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FINAL PROJECT REPORT

DEVELOPMENT OF A VIRTUAL AIRPORT ENVIRONMENT AND OTHER APPLICATIONS OF VIRTUAL REALITY IN THE AVIATION INDUSTRY

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TITLE: PRACTICAL APPLICATIONS OF VIRTUAL REALITY IN THE AVIATION INDUSTRY

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ABSTRACT

Virtual Reality (VR) technology offers the ability to immerse users in computer-generated environments. This new technology holds a significant potential to reshape procedures across many sectors of the airline industry. These systems may be implemented in many fields, from aiding designers in the development of aircraft or related equipment, to testing of operational procedures to providing a more in-depth training.

As a first step in the analysis, the characteristics, strengths, and limitations and how it could affect implementation in the airline industry will be discussed. Virtual Reality is a technology that can be adapted to its users' needs, aiding in operational challenges, collaborative decision-making processes, or the simulation diverse scenarios.

The user experience in the VR platform will be evaluated in the assessment to encompass, not only the effectiveness of the VR technology but also its practicality and adaptability to day-to-day operations, aligning to the needs of professionals in the aviation industry.

More in-depth case studies will be performed in certain non-conformities, incidents or accidents that could have benefited by any preventive or corrective action that takes advantage of Virtual Reality and thus, increasing safety and mitigating operational errors.

As a final step and to prove the capabilities provided by Virtual Reality, a simulated airport environment will be developed together with functional ground service equipment. This simulator may act as a demonstrator of VR capabilities and preview the advantages that could be achieved if further developments were made in the field.

TABLE OF CONTENTS

TABLE OF FIGURES

1 INTRODUCTION

With current trends in aviation focusing in minimizing its ecological footprint, efficiency and cost-effectiveness have become fundamental principles, reflecting a commitment to sustainability and responsibility. These values align with the priorities of both airlines optimizing their operations and passengers seeking dependable yet affordable travel options.

Aviation needs to adapt and incorporate new technologies with the goal of streamlining processes and improving efficiency. Virtual Reality appears as a technology that offers benefits ranging from streamlined training processes, enhanced maintenance procedures, more efficient design processes and improved passenger experiences.

Whilst the first studies and prototypes of Virtual Reality technology date back to 1950s, and 1960s. During the 1970s and 1980s, various laboratories from companies like NASA or software developers such as ATARI performed research in the development of more advanced VR devices. These first products were functional albeit extremely complex, expensive, and limited.

In the 1990s and 2000s, research focused on the ability to run virtual reality equipment in more modest or even low-end computers. It was finally in 2012 when the first affordable, high-quality headsets intended for the consumer market were released, the Oculus Rift. This device solved many of the limitations present in previous VR headsets. Research is still being carried out to produce better and more cost-effective equipment, making current VR glasses an extremely interesting product with promising advantages and use cases.

VR technology has become an affordable and interesting technology with limitless applications and extreme versatility. By examining real-world applications, industry trends and technological advancements, a straightforward understanding will be provided of how VR can be integrated into everyday operations, making aviation a more efficient and cost-effective endeavor.

1.1 Problem approach

In the efforts to make aviation more efficient and practical, there are challenges that need to be faced. Current procedures may benefit from significant changes that could improve its efficiency and reduce wastes throughout. Another issue that may cause wastes and unnecessary costs are operational safety violations. Plenty of the incidents caused, for example, during ground handling operations, can be traced back to lack of training or proper knowledge of the rule. Virtual reality may play a significant role in the optimization of processes and the creation of new training methods that could aid.

1.2 Project objective

The objective is to make a study of the market, see what the market needs and possible evolutions, and then thinking of possible use cases in which Virtual Reality may be a helpful tool to improve efficiency and competitivity.

After performing the market analysis, the goal is to create a working demonstrator of a Virtual Reality airport environment to test and highlight the advantages and capabilities this new technology offers, making some conclusions regarding the results obtained.

2 CHARACTERISTICS OF VR

This section of the report focuses on the practical aspects of virtual reality devices. This involves a discussion about the requirements for its use and the characteristics in terms of user experience of virtual reality devices will be discussed.

2.1 Hardware

A Virtual Reality device is used for immersing the user in a computer-generated environment, providing a three-dimensional, interactive experience. Virtual Reality relies on several separate hardware components and processes to operate. Here is a general overview:

Headset

The headset is the head mounted device. This is the main device for virtual reality. It contains the display, audio system, tracking system sensors, and in some low-end devices, even the processing unit.

