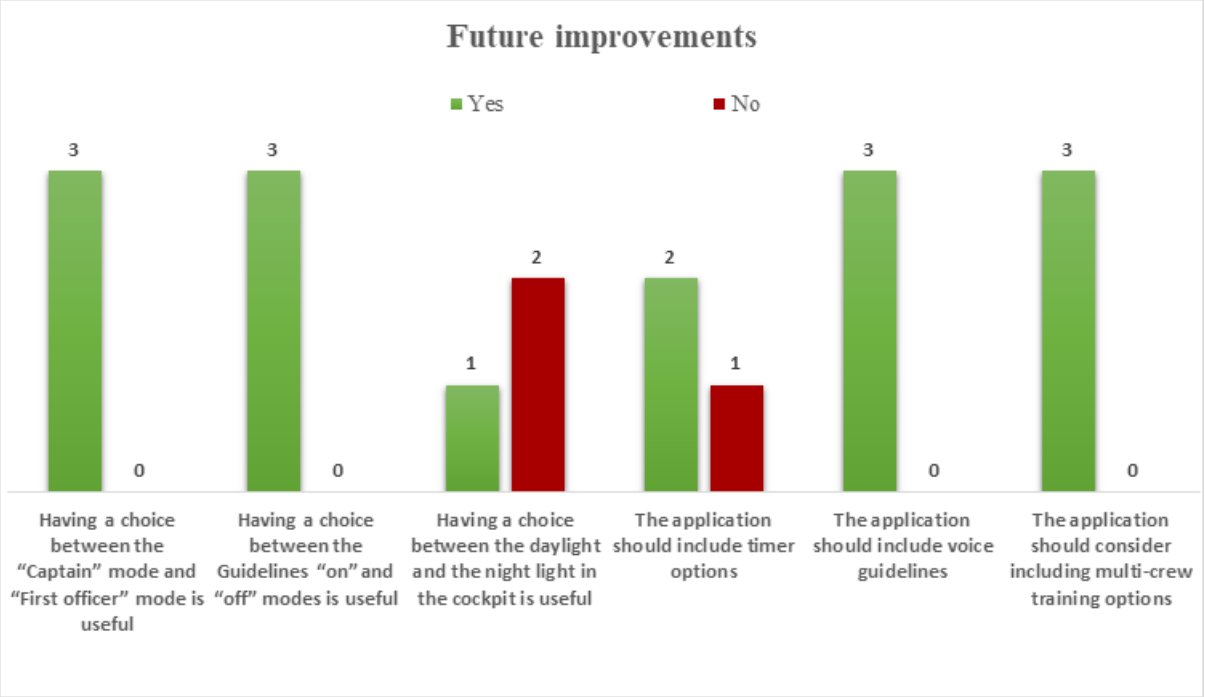

Figure 5.7. The results of the survey's section "Future improvements"

Besides the improvements of the user requirements, the survey has been also meant to help establish new targets for future iterations. Therefore the users also evaluated additional options of VR procedure trainer proposed for the next iterations. The users agreed with the idea of having voice guidelines, choice of roles and multi-crew training options. They have also agreed that an already existing function such as two different modes of training is useful, meanwhile the proposed in the app choice of daylight or night light outside the cockpit has not been considered necessary.

In conclusion the participants were also asked whether they had their own suggestions for improvements.

- Do you have any suggestions for the improvements to the application?

One of the pilots has agreed with the improvements' proposed in the previous section and did not add any to those. The second pilot marked that the joystick on the hand controllers was too sensitive and the boundary of action that gets set for the sitting VR experience in Oculus was distracting - at some stages of the training the pilot leaned a bit forward with stretched arm, this awakes the boundary and displays a net to the user. The pilots' training manager had multiple ideas regarding this question:

“It should have an "exploration" mode that would let the user try out different systems and see how would they respond; Should remain realistic to maintain the trust, e.g. if you push wrong - than you see the realistic feedback of what is wrong; It is very useful to the newcomers to try out how does the system works; More potential to train Normal Procedures - as there are more of the memory items; Would not recommend VR as a flight simulator as it lacks realistic motion, but as a procedure trainer - yes.”

5.3.4. Findings from the heuristic evaluation

The heuristic evaluation helped to reveal a few of the functional issues that should be improved and tested in the next design iterations.

- The same issue mentioned by the pilot: the joystick on the hand controller is too sensitive.

This joystick was needed in the current design iteration, due to the lack of information about the proportions of how high should the seat be, how far should the panels be and the provided 3D model apparently did not have them set in the correct way either. It is an alternative to help the pilots move in space if in this iteration the elements are too far or too close. Presumably, in the future iterations it is possible to implement settings on adjusting the height and position of the seat and then remove the use of the joystick completely.

- Instructions should include illustrations

This might improve the ease of learning how to use the application, especially for the users who did not use the VR goggles before. Current text instructions are helpful, yet the visual representation can be very useful too.

- During the training in the Guidelines “ON” mode, if the user reaches first the step nr.1, then nr.2 and then accidentally touches the 1st step again - it causes a bug in displaying guidelines description.

It displays the text about step nr.2 and nr.3 simultaneously. While in the app, it is possible to fix it by touching step nr.2 again, but the script should be reviewed anyway to avoid the bug in the future.

- Since the step nr.3 and nr.4 are located closely, in some cases they might get updated green simultaneously

The issues might be fixed when the realistic interactions in the cockpit will be implemented. It will be possible to complete nr.4 only after a full interaction with the nr.3, not just after touching the needed controller, as it is at the current early iteration.

- Adding a 3D model of the controller in the main menu

This suggestion can be practical for the consistency improvement, as currently the main menu has only the pointer on the UI elements and the training modes have the pointer on the pause, information, completion tabs and hands for interaction with the elements. In the main menu either hand controllers or hands could be visible too.

Besides the revealed issues, the employee ATS testing participant thinks that the VR procedure trainer is very good and useful, it looks good and is attractive. It seems very helpful with the steps and for pilots it is a good step in between the classroom and simulator

studies, to get used to the upcoming full simulator training, and get the feedback from the system to the conducted actions.

5.4. Additional findings and results

During the interviews and surveys after the usability testing, one of the pilots and the pilots' training manager have proposed that the same concept of the VR procedure trainer might be even more useful for normal operations. They have explained that in comparison with the abnormal operations that occur rarely, normal operations are more routined and are mandatory to go through before each of the flights. Normal operations might have even more of the memory items that the pilots are required to know by heart. Therefore, it has been proposed that the VR procedure trainer for normal operations might be also a good idea to investigate and develop, also as a complimentary tool in the pilots' training.

5.5. Further steps at ATS

The VR procedure trainer has been submitted for financing its further development, using the feedback collected during the interviews, usability testing and surveys. The project has received a positive answer and approval for further development.

One of the next steps to focus on the VR procedure trainer is to fix the functional and non-functional issues that have been discovered during the research and testing. The next phases of the development should continue filling up the blank spaces in procedure trainer's instructional, visual and interaction content. Besides, one of the steps to implement is to develop ATS own 3D model of the cockpit to be able to use the product for commercial purposes. For example, there have already been attempts, yet due to the time limits the focus had to be aimed at other tasks.

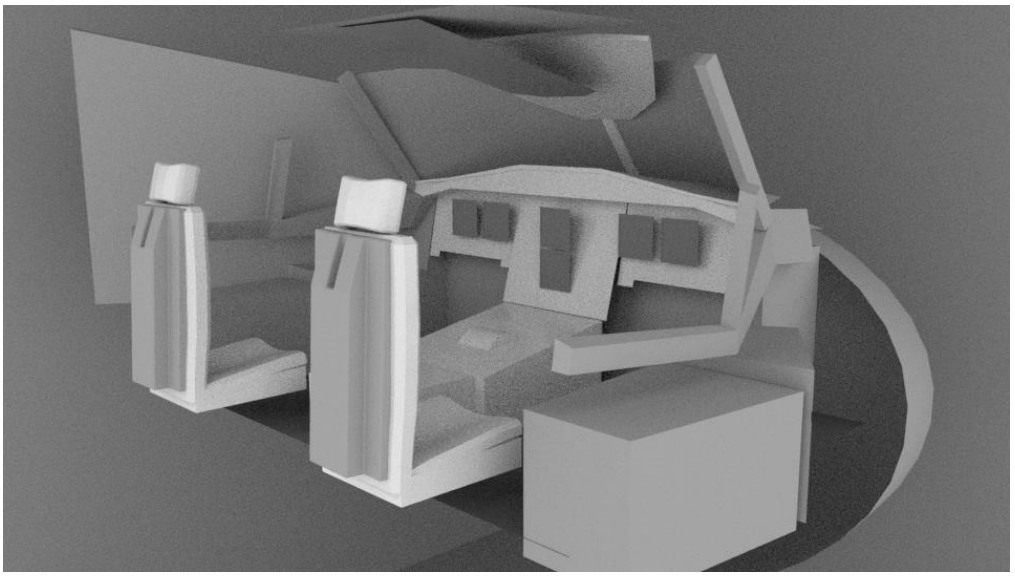

Figure 5.8. Early stage of the 3D model of the Airbus A32oneo development in Maya Autodesk

6. Conclusion

A VR solution for procedure training of abnormal operations has been developed as a complementary tool to the traditional approach in the pilots' education. The VR procedure trainer lets the pilots train one of the abnormal operations for the Airbus A320neo: "Engine Failure during cruise". An instructional design has been implemented for the virtual learning environment and offered to the users in two modes. The first mode of the VR procedure trainer lets the pilots follow the informative guidelines and the order of steps placed by the related elements on the cockpit's panel. The second mode has been developed to provide an opportunity for self-assessment, whereas no guidelines are shown, only the amount of the required steps. The pilots have control over their training process: it can be interrupted or restarted at any time and repeated as many times as it is needed for pilots to reach their own educational goals. In order to complete the steps of the procedure, pilots are expected to apply their motor skills and reach the required elements of the cockpit's panel as they would do in the physical cockpit.

The main areas of research when developing this VR solution were the feasibility of the design solution implementation, the effective method for placing the instructions of abnormal operations' procedures onto the VR platform and the potential advantages of developing such a solution for procedure training. In order to accomplish the goals of the research, a Human-centred design approach has been applied as the main guideline for the VR solution development. The framework included a deep analysis of user requirements, the contexts for application's use and testing the system's usability for confirming and improving the user requirements, setting new targets for the future VR procedure trainer's design iterations.

The Human-centred design implies the involvement of the target users in all of the development stages. Therefore, the pilots and the training manager of different backgrounds and experiences were invited to interviews, tests of the system and the user experience evaluation.

The project development has been carried out in cooperation with Applica Training Systems AS (ATS), which provided the research with the 3D model of the cockpit, connections with the target users' representatives, learning materials and support. One of the ATS employees joined the system's usability test to reveal any additional technical issues of the solution.

The hypothesis of the research: "A standalone VR provides an engaging learning environment for more efficient and practical knowledge reinforcement of abnormal operations' procedures for pilots.", has been mostly approved through the observation of users' interaction with the developed solution and their response to the survey, which was aimed at clarifying different functional and educational aspects of the procedure trainer. The participants of the usability testing confirmed that in comparison with the traditional methods of training the abnormal operations' procedures, the VR technology has useful potential. The research presents a detailed guideline on the solution's development, which confirms that the

implementation is feasible and that there are effective ways of placing instruction onto the VR platform, even though it requires and has a lot of ways to be improved.

In addition, the research has revealed that normal operations procedure training might be also proposed for development following the same framework.

6.1. Future work

The presented VR procedure trainer of abnormal operations is at its' early design development stage, therefore it has a lot of options on how to be improved in the new stages.

To begin with, it is needed to fix the functional challenges revealed during the usability testing: a more realistic implementation of users' interaction with the cockpit's elements is needed. For example, it requires information about what direction should the lever be pulled or pushed to and to which extent? What are the sides the users should turn the switches to?

The instructions in the application were useful, yet it would be better to add the illustrations capturing the placement of buttons on the hand controllers. The virtual learning environment should also have more advanced rendering settings for a better quality of representing the cockpit and UI elements.

After improving the issues revealed in this research, the next phases of production should be aimed at adding the voice guidelines into the virtual environment, other procedures available for training, and the opportunity to train the procedure from both seats on the left and right sides. One of the desired results for the final product could have options for multi-crew training and implementation of "exploratory" mode, where the pilots can freely interact with different cockpit's panel elements to learn how the systems of a particular aircraft work.

Figure 6.1. A realistic render of Airbus A320neo cockpit

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Appendix A

User stories and Personas

The Personas descriptions have been inspired by the interview's participants. The names of the personas are not real, these were invented just for the analysis.

Henrik Olsen
Henrik is 47 years old, he has been a pilot for around 25 years and has experience of flying as both a captain and a co-pilot. Henrik is a pilot of Boeing 787 Dreamliner.

The COVID-19 pandemic has caused a lot of changes in the airline he has been working for. Currently the airline considers exploiting the Airbus A320neo aircraft instead of Boeing 787, therefore pilots like Henrik will have to complete the Type Rating - a pilot's qualification to fly a particular aircraft (baatraining.com, 2019). Nevertheless, the restrictions related to the pandemic change a lot, causing a lot of challenges for pilots to manage the process. Henrik lives in Trondheim, while the airline's training center with the required equipment is located at Gardermoen. It is very problematic to travel down to the airline's hub and in addition, the restrictions do not allow people to gather in small spaces. One of the Type Rating phases requires training in a flight simulator with the crew and with the instructor, yet it is not possible to conduct. Henrik reads the manuals of the Airbus A320neo, however it is not enough to get used to the new cockpit, memorize how and where to reach a needed switch on the panel in case of an abnormal situation.

Martin Anderssen
Martin is a young and enthusiastic student at the Flight Academy. He has recently been introduced to the abnormal operations' procedures during his training in a flight simulator. Martin would really like to train the procedures more, get used to the cockpit's panels, learn what and where is located. Nevertheless, his class is quite big: there are 15 students, yet the flight simulators are not freely available, instead - students have two paper tigers. It is not enough and it does not provide a feeling of presence in the cockpit. Martin would not mind exploring how the system's of the plane work and train the procedures. Besides, he has explored some VR apps before and is quite familiar with the technology.

Adrian Sørensen
Adrian is a pilots' training manager in a large airline company. He has noticed that even though some of the trainees have great theoretical knowledge, they still struggle to present better results in the practical part of situation awareness in the subject related to the safety and abnormal operations training. Following the plan, Adrian will soon have a Type Rating course with young pilots, so he considers offering pilots additional approaches to learn the materials.

User stories

"*As (a type of user), I want (a goal), [so that]*."

As a young pilot without an experience of flying the aircraft with a crew and passengers, I want	● simple guidelines on how to complete the procedures, so that I could learn them efficiently ● to not be dependent on my PC, so that I could start the VR app without it ● to get used to the new cockpit and location of all the controllers, so I feel confident during the training in the full-flight simulators and during the tests
As an experienced pilot, I want	● to try new technological solution for training the abnormal operations, so that I could get used to navigation in a different plane ● to get a full immersion in the training environment, even though I do not have an opportunity to travel to the training centre ● to have an option to look at written form of the procedure steps during the training, so that I could get all of the details better
As a pilots' training manager, I want	● to offer my students a new alternative for training the abnormal operations, so that they try innovative learning approach ● to investigate whether the involvement of physical motion and the interactive system will improve the pilots proficiency tests' results ● the student to follow and memorize only concrete sequence of the procedure's checklists, so that the human factor would have lower influence on their actions in real life

Appendix B

The interview questions prepared for pilots

Pre-interview beginning with the projects and research brief description and the pilot's introduction.

1. How long have you been a pilot?
    a. Are you continuing your career right now?
2. Which planes did/do you fly?
    a. How long have you been flying A320neo?
3. Do you fly as a captain or first officer?

The first part of the interview - to clarify basic information about NNPC, the structure and methods of learning them.

1. What are the NNPCs?
    a. The difference in terms: NNPC, AO, AP, ES, etc.
2. What is the traditional way to study NNPC for pilots, offered by the aviation educational institution? What year of study/time do pilots study NNPC?
    a. How many hours of practical training are required for pilots to get their commercial pilot license?
3. What is your personal attitude to such an approach? (Whether it is efficient or is it missing something, e.g. a better way of memorizing the gestures)
4. In your career, did you ever need to apply your knowledge of NNPC in practice?
    a. On average, during the whole pilots' career do the situations that require NNPC appear often?

The second part of the interview - to clarify the ways the pilot keeps NNPC fresh/up-to-date in memory.

5. How often do you train/go through NNPC? (E.g. At your educational institution? At home? Before flights?)
6. Which tools do you use in order to train NNPC? (E.g. online interactive tools or physical handbooks)
    a. Do you train NNPC in flight simulators?
    b. How do you get access to a flight simulator if you need to use it for training? Do you need the assistance of an instructor?
    c. What is your most preferred way of memorizing / training NNPC?
7. Are there any stress triggers during the training, e.g. time limits?
8. What is the way for the assessment of NNPC knowledge? How often is it checked?
    a. Are there any standards or regulations about how the pilots should keep the NNPC up-to-date in their memory?

1. How often do commercial pilots switch the planes they are flying? How many times per career on average?
2. Is there any in-between training when switching the plane? (E.g. whether you need to book a flight simulator of another plane to go through particular subjects like NNPC)
3. Are the NNPC significantly different between each plane? How often do NNPC change for a particular plane?
4. Where do you get the learning materials about the NNPC from?

The third part of the interview - to explore the pilot's personal opinion and attitude to VR technology application in training of NNPC.

1. Have you ever tried standalone VR headsets?
    a. What kind of experiences? How was it?
2. Have you ever experienced cybersickness/motion sickness?
3. In your opinion, would a VR NNPC trainer be a useful knowledge reinforcement tool for pilots?
4. Would you use it for your personal training?
    a. What advantages of using VR technology for training NNPC could you assume?