The most significant part of the headset is the display. The headset may have one common display or two displays (One for each eye). The displays may be divided into stereoscopic, two different images are displayed to generate a perception of depth, and monoscopic, both eyes see the same.

The images shown on the display often need to be distorted (Barrel distortion) and additional chromatic aberration filters need to be applied.

The figure below shows the image sent to a virtual reality headset. This image shows the distortion found on images displayed in a VR headset.

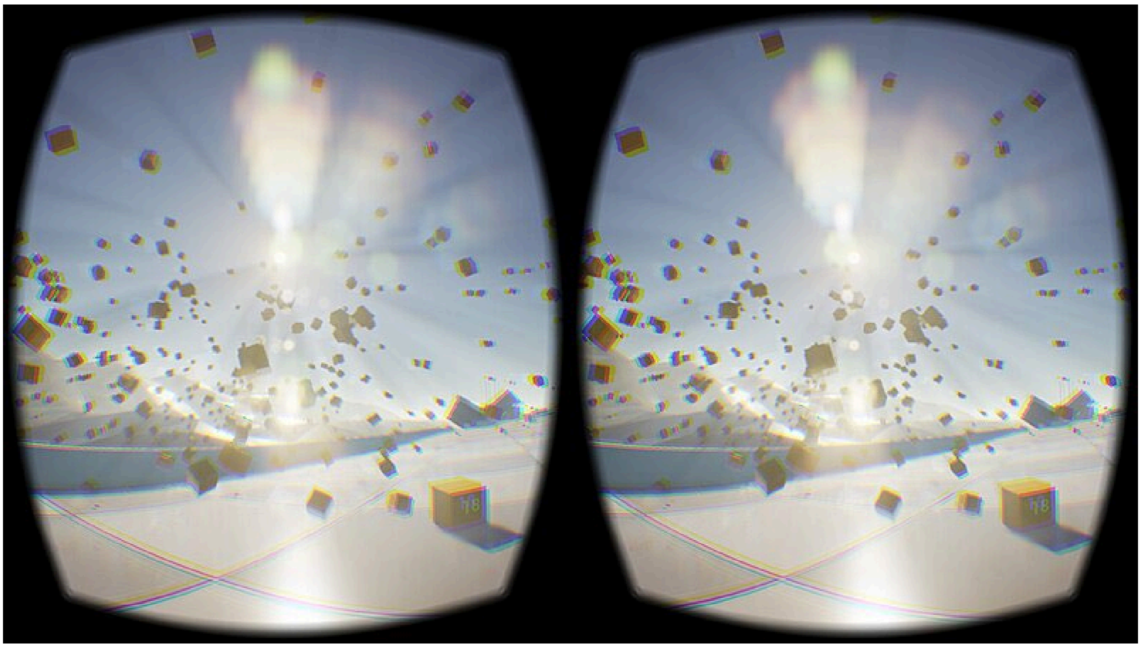

Figure 1: Image displayed by a virtual reality headset.

The headset often uses lenses to focus and shape the images for each eye so that the image is seen as undistorted. The combination of filters and the effect of the lenses can create a perception of depth. These are adjustable to fit users with different distance between eyes.[1] The lenses can also be graduated to suit users that need correction. The headset also has headphones to create a simulation of spatial audio and improve immersion.

Tracking systems are also installed in the headset. The headset has cameras and photonic sensors to track its movement.