Appendix C

The interview audio-recording transformed into the written form with pilot 1

The text has been written following the voice recording. It includes some edits, e.g. removing unnecessary for the context words without changing the sense of the content and keeping the vocabulary of the participant. Most of the sentences keep the interviewer's and participant's structures, even if those could have been rephrased into more grammatically-correct structures.

- How long have you been a pilot and whether you're continuing your career right now?
    - I started my flight school in autumn 2015 and I was flying until the last year December (2020). So I'm flying on and off for about 5 years.

- Do you fly as a commercial pilot?
    - Yes, for three years. I have been flying on Boeing 737-800 and 737-700, which is basically the same aircraft, just with different lengths. For flight training, when you do a recognitional paper, I was flying Cessna 182 and Piper PA 31.

- Do you fly as a captain or first officer?
    - First officer.

- Could you, please, tell me what are the Non-Normal Procedures checklists and whether there is any difference in terms because I've seen other terms such as Abnormal Operations, Abnormal Procedures, Emergency situations in the same context? What do you use in your terminology?
    - I used a bit of each, sometimes it would be normal to talk about the abnormal operations and normal operations, or we would use non-normal procedures. These describe a bit different aspects of a situation. If we, for instance, are talking about take-off and there is some sort of failure, then it would be an abnormal operation, and to handle the abnormal operation you use non-normal procedures. In order to use the non-normal procedures, you refer to the non-normal checklists.

- What are the traditional ways to learn the abnormal operations for pilots? How did you learn them in your academy? In which year of your studies did you learn them?
    - To become a pilot these days, you initially do basic flight training, which is what I did at the University of Tromso, and where you get your basic licenses.

In order to fly for an airline, you take a type rating. A type rating is a specific course that is only relevant to that specific aircraft. So, let's say, Boeing 737 versus Airbus 320, they are similar in size and engine power but systems are so different, that you can hold only one

rating at a time. So I did my type rating on a Boeing 737 in England with Ryanair, so that was basically my flight academy for the airline-specific type rating.

- How long did your education last?
    - For commercial license - 2 years. The type rating course itself would take between 3 to 4 months.

- Did you take it at the beginning of your whole education? When did you learn about abnormal operations?
    - The abnormal operations that you learn for a specific airplane - that's towards the end of your course. For the commercial pilot license that you would take as a baseline, these are your building blocks to become a commercial pilot. Then you would go out, you would look for a job and then you would go to the training organization to take a specific type rating. And that is a type rating that takes between 2 to 4 months. It introduces you to all of the systems that are on board, and you quite quickly stop flying simulators, which are called base simulators, which are just for training procedures, which are primarily just for normal procedures to get used to the aircraft and all of the systems. As soon as you are used to the systems you start introducing failures. This is a training that involves crew cooperation, so for instance, interfailing during the cruise... I don't think I did that once during my training because that is something that gets covered by other parts, the main parts that you truly train on during the type rating course, are the ones that are very time critical and time specific.

- So those that you always need to keep in your memory? The ones that when it comes to the emergency situations, you've got to be context aware and start acting straight ahead?
    - Yes, so what you learn is to truly perform these correctly, those requiring memory items. In general, it will call out in your memory a failure in QRH *(Quick Reference Handbook - author's note)* which describes all of the failures, so you cannot cover all of them in the course. Some of them are just like: "The system has failed; and how to deal with the system", so what you train is actually, how to read from the handbook and how to properly use QRH, how would you handle the emergency situation.

- When you are in the cockpit, do you have this handbook somewhere next to you, to refer to when it comes to the emergency situations?
    - Yes, and it is convenient, in the 737, it differs a bit from airline to airline, but we always have that on board. In SAS we had a book on the right inside by the first officers, just a small pocket by your leg and Ryanair used to have it on the right side. In addition, we also have it on our electronic flight-pads, basically iPads, so we have it in several places.

- So for the less extreme emergency situations, do you basically read and learn about them in a handbook? How do you find this approach of just reading? What if while reading, you want to get to the flight simulator and test something out? Do you have such an opportunity?
    - In Ryanair we did, yes. You could go and book the simulator, which was a fixed base simulator either in Dublin, Stansted or in Italy, they were queued; As long as there was available time - just go use it. In SAS, I don't think you can do it in the same way because they are twiced up with the CAE *(Canadian Aviation Electronics Inc., "...manufacturer of simulation technologies, modelling technologies and training services to airlines, aircraft manufacturers, healthcare specialists, and defence customers"* (Wikipedia, 2021) - *author's note).* They have different training organizations that deal specifically with simulators, basically where they rent them from. I don't think you could do it there this way.

- So it really depends on the company, what do they offer? (- Yes) For those who offer such an opportunity, are their flight simulators easily accessible? Do you have to wait in line to get to the flight simulator? Do you need to pay?
    - You do not pay in Ryanair, but the problem with Ryanair is that they have their bases across all of Europe, only three locations where you have access to the flight simulator. So if you were not based in these places, you would have to travel there. Hotels and other expenses you would have to cover yourself, travel - in Ryanair where you were employed, it was totally free. Booking the simulators themselves, as long as there was an available time slot and the simulators would just stand there, you could use them as you wish.

- But the main challenge is choosing the time and doing the other planning if you are placed in another location? (- Yes). You would always have access to the handbook, even if you can't get there.
    - I would also add that people from my generation, at least, use online simulators as well. I don't know if you have looked into Microsoft Flight Simulator.

- Do you use such applications too?
    - Definitely, because some of the aircraft that were released there are to such a level, as you call it a study level, that you can use them to basically get an idea of how the flow works. A lot of those simulators - you can use them to study there. There are, of course, some systems that are not 100% simulated correctly but I know from myself, you have a huge aid for your studies. A lot of guys tend to use them just to get hold of it.

      Now in SAS a lot of guys are transferring from 737 to 320 *(Boeing 737 and Airbus A320 - author's note).* So having an opportunity to just go into a

simulator and just having an idea of how it looks and how it feels like.

- In your practice, did you ever have an emergency situation when you had to go through the non-normal procedure?
    - As of the failures that I have had… It is quite rare to have a typical engine failure. The failure that I had was a ground proximity warning system failure, which is basically just a system that calculates the position of the aircraft and compares it to a GPS database. So if you have a closure towards terrain, in non-static cooperation , (if the plane is where it should be but if it does not make sense for the system - it gives a warning; Terrain escape maneuver - EGPWS - CFIT, it is the most common reason for airplane crashes) it would scream at you: "Terrain, hold up!". Basically, just a safety system that has failed.

One of the operations, which was just a tiny failure: you lose the radio altimeter callouts, which is something… The only reason I remember that it was special is because you get so used to it... I don't know if you heard a cockpit landing and we hear: "50, 40, 30, 20, 10". There were callouts that did not work and it's not a big issue, you still are flying the aircraft. When you are so used to using those oral queues, to figure out how quickly I am approaching the ground. If you are too quick, you will have "50, 20, …", and if you don't do anything by then, you will feel it *(feel the rough landing - author's note)*. That is one of them.

Also, window heat failure can happen, that's basically just the window heating element getting too hot and the system switching itself off. The only procedure that it tells you to do is just "flick the switch off, wait a couple of minutes, turn it back on". If nothing happens, then the system is working, then if you get an overheating warning again, just flick it off and then just maintain below 250 odds below 10 000 feet - The only reason you do that is because in case you were to heat the bird, your windows will not be certified, you could probably still handle the bird strike but… Those are the only failures I had, so in a sense, I have been lucky. Again, you rarely experience failures.

- I have read that all of the procedures on board are made in such a clear way that if you follow those, you can barely get to dealing with a failure.
    - More or less, yes, and other than that, the bird strikes I have had… It just becomes normal, if you hit the bird, you just continue, you check if all of the systems are fine. Some smaller air conditions and other things that do not really affect you.

- You don't train such cases in the flight simulators, as they are not so critical, you don't need that as you know that the required descriptions are in the handbook?
    - Yes, because you have studied the systems to the level where you understand how it, to a certain degree, works. You do not, by any means, have to demolish aircraft mechanics. So whenever you would have the opportunity, it is worth asking a mechanic to see how stuff works, also if a system has failed, you land

on the ground.

If you have a technical issue, which you know is not critical to fly with but, let's say we're flying from Oslo to Svalbard, and if I have a system failure for the pneumatic, well, basically, the air conditioning system, the pack system, I could still fly without it. I would only need one, and that would be completely safe. And the only thing is when I land in Svalbard, then I would have to follow different rules because then I have to plan the landing with failure. You think differently because the situation is coming in and you could end up in a situation where you are not allowed to fly with passengers, you just straight up are not allowed to fly at all. So these are the things you also got to consider. You are in a case where you would contact the maintenance and they would tell you that due to the consequences for the next flight, you are most likely to return back to Oslo. This can happen.

And another failure I just got to think about was, when I had to fly from Oslo and heading towards Germany, and being on 2000 feet we got a door warning. Which basically tells that one of the doors is open. That was a bit interesting and the only thing you would have to do is to level up, the captain has had this failure before, just asking cabin guys, if they can go check the door, whether it is properly closed. It was just a sensor failure.

- I see, you don't need to train for such cases.
    - You have the time to handle those so you don't need to train for those.
      I see, It's all about how much time you have and how critical the situation is.

- It is one of the reasons where the idea of the VR application comes from. It would provide the pilots with an additional alternative to the handbook and let them train from home or before flights the abnormal operations, that they, for instance, did not have an opportunity to go through in the simulator but they would still like to clarify something.

- How often do you train, read through the abnormal procedures to keep the memory items up-to-date?
    - It really depends, I know, a lot of pilots would not really read all that much, especially those that are 2-4 years into flying, and you would mainly read whenever a change happens. But I always would just enjoy it, just having a look at my procedures, just something that I think is unclear, I'll just read up on it and just bring it up as a discussion topic with a captain I'm flying with for that period. So for me, I would say, I would check it between once or twice a week.

For example, I am flying to Svalbard. I would not need to read up about the requirements for fuel, I would read about the meteorology related to Svalbard. It also depends on what you are doing, for instance, if you are doing the operations that you are just very very familiar with, that I have been doing for quite a lot or I would be clearly refreshing my knowledge

whenever I start doing things that I have not been doing in a while; bring up the book, have a look if there is something I have forgotten.

Emergency procedures and what is related to that is not something that you would normally refresh once a week because you also have a simulator session two times a year, where most of those are practised and handled. This is how I ended up doing that primarily, whenever I got close to the simulator sessions, I would read up on those emergency procedures. And also every now and then I will also just have a look at if I remember the items.

- I was also wondering what are the assessment methods of those abnormal operations' knowledge? Whether there is an exam or anyone going through your knowledge of the critical emergency procedures with you? Whether the training managers provide you with feedback?
    - Yes, they do. You have two simulator sessions a year. One of them is more of the training session, where (both in Ryanair and SAS) you have more like a survival training, where are the failures and procedures that are not required by the authorities, but just training which you do in order to increase your confidence in the cockpit. It is not graded, it is a supplementary session, which will not affect your pilot license.

And, also, a course building for skills. Normally, you would have a scenario which you're sort of prepared for, where you would do a normal flight, you would have a technical issue and as that issue goes you would just have to use your knowledge of the aircraft, your knowledge of the checklist in order to handle a failure. Afterwards, you would have a deep briefing, where you talk about: what do you think went well here? How is your communication skill? How are your hand flying skills, how did you manage to handle the information, how is your situation awareness, and how are all of these specific points which you do get graded for. You get to know whether your situational awareness is good, whether you struggle with the manual handling, so focus on this and you can bring that on. They do grade by an evaluation scheme for you.

- Is there mandatory training that you have to go through when you as a commercial pilot switch the plane? For example, as with the case when switching from Boeing to Airbus A320, do you have to train for a particular amount of hours and go through particular procedures?
    - Yes, that would be like studying back at square "1" because that is a completely different type rating so you have to do another 3-4 months course because the systems are so different. So yes, it will take you about 3 to 4 months to switch between types of aircraft. You have to learn the systems at a very detailed level, how to manage the aircraft… Yes, it takes about 3 to 4 months.

The only time when you can shorten this training time is when I switch, for instance, from Boeing 737 to 777 - almost the same aircraft, because the philosophies of the designs are

quite similar, so this is a possibility to reduce the time of training there. And I know for Airbus, for instance, if you have learned the 320, the 330, 350 - these are quite similar, so there is something called "a common type rating". I know this is something that SAS plans on doing. I know that the now-bankrupt airline Monarch Airline had a common type rating of 320, 330. For instance, you could have one week of where you were flying the 320, then you have a trip to the USA with 330. That's quite interesting to think about as well because the 320 is 70 tons aircraft and then 330 and you are talking about 200 tons aircraft. The systems are quite similar but you have such things as inertia and the aircraft is almost three times as big, so it will have it differently. But that's to answer your question, you have to re-do your type rating.

- Does the type rating learning process involve the training in the flight simulator? And you get the handbook that you would study yourself?
    - How would type rating go is that initially you would do some basic classroom training and you would do the technical training first, which would be learning about the hydraulic system, the air system, the landing gear system, the emergency equipment on board - this technical training is basically just classroom training where you learn about the systems. You do an exam on those, just to make sure you have the basic technical skills required. You would continue to, for instance, FMS *(Flight management system - author's note)*, computer training, which is specific training for how you would manipulate, how you use the flight management system and once that is complete you would continue on to the simulator. In between, the way most pilots do it, even to the state, is to use a so-called "paper tiger".

Paper Tiger is basically just a paper mockup of the flight tech, so you would just have the pack of the cockpit with the overhead panel, the throttle lever, etc. So you would sit with your checklist and your operator manuals and you would just study the flows of the aircraft. For instance, the pre-flight checklist, how you would do that, how you would do the startup sequence. We did that a lot: just going through all of the segments to get the callouts correct, to get the flows correct, to make everything go.

- Yes, to know where all the elements are located in the natural size. I think it reminds me of what we are working on, actually.
    - Yes, and that was also what I was hoping for because what I personally miss about the paper tiger is having feedback because it is easy to do it in the aircraft when you have that system that responds to you. So if you could have a training program which does that - that would be very very nice. And having, basically, a digitized paper tiger could be very very useful, to see how the system responds.

- That was it about the studies of the abnormal operations. My last part is quite short, I was just wondering about your experience with VR technology, whether it is going to be your first time to try it?

    - I have not used it myself, I have seen it being used, but not myself, so I am quite excited to see how it works!

- Since you are a pilot, I would not expect you to have motion sickness, but do you feel motion sick when you travel?
    - No

- Before we actually test it, what is your opinion, would such a tool be useful and practical, would it be used amongst the pilots?
    - I think practising emergency procedures is going to be difficult because there are so many nuances that it would have to handle. I know myself, I would have tested all the simulator's systems; when you test a simulator itself, you straight away figure out that there is something slightly different, it is very easy to get focused on the details that are not correct. So I think, to do that, to make a really good product to simulate emergency procedures - that's a challenge.

Appendix D

The interview audio-recording transformed into the written form with pilot 2

The text has been written following the voice recording. It includes some edits, e.g. removing unnecessary for the context words without changing the sense of the content and keeping the vocabulary of the participant.

- How long have you been a pilot and whether you are continuing your career right now?
    - I have been a pilot for 31 years, and all of those years - in SAS. Now I am part-time in (another company), due to the corona situation.

- Which planes do you fly?
    - Now I fly the Boeing 737, I have been flying the Boeing 767, DC9 and MD-11 - so I only fly the American-produced aircraft. I am not familiar with the Airbus non-normal checklists.

- Do you fly as a captain or as a first officer?
    - I have been a captain for 14 years.

- I was wondering what Abnormal Operations are and what is the difference in terminology between abnormal operations, abnormal procedures, non-normal procedures and their checklists?
    - Normal operation - is what you do in every single flight, abnormal operation is a procedure you do if something abnormal happens, which is not on the everyday, regular flight.

- Could you tell me how you studied the abnormal operations during your time at the educational institution?
    - To start with, you read the manuals and… When I started we actually had a CBT, computer-based training, with large laser disks, at the beginning of the 1990's - it was very modern at that time. So a combination of reading manuals and computer-based training. And it actually is still that way, we have our computer-based training on our iPads, and we do a combination of reading manuals and CBT.

So VR is only, I would say, the next step. We have been introduced to VR and tested it but we don't use it. We don't have very much classroom teaching, it is mostly self-study.

- How long does the training of a commercial pilot last? How long does it take to become a commercial pilot?
    - For me, the school I went to,1 year practical and theoretical and then 1 extra year practical. So totally 2 years.

- Do you remember when you were introduced to abnormal operations as a subject? Was it, for instance, in your first year or in the second?
    - You talk about these very early, you have to be prepared for non-normal operations in every single flight from flight number 1. So that is a part of all the training you do.

- Have you ever felt while reading the manuals that you need to test something out in a flight simulator? In order to understand something better? Was there anything missing in simply reading the manuals? Did you have such an opportunity to access the simulator whenever you needed to?
    - That's a good question, the only thing you have to learn by heart is, when you talk about non-normal operations, are the most critical items. So there are only very few items you have to learn by heart, the quickest items that are the most important to do very quickly and they are so few that you don't actually need to go to the simulator to learn only those few. Normal operations - is a quite different thing, you have to learn maybe a 100 items by heart, but they are not crucial. And that's the point, now I am talking about Boeing because I don't know Airbus, so I don't know how many memory items or what they have to learn by heart. Maybe fewer, actually, on the Airbus because they have electronic checklists in the cockpit. We don't have electronic checklists in Boeing, so we have to learn some items by heart. I would guess that the Airbus (pilots) don't have to learn the memory items by heart, that's only my guess.