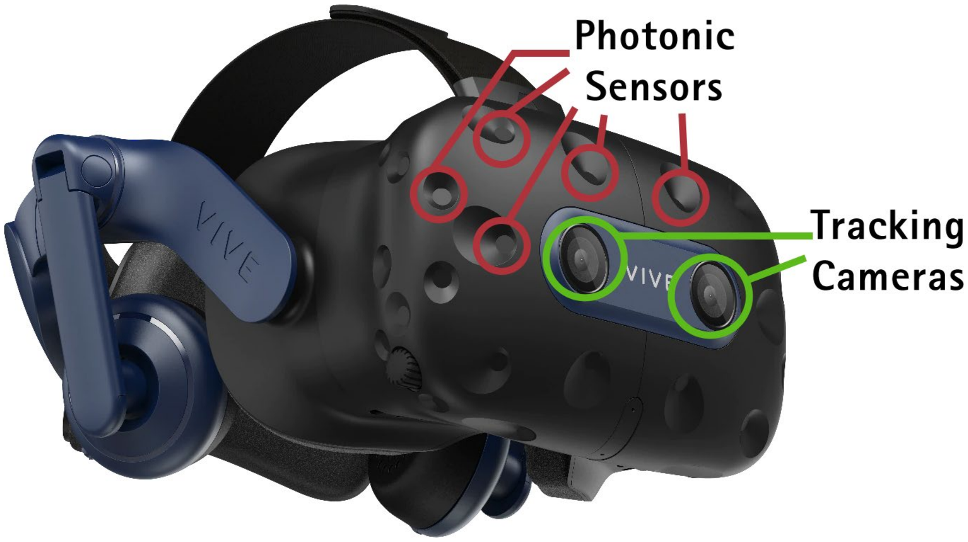

Figure 2: Sensors used by the headset for movement tracking

Computer

The computer is in charge of generating the images that will be displayed in the headset. As it was mentioned, some headsets may be standalone and have a computer in the headset, however, the headsets required to run professional simulators need of a powerful computer to operate.

Connection to the computer is usually done through a hub, which connects to a PC input, to send all the information and actions performed in the VR headset to the computer, a PC audio and video output that transmits the information that will be displayed in the headset, and a power supply.

The computer runs all the applications needed to run the device, handles tracking data, and renders the virtual environment in real time.

Hand controllers

The controller is used to interact with the virtual environment. These come in a variety of shapes and functions. For virtual reality, tracked handheld controllers or even gloves are often used to interact with the virtual environment. These controllers can react to different inputs, such as touchpad trackers, buttons, triggers, or grip sensors. Controllers also have haptic output, capable of simulating vibrations or sensing things in the virtual environment. [2]

For certain industry specific use cases, purpose-built controllers may be used such as a yoke, rudder, and throttles setup to simulate an aircraft, or a steering wheel and pedals setup to simulate a road vehicle.

[1] Hamacher, A. (2021). *Stereoscopy in virtual reality.* International Journal of Engineering Trends and Technology, 69(6), 126–130. https://doi.org/10.14445/22315381/ijett-v69i6p219
[2] Controllers. Valve Index® - Valve Corporation. (n.d.). https://www.valvesoftware.com/en/index/controllers

Base stations

Base stations are tracking devices. Whilst the tracking is performed by the headset itself, additional tracking devices or "lighthouses" may be used to improve tracking accuracy, these devices are optional. The base station uses lasers to sweep the room and track photonic sensors in the headset and controllers. This way, the headset can use both external tracking (External sensors track all the devices) and Inside-Out tracking (Sensors are embedded in the headset itself, allowing it to track its own movements) for extreme precision.[3]

2.2 Advantages and limitations

To gather knowledge about the advantages and limitations of virtual reality devices, thorough testing was conducted in different software, both aviation and entertainment related. The most remarkable factors experienced are:

2.2.1 Human Scale

Whilst working around 3d objects, often flat screens are not able of transmitting a true feeling of size of whatever is being shown on the display. Virtual reality can solve this problem. The stereoscopic display creates an accurate enough perception of perspective that helps in determining the true size of things.

Another factor that helps in creating this effect is using the body to control the software. Since head and hand movements are tracked, any movement performed by the user will be closely represented in the virtual environment, thus, making it necessary to move or stretch the arm to reach parts far away, helping in giving the feeling of true size.

2.2.2 Highly immersive

The virtual reality device uses a combination of tricks to make the user feel inside the virtual world. Among those tricks are the stereoscopic display, controls by body movement and the spatial audio played by the speaker system. This allows the user to feel completely immersed in the virtual world.

2.2.3 Configurability

One of the advantages of virtual reality is its ability to be configured to suit everyone. However, this can also be a limiting factor. The setup of the virtual reality headset can be overwhelming to the user. During the first run, it is necessary to[4]:

- Place all the devices in appropriate locations. Some devices may even need permanent installation.
- Connect all the cables and devices accordingly.
- Install all the software and drivers to ensure that the computer detects all the devices in use.
- Pair and calibrate all devices.

The headset has adjustment for:

- Headset band for different head sizes.

[3] Base stations. Valve Index® - Valve Corporation. (n.d.). https://www.valvesoftware.com/en/index/base-stations
[4] VIVE Tutorials. (2021, June 2). *Setting up your VIVE Pro 2.* YouTube. https://www.youtube.com/watch?v=xzgyeu35PJ0

- Headset strap for different head sizes.
- Earphone placement.
- Visor distance, to fit prescription glasses or long eyelashes.
- Interpupillary distance.