And we train in a simulator every six months and then we study up our memory items again. But they, I've mentioned, are so few, I would not need to go to the simulator just to learn them or to remember them.

- Is it easy to access the flight simulators whenever you need them?
    - No, we have what I'd call… Do you know what a "Paper Tiger" is? (- *Yes, the previous pilot has briefly introduced me to that. - author's answer*) It is just a flat simulator. It's just a picture so it's the same like a… We have access to two paper tigers, on the Airbus - this is a really old-fashioned way of training of course, and this is where I find VR interesting because then you can not only look at the button, but you can also push it and see what happens.

- Interesting, that nowadays in 2021, the Paper Tigers, flat simulators are still used in the training.
    - In SAS they do, and I find it quite strange, in 2021 we use Paper Tigers, I don't know why. So there is quite a potential for VR.

- In your career, have you ever had emergency situations when you had to apply abnormal procedures?

    - Yes… Most of us during our careers will experience loss of cabin pressure, maybe not a rapid one, but decreasing one. And the first item, that we go for both Boeing and Airbus, the first critical item is, of course, putting on the oxygen mask because you lose the oxygen, air pressure in the cabin. That's, of course, a memory item, you don't have time to grab a checklist and see: "Ok, the oxygen mask is the most important part to put on, then you can start a procedure".

- Do you train between your flights? For instance, when do you read through the checklists in the handbook? Before every flight or?
    - We brief non-normal situations before every flight actually. If we fly with the same pilot, we skip briefing until we change our co-pilot. We brief non-normal situations that could happen during the takeoff roll and after initial climb. We also brief a loss cabin pressure - that is a mandatory before every flight.

It's mandatory for Boeing, I guess it's mandatory for Airbus. For example, I would also brief what to do during the engine fire or an engine failure, or a wind-share (the change of wind direction, a speed during the take off, that could be critical for the flight) - these things we talk about before the first departure, so we know what to do. And it's the same every time: hand grips, the throttles and the speed - it's the same brief before each flight, but anyway it is important. That's just to get motorics, motor skills.

- So when you brief the non-normal situations, do you actually go through showing how to interact with the panel?
    - Yes, and that's also what I would do in the paper tiger, or rather in VR.

- When you train in the flight simulator, do you book it for training with the training manager, or do you have an option to train alone?
    - I cannot go alone. I have a schedule, every six month, together with a co-pilot and an instructor.

I have also been a Boeing instructor earlier, then I could go to the simulator whenever I wanted.

- Where are the flight simulators located? Are they far from here?
    - Yes, they are at Gardermoen. (*The interview took place in Kristiansand - author's note*), at the airport, just a few hundred meters away.

- Is there a queue for accessing the training in the simulators?
    - Yes. SAS is doing all the bookings, so we don't think about the queue, but they are fully booked all the time. So SAS needs to book several months in advance.

- So they notify you, when you need to come?

    - Yes.

- When it comes to the case when a pilot would need to change the plane, is there any specific procedure for training, changing the specialization?
    - Oh yes, that's Type Rating. Your license is for a commercial pilot and you need a type rating in your license. And a type rating would be… Well, it's been 20 years since I had my type rating or even more. Type rating is: 4 weeks of theory and 4 to 6 weeks of simulator training. Then another 4 weeks of flying together with an instructor as a commander of the aircraft and with passengers. So, let's say, three months in total before I can be an Airbus pilot.

- Do you fly as a first-officer (co-pilot) during the training then?
    - No, you can fly as a captain, but not as a commander. The difference is, the captain has certain duties, but the final responsibility is with the commander. So I fly with the captain's duties, but the instructor, who is seated in the co-pilot's seat, is the commander of the flight, so he has a final decision and also responsibility if anything happens. So there is a small difference between the captain and commander. Normally, the captain is the commander, but during the training it can be different.

- I'd like to ask you a bit more about the training. Do you have any stress-triggers during the training? For example, do the training instructors set you the time limits to complete a particular procedure?
    - No.

- What is the assessment procedure for your training? Do you have any kind of exam?
    - Yes, we have, we get an assessment sheet afterwards. They assess all parts of the training, not only the technical part, but also how you manage communication, crew coordination, and I would guess stress as well.

- Good, I see! I also have the last part of the interview, which is about VR. Have you ever tried a standalone VR Headset before?

    - Only once, like I've told you, to open the door - that's the only time I've tried VR. (*Before the interview, the interviewer and the pilot had a brief conversation about VR and aviation. The pilot has mentioned that he had an opportunity to try a VR app, where it was possible to train closing the cabin door, turning its handle and making sure it is fully closed. Then, also train to open it, - author's note*). That's the only experience.

- Do you know whether VR is being used in any other airline?
    - No, I don't know. I guess I would have heard about that, but I don't know. I think they (VR application) should have been used for the last 5-10 years, the

technology is there, so I don't know why we don't use it yet.

- In your opinion, would you use it for your personal training, if you had VR goggles by yourself?
    - Definitely! We use Paper Tigers...Now I'm talking mostly about normal operations, because there are so many items that have to be learned by heart, and using a paper tiger - nothing happens when you push a button to learn something to learn something by heart or by muscle memory. It is much easier if you see what happens every time you touch something, what to expect when you push something. Paper tiger does not show you what to expect.

For Airbus, I know we have two paper tigers for SAS, and maybe 20 pilots are doing a course at the same time, and you have only two paper tigers. It would be much better to have VR goggles for loan. You don't have to own them, but the company could have 5 or 10 sets of VR goggles that you could bring home. Now you have to be, for paper tigers, at Gardermoen to use them and maybe there is somebody else already, you don't get time to book it. So I really see the potential with VR goggles.

- You also mentioned that it would be nice to use VR for normal procedures' checklists?
    - Even better!

- I have one last question, do you ever experience motion sickness?
    - No.

But actually, in the most modern simulator at Gardermoen, when taxing on the ground - that's the worst, I don't know why. Not when flying, but when taxing on the ground, motion is poor.

Appendix E

The interview questions prepared for the pilots training manager

Pre-interview beginning with the projects and research brief description and the pilots' training manager introduction.

1. How long have you been a training manager?
    a. Are you continuing your career right now?
2. Which planes did/do you train the pilots for?
    a. (If multiple) How long have you been training for A320neo?

The first part of the interview - to clarify basic information about NNPC, the structure and methods of learning them.

1. What are the NNPCs?
    a. The difference in terms: NNPC, AO, AP, ES, etc.
2. What is the traditional way to study NNPC for pilots, offered by the aviation educational institution? What year of study/time do pilots study NNPC?

3. How many hours of practical training are required for pilots to get their commercial pilot license?
    a. How many hours are usually spent in a flight simulator?
        i. What is the maximum amount of hours allowed/required to spend in a flight simulator?
        ii. Does it cost something?

4. Do you train NNPC in a flight simulator?
    a. How much time does the explaining NNPC usually take?
    b. What is the assessment method of NNPC?
5. Do pilots have an opportunity to access the flight simulator whenever they need it?
    a. Is there a booking system? Does it cost?
    b. Is it possible to have an instructor by side?
6. How do pilots train NNPC afterwards (after graduation from aviation academy and later in their career)?
7. Do they have to learn the new NNPC if they change planes?
    a. Is there an assessment of that?
    b. Is someone accompanying/explaining?
8. On average, during the whole pilots' career do the situations that require NNPC appear often?

The second part of the interview - to take a closer look at the situations when the pilots need to apply their theoretical knowledge to practice.

9. What do pilots do when a dangerous situation happens onboard?

    a. What is it expected for pilots to do?
    b. How much time do they have?
    c. Is there any handbook to refer to?
10. Are pilots trained for acting under stressful situation pressure?
11. Do they rely on their kinaesthetic memory?
    a. Which role does a psycho-motor domain (coordination, physical movement in terms of speed, precision) play in a dangerous situation?
12. Do pilots have an opportunity to check NNPC in between/before flights?
    a. Do they have any obligatory procedures of going through the safety elements before a flight?

The third part of the interview - to explore the pilots training manager's personal opinion and attitude to VR technology application in training of NNPC.

1. Have you ever tried standalone VR headsets?
    a. What kind of experiences? How was it?
2. Have you ever experienced cybersickness/motion sickness?
3. In your opinion, would a VR NNPC trainer be a useful knowledge reinforcement tool for pilots?
4. Would you use it for your personal training?
    a. What advantages of using VR technology for training NNPC could you assume?

Appendix F

The interview audio-recording transformed into the written form with the pilots training manager

- I would like to start with the introduction to you, would you tell me about your experience as a pilots' training manager?
    - I started with the training business in aviation in 1988, as a technical instructor for pilots in the Norwegian Airline, at that time called Braathens SAFE. My background is as a flight engineer from the air force. I left the air force in 1988 and started, as I said, as a technical instructor for pilots of the 737 *(Boeing 737, - author's note)*. I was there for a period of time, I became a chief ground instructor in 2000 or 2001, and then we were acquired by SAS, so in 2004 I was transferred to SAS Flight Academy, still as an instructor, and later as a training coordination manager - that means I had the overall responsibility for the training and the paperwork for pilots doing the training in Oslo because there were head offices in Stockholm and London, so I was managing pilots' training in Oslo.

I was there for almost 8 years, I guess, doing all kinds of training: technical training, also operational training, some procedure training in the simulator, later started doing instructors' training on more of human factors' type of training. Then I left the academy in 2012 and started as a chief ground instructor/deputy manager training in Norwegian and I was there until last year. So the last few years I did instruction, I more or less did the administration part of the training, but overall, I am approximately 30 years within aviation training.

- I would like to ask you more about the procedure training: could you explain to me, please, such terms and their differences as abnormal operations, non-normal procedures' checklists, abnormal procedures?
    - You can still have some pilots discussing the differences between "non-normal", "abnormal" and "emergency". I think it's more or less the same, it depends on what kind of aircraft you fly.

If you fly Boeing aircraft, you normally use "non-normal-" or "abnormal situations". Some of them like Airbus aircraft might use "non-normal" or "emergency". Most of the time, they don't use the "emergency procedure" because that is a negative word. But when it comes to "non-normal- " or "abnormal procedures", it is more or less the same, it depends mostly on the type of the aircraft, what manufactory do you fly.

- We will use a 3D model of Airbus A320neo's cockpit, so I suppose, would it be more correct to use the word "non-normal procedures " then?
    - I am not too familiar with Airbus, but I would guess - yes, or maybe they have also adopted the "abnormal - " because that's more… "Non-normal - "

depends on how you define the word, but “abnormal - “ is a more widely used term.

- Which planes did you train the pilots for?
    - Mostly Boeing 737. Also, partly with 787, but that was not too much.

- What is the traditional approach to training abnormal operations? For example, if the pilot is in the simulator with you, how do you go through this subject? Is it an independent part of the training or is it a part of another subject?
    - Depends if you have new pilots, new to the aircraft, when did they do the type rating course, and you also have pilots who have never been flying the aircraft before. We mainly do the ground school focused on the systems and the normal procedures. In the simulator we had, I think it was 4 or 5 simulator sessions, with only normal procedures before we introduce the abnormal procedures.

- How long does it usually take in total to train a beginner pilot and go through all of the subjects in such a course?
    - Including the theoretical part? Or just a simulator? *(- Would you tell me a bit about everything?)* Yes, the whole course is normally, well, it depends again on the aircraft and the school because the regulations do not say how long the course has to be, it just says what it has to be included there. Normally, I would say, we would have 10 and 15 days of ground school and then you have, I think, the regulations say you need to have at least 32 hours of the simulator. So if you have the simulator session of 4 hours, it means at least 8 simulator sessions, but then it depends on the complexity of the aircraft and the experience of the pilot. If you have a young inexperienced pilot coming from a small prop-aircraft *(Propeller aircraft, - author’s note)* with limited experience, he will normally have 10 to 12 simulator sessions. He needs more training because he is not used to it.

If you have an Airbus pilot transferring to the Boeing 737, he will normally manage 8 simulator sessions. Because he is used to the working environment, he just has to: “Oh, the switches are there and there”, - something like that. Normally, he would be happy with the 8 simulator sessions.

But modern training is more inclusive, so you don’t necessarily have 10 or 15 days of only ground school. You can have a half of the day with the theoretical part and then you go into the simulator and practise hands-on training and you practise what you had in the classroom and some procedures. I know Boeing is doing that on 787: you have just a few days with the home study, then you mix the rest of the days with a procedure trainer and classroom.

- One of the pilots that I have spoken to said that whenever they train in the simulator, they don’t focus on all of the abnormal operations, but only on the most critical ones.

The least important abnormal operations - they read them at home in their handbooks and manuals, is it correct?

- Yes, if you look at the abnormal or non-normal checklists, you have so many scenarios, you can't train all of them. So what you need to do is to train to understand the philosophy of procedures and the checklists, understand "why" and "how", then how to find them, so you can easily find the needed checklist.

If you look 10-15 years back, there were a lot of memory items, which means, if something happens, you have to do "this, this and this" by memory, then you do the checklist afterwards. The number of memory items has been taken down so it's just a few memory items. That means, not often you need it, to do a lot of stuff before you do the checklist.

- So if we imagine an emergency scenario, then the pilots should rely first on their situation awareness, do some actions and then check whether they have done it correctly and look for the next actions?
  - Both, you need to check if you have done it correctly, but then you also do what is next, because there is not always a need to hurry up. You don't have to do something immediately. On the Boeing, you have to do something immediately: you have to disconnect the autothrottle, the automatic power, and you need to take control - that you need to do. Then you do the checklist, afterwards.

That means, the training needs to focus on what checklists should I use, what memory items do I need to know; you have to find a checklist and know exactly what checklist has to be used and how to read a checklist because for new young pilots it might be complicated. You have bold letters, you have dashes, so you need to know what it means and how to interpret these checklists.

- The manuals, they are always there in the cockpit, somewhere on the right side in the cockpit?
  - Yes.

- I've heard the pilots also have tablets with the checklists, manuals.
  - Yes, they have all the manuals electronically, but abnormal/non-normal checklists - in modern aircraft, you have them on the display, so they come upon the displays in front of you, but on older aircraft like 737 - it's a paper manual. Because if something happens, you don't have to be very fast, but you can't start looking in your tablet for it. That's why you have to pick up your paper, your checklist for it. But on the Boeing 787 and I would recon most of the Airbus, it comes up, if you fly and something happens, it comes up on your screen, and you just look at your screen and you have most of it and you click "down" when you do the items.

- Another question I have is about the pilots training after they complete their education, do they train the procedures between the flights? Is there any kind of check-up on whether the pilots keep the memory items “fresh” in their memory?
    - There are two types of training or checking, which means to keep your license, then you need to do a simulator check every year. A proficiency check once a year - that’s to keep your license. When you fly for an airline, you need to do an operating proficiency check.

Proficiency check every year - to keep your licence valid, operating proficiency check - to be allowed to fly for the airline, you need to do this simulator training every six months. You can do the licence proficiency check within the operating proficiency check (OPC).

- And how is the assessment? Are the pilots together with an instructor or with another pilot in the simulator? What does the process look like?
    - You put the crew in there and you have to be an examiner, not an instructor. There is also a difference, you have a type rating instructor and a type rating examiner. You can do training as an instructor, but you can’t do the PC (the Proficiency Check), you need to get an examiner. And the simulator is divided into different sequences because you need to do for the OPC a Line-Oriented Flight Training (LOFT scenario), that means you have a flight starting from A to B and the examiner does not interrupt, you do everything and something happens during your flight or your takeoff or whatever, you just have to do whatever you would do when you do a normal life flying. With the finish of the whole scenario, then you do the deep briefing, and then you would have to say why and how did you do it this way, how did you react, because then it would rate you as an airline pilot, making the right decisions. Because sometimes there is no single correct answer. So that’s why the LOFT scenario is based on the fact that you have to act as a pilot on a normal life flight.

And then you have another sequence which is the manoeuvre part, and that’s when you do your license check, that you have to prove on the exam that you are able to have the aircraft. That one you can actually fail, let’s say you’re not able to fly the aircraft correctly.

But you can also fail the LOFT scenario, but that goes to the human factor part, that your decision making, the process of the decision making was not good.

- The Type Rating training, how long does it usually take? Does it also include this kind of scenario check at the end?
    - Yes, but again if you’re going to another aircraft, it depends on the size and complexity of the aircraft. But normally, as I’ve said if you have 10-15 ground school days and if you have 8 or 10 simulator sessions, so… Depends also on the airline. For the airlines I worked for, we emphasized the different phases of the simulator check. In my opinion, I can say that before you can start handling the aircraft... If an engine stops, you need to be able to handle the

aircraft, both engines, or four engines. Before you can do that you need to know how the system works.

So the first two or three sessions are just procedure training, you need to know where everything is in the cockpit, how to operate it, how it works, and how the aircraft works. Then you need to learn how to fly the aircraft, and then you manage that, you also progress checks in between, and then you know you are familiar with all the procedures, with the cockpit. Then you are familiar with the aircraft, then you can start introducing what if an engine stops, what if you have a bad function. Then you go into more operations specific, how to fly in bad weather… So it's four phases and then you have a skill test in the end, that's your license check, to be able to get your rating for that aircraft.

- I have heard about the paper tigers too, that the pilots use them a lot.
    - Yes, it's a very useful, underrated tool, cheap, it's just a poster of the cockpit, but it's fantastic especially for the new pilots. If you were flying this small Cessna and you're coming to a big Airbus or Boeing, and you need to know all of the systems, all of the procedures need to be known by heart. So then you sit in and then you start putting all the systems on, you need to know where to do it. Paper tiger is fantastic because then you can touch it. That's where I would use VR.

- Do you think it would be a good scenario to use VR applications instead or in addition to the paper tigers?
    - I was actually playing with that, not necessarily with VR glasses, but more like VR over-screen. My idea, how I would like to have it, is that, two or three ways to use it. First, brand new pilots, never been there before, then you can put all your glasses on or do it on screen, and then you're prompted to highlight the switches in a sequence you should use. So it guides you where to do it (procedures). Then you can have a "free play", so you can do it on your own. Then for the problem check, I would like to have… Let's say you have 10 steps in the procedure, then you have to do 8 or 9 steps correctly, depending on how you put it, to pass that check. So you can have three races: guided, free-play and test.

- Besides the paper tiger, are the flight simulators easily accessible for pilots whenever they need them?
    - No, they are extremely expensive and bookable only by the company, so that's why we came up with a paper tiger. So we have a lot of "in-betweens" between the simulator and paper tigers: we have a procedure trainer, fixed-based simulator, and the real simulator. They are expensive, maybe 3000-4000 NOK per hour. As a pilot, you can't afford it, as a captain - they don't pay you to do it. That's why we had paper tigers since the beginning because it has been a cheap tool, and it was actually quite useful.

Then you have procedure trainers, which are big flat screens, it's a computerised paper tiger. You don't have the real switches, you have just wide screens overhead, the instruments and everything, but these are just computer screens, so you touch just the screens. It's more interactive than a paper tiger, but it's not a simulator.

- But you are not placed in the cockpit when using a procedure trainer?
    - No, you sit in a room like your office or specially equipped room for it. A good thing about it is, I have seen some of them, when you do the ground school you can press the switch for the electrical system, and then you have on the screen in front of you, you can see the electrical schematic, you can see what happens with the battery when you turn on the engines. You can see what is happening - this is useful about the procedure trainer.

And then the next level is the fixed-based simulator, which is more or less the same as in the full flight simulator, but there you don't have the visual system, you don't have the jack, so it's not a motion, but the switches it has - almost like in the cockpit.

I would say that the VR would be a very good substitute for the paper tigers because they are cheap and they require a lot of room, so you actually have to go to the training centres and most of the training centres have one or two paper tigers and a class of maybe 10 students. If you had a VR - you're free.

- Do you know whether any airlines or training centres use VR?
    - I can't remember at the moment, but I know that a few years ago, I was at the training conference. It was a Danish company selling VR, but at that time it was mainly used to walk around and inspect the aircraft, the external inspection of the aircraft. Because that is also a very good thing if you look into VR because that's mandatory for training pilots that are new to the aircraft. It is kind of complicated because it is hard to get access to the airport, to go outside with 10 students and actually go around the aircraft. So they did sell the VR for external inspection. I don't know whether any of the airlines bought it, but it was there.

- Have you ever used VR before, for any kind of experience?
    - Just tried it briefly for that external inspection and some other occasions.

Appendix G

User requirements, & 7 dimensions model, MMP principle

1. User *Who are the people/systems/devices that will use/directly interface with this product?*	• Student-pilots • Commercial pilots • Pilots training managers • Pilots training instructors Stakeholders: • Airlines • Pilots' training organizations
2. Interface *What will the interface look like? What technical design will satisfy the user experience?*	• Appropriate terminology for each abnormal operation • Realistic representation of the Airbus A320neo cockpit • The intuitive design and interaction patterns that would correspond the actions as if the training took place in real life
3. Action *What type of actions will users take when using this product? What are the capabilities the product offers its users?*	• The VR HMD should have comfortable ergonomic design so that the users don't get tired quickly • The hand controllers should provide accurate and well-calibrated input to the system • The head and hand-tracking technology should be precise • It is preferred to have a standalone/wireless VR HMD and hand controllers in order to simplify the setup process
4. Data What data is needed to support those user actions? Where do we store, protect, and expose the data?	• The users would only need the Internet connection to start the app. It is prioritized to avoid storing any personal data. In this concept of the procedure trainer the progress data will not be stored either • The application itself needs a VR platform to be stored on
5. Control *Are there any constraints on what the users can do/what they can access on this product? What regulations or internal*	• This to be discussed between the Applica Training Systems AS as owners of the product and potential customers

policies do we (the business) need to conform to for this product? How do we ensure that the product interface is secure?	
6. Environment *Which software and hardware platforms will be used?*	● Standalone VR HMD ● Hand controllers, left & right, for the VR HMD ● VR procedure training of abnormal operations application
7. Quality Attribute *What are our customers' expectations regarding things like speed, usability, performance, availability, etc.?*	● The application is expected to have a high-quality visualization of the cockpit with realistic panels and their elements ● The procedure trainer's system should prevent the UX from latency and technical issues that might lead to the distraction from learning process, confusion and motion sickness ● The instructions on how to use the application should be clear for users with and without an experience of using VR

Questions to the each dimensions (Idris, 2020)

Appendix H

Interview & Usability testing
Consent form

This VR application is aimed to provide pilots with an alternative method of training and memorizing abnormal operations. As a platform for training, a cockpit of an Airbus A320neo is represented in the app. Currently, it includes only basic, yet most important functions for training a procedure “Engine Failure during the cruise”.

In the interview, you will be asked questions regarding the learning process of Abnormal operations, your personal approach and attitude, your experience with VR technology.

In the usability testing, you will be asked to perform certain tasks in VR goggles with hand controllers. After the usability testing, you will be asked to evaluate the experience by answering a few questions.

This consent form is a confirmation that you agree to participate in this study conducted by Applica Training Systems AS & Nicole Shevchenko (UiA).

- **Purpose of this study**

The main goal of the interview, usability testing and post-evaluation is to investigate the intuitiveness, functionality and potential of using a VR application for the training of Abnormal Operations. The VR application is at its early development stage. This study will help to figure out the main areas for improvements and any requirements for changing the design of its structure and content.

- **Information that will be collected**

During the interview, your answers will be recorded, as well as relevant notes will be taken down. During the usability testing, you will be observed, the notes and screenshots of the interaction process will be taken as well.

The information will be used in an anonymous form and will not reveal your identity.

The findings of the usability testing will be used for academic research and further VR application development.

- **Non-disclosure**

In this procedure you will get access to the materials that belong to Applica Training Systems AS, therefore you confirm to preserve the copyrights of the owner.

- **Freedom to withdraw**

Participation in this study is fully voluntary. You can withdraw your consent to use the results of the experiment and stop participation at any time.

If you have any questions after today, you can contact Tom Ivar Stie: tom.ivar.stie@applica.no or Nicole Shevchenko: artnicolee@gmail.com

Please sign below to confirm that you have read and agreed with the information on this form and that any questions you might have about the session have been answered.

Subject’s signature, date

_____

Thank you!
We appreciate your participation

Appendix I

Heuristic evaluation

A brief pre-interview:

- What is your profession? What are your fields of interests to work with?
- Have you ever worked on VR projects? What were they about?
- Have you ever worked on projects related to pilots' procedure training?
- How long have you been working in Applica Training Systems AS?
- What is your contribution to this project? Why are you taking part in it?

Set of Heuristics to evaluate:

- Natural engagement

Did you get a feeling about training one of the procedures for pilots? Did it feel like a real tool for memorizing actions?

- Compatibility with the user's task and domain

Have you felt control over your experience in the app? Were there any functions missing that would make your interaction more convenient?

- A natural expression of action

Did the system's responses to your actions match your expectations? Were the interaction paths placed in a logical order?

- Close coordination of action and representation

Latency, preciseness of interactions, motion sickness

- Realistic feedback

Did you feel that you were aware of the processes happening in the application? Did the application provide you with any feedback on your actions?

- Faithful viewpoints

Rendering, hands and head tracking

- Navigation and orientation support

Did it take you a long time to get used to the application?
Have you experienced any errors? Did you get sufficient information about what has happened and how to fix it?
Did you need additional help in understanding the system of the application? If yes, have you found any helpful information or instructions in the application?

- Consistent departures

Did you feel that the app has been consistent and the UI elements lead to consistent interaction paths?

- Support for learning

Does this application provide an opportunity for memorizing a provided procedure? Does it support the learning process?
Did the application let you complete the tasks in an efficient way? Did you manage to complete the given tasks?

- Sense of presence

Did you feel the presence in the cockpit?
In your opinion, is the design pleasant to look at and interact with? Did you feel that the elements in the cockpit were somehow limiting your interactions? Did the cockpit look overcrowded with the UI elements?

• Graphics display (3D depth or perspective distortion, poor resolution of image)	• Satisfying (if no issues) • If problem: Severe, Annoying, Distracting, Inconvenient
• Moving and manipulating the user presence, sub-divided into the hardware device being used (e.g. glove, joystick, 3D mouse, etc.) and the representation of the user in the VE	• Satisfying (if no issues) • If problem: Severe, Annoying, Distracting, Inconvenient
• Interaction with objects and tools in the VE	• Satisfying (if no issues) • If problem: Severe, Annoying, Distracting, Inconvenient
• Environmental features	• Satisfying (if no issues) • If problem: Severe, Annoying, Distracting, Inconvenient
• Interaction with other controls, such as floating menus and palettes	• Satisfying (if no issues) • If problem: Severe, Annoying, Distracting, Inconvenient
• Other hardware problems	• Satisfying (if no issues) • If problem: Severe, Annoying, Distracting, Inconvenient

Appendix J

Survey
Link to the survey: (Shevchenko, 2021)

- What is your overall impression of the VR application?
- In your opinion, what is the biggest advantage of such a training approach?
- Would you personally use such a tool?

The overall impression from the application

	Agree	Slightly agree	Slightly disagree	Disagree
It is easy to use and navigate in the VR application				
The application design looks pleasant				
It took me a long time to get used to understanding how the application works				
The instructions in the main menu were helpful				
The virtual cockpit looked overcrowded with the guidelines turned on				
The terminology used in the instructions was appropriate and correct				
The experience of using the VR application was frustrating				
I felt motion sickness symptoms while training in the application (e.g., dizziness, nausea, headache, etc.)				

The interaction within the application

	Agree	Slightly agree	Slightly disagree	Disagree
The VR technology distracted me from the learning process				
VR controllers have provided precise and well-calibrated interactions				

VR controllers let you interact with the elements in the cockpit without any latency				
I felt full control over the process				

The educational aspect of the application

	Agree	Slightly agree	Slightly disagree	Disagree
The guidelines of the application were effective				
VR application would help to memorize abnormal operations				
VR application provides all the needed information to conduct the abnormal operation “Engine failure during the cruise”				
VR application provides more opportunities for better training of abnormal operations than traditional methods				
VR application did not help to memorize the abnormal operations in an efficient way				
I enjoyed the opportunity to do the physical activity in the training				

Future improvements

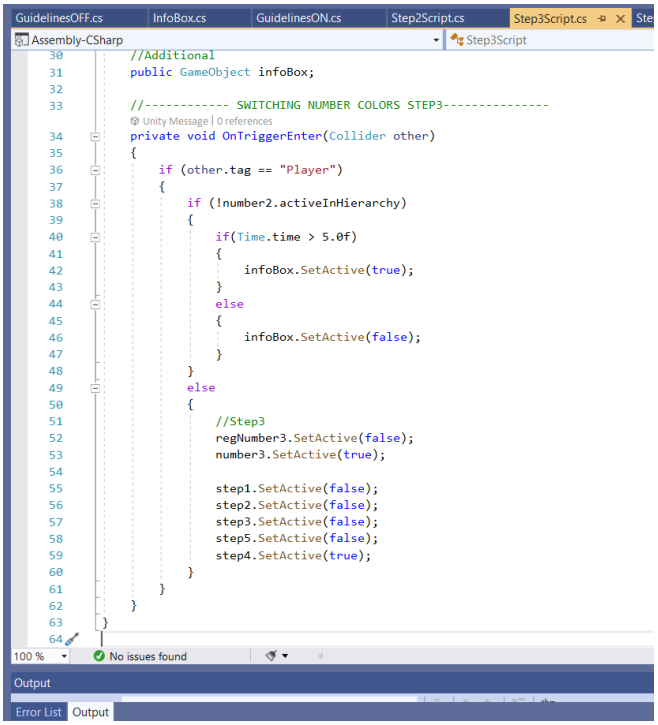
	Yes	No
Having a choice between the “Captain” mode and “First officer” mode is useful		
Having a choice between the Guidelines “on” and “off” modes is useful		
Having a choice between the daylight and the night light in the cockpit is useful		
The application should include timer options		
The application should include voice guidelines		
The application should consider including multi-crew training options		

- Do you have any suggestions for the improvements to the application?

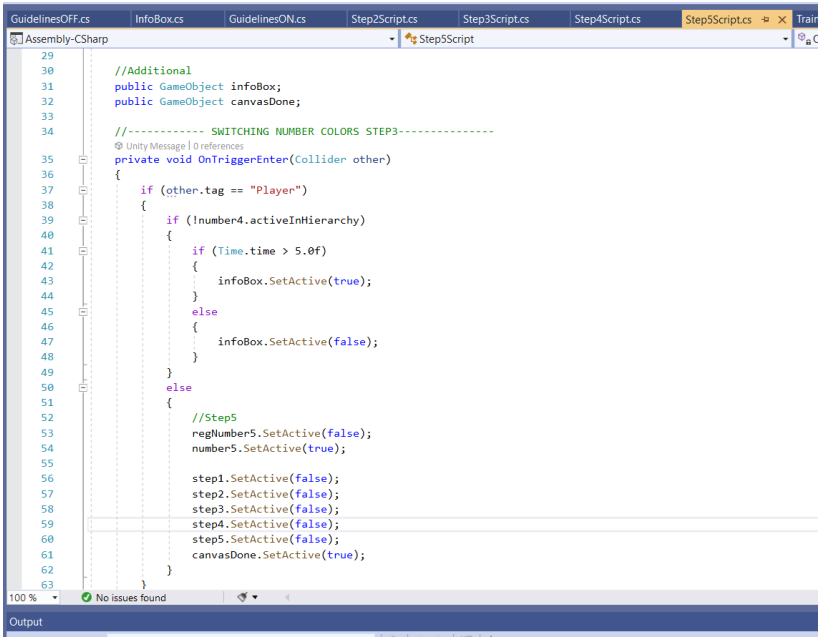
Appendix K

Scripts / Examples of scripts implemented in Visual Studio:

1. Toggling the “On” or “Off” option to choose the training mode



2. Steps updating green when completed



Appendix L

UI & UX related questions to pilots

The VR application for training pilots consists of two parts:

- Main Menu
- Training space

1. In the main menu, pilots have the opportunity to get acknowledged with instructions on how to use the app, how to interact in the cockpit, edit some of the app's settings and, of course, choose all the necessary features for training.

   The choice of features for the training will be the main focus during the upcoming user-testing, therefore some details regarding UI (user interface) elements need to be clarified.

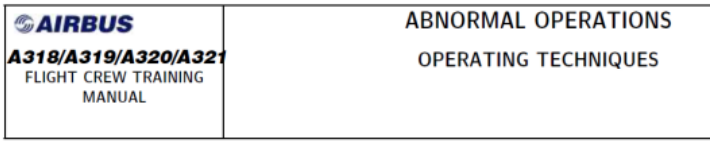
Example of the start page the user gets to see when opening the app. Instructions and settings will be on the left side of the user's head when in VR, in 3-dimensional space. The central tab and the right one will be right in front of the user.

Questions about the correct terms:

1. **Abnormal Operations**
   I have seen on the Internet and also during our discussions with ATS that there are multiple terms meaning the same subject: *Abnormal Operations, Abnormal Procedures, Non-Normal Procedure Checklists*. Which term is the most relevant and the most commonly used?
2. **Seat**
   In this VR app, I would like to implement an option for the pilots to choose their location in the cockpit when training: the seat on the left or on the right side of the cockpit. What are the correct titles of the pilots: *Pilot & Co-Pilot, Captain & First Officer?*

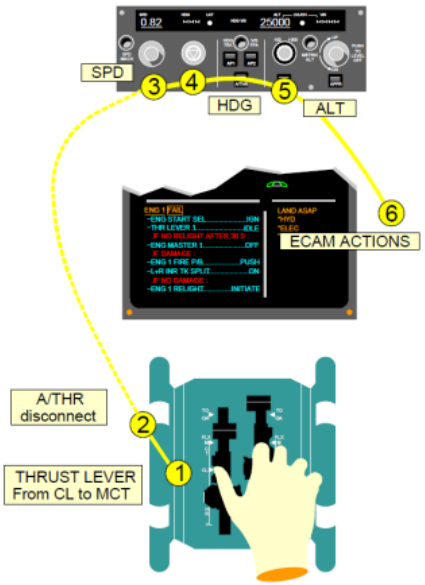
The word *Seat* itself, does it look relevant, or it would be better to replace it with another term, e.g. *Position, Role, Side*?
2. For the training space we have chosen to implement a procedure **"Engine Failure during Cruise"**, however, I need more explanation on gestures and interactions for the actions in order to implement them in VR.

PROCEDURE
As soon as the engine failure is recognized, the PF (pilot flying) will simultaneously:



1. Set MCT (maximum continue thrust) on the remaining engine(s)

What is the usual initial position of the handle before this step? Does this step require moving the handle forwards or backwards? What does CL mean?



2. Disconnect A/THR (auto thrust)

Does "disconnect" mean rotating the wheel? If yes, in which direction: forwards or backwards?

Then, PF will

3. Select the SPEED according to the strategy
Does this step mean rotating the switcher on the panel? To the left or to the right and how much?

4. If appropriate, select an HDG to keep clear of the airway, preferably heading towards an alternate. Consideration should be given to aircraft position relative to any relevant critical point
Does this step mean pushing/clicking that button/switcher on the panel?

5. Select the appropriate engine inoperative altitude in the FCU ALT window and pull for OPEN DES
Does this step mean pushing/clicking that button/switcher on the panel? Interacting with more buttons/switcher on the panel?

Then, PF will
6. Require the ECAM actions
At high flight levels close to limiting weights, crew actions should not be delayed, as speed will decay quickly requiring prompt crew response. The crew will avoid decelerating below the green dot.

Thank you!