It is essential to set everything correctly, since an incorrect setting in any of the steps mentioned above may lead to motion sickness, headaches or issues when using the headset. However, since the setup depends on factors such as the user, room size, and the computer that will be used, there is no easy method to set everything up correctly the first time.

2.2.4 Cables

A standard virtual reality setup uses a significant number of cables. 3 cables are needed to setup the hub, a USB data cable, a DisplayPort video and audio cable and a power supply cable. The base stations (2 in a standard configuration) need a power supply cable. The headset is connected to the hub with another cable. Meaning that at least 6 cables will be needed to use the virtual reality device.

Among those 6 cables, the headset cable is the most problematic. To be able to move, the cable needs to be hanging with certain slack. If the user is not cautious enough with this cable, the user may become entangled in the cable, with a risk of falling.

Shown on the figure below is the standard wiring configuration needed for using a VR headset. Shown on red are data cables, on blue power cables and on green the video DisplayPort cable.

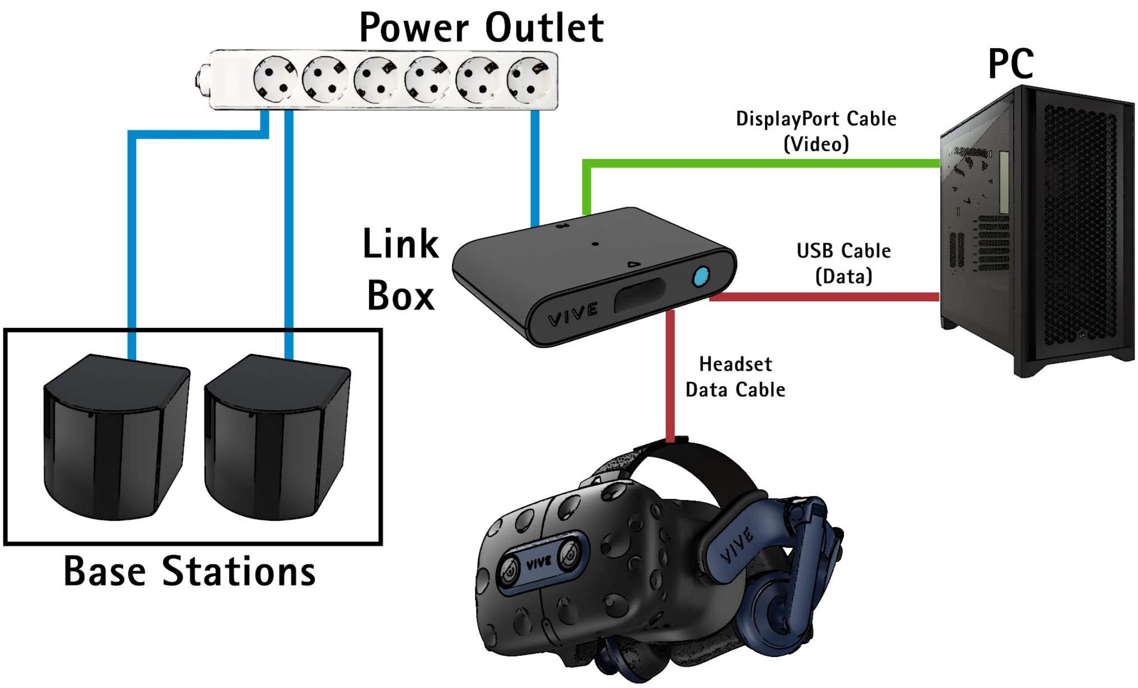

Figure 3: Standard Cabling setup for a VR headset

2.2.5 User limitations

Even if virtual reality offers a significant number of advantages, use sessions are of limited time. The use of a virtual reality device is tiring.

One of the issues experienced with the device is sweat. The device consists of a screen, sitting around 3 centimeters away from the user's face. The screen and all the electronics in the device get warm during use. Additionally, the device, to prevent the entry of outside light into the user's eyes uses a leather seal. These factors together can make the user sweat, which can cause the lenses to get foggy, making the vision blurry and breaking immersiveness. A glasses cleaning cloth is provided.

One aspect that limits immersiveness and tires the user is headset weight. The headset weights just under 1kg and is held in place by just a head band and a strap. As mentioned before, sweat may accumulate around the face leather seal, which can cause the headset to slip downwards, off the ideal eye position.

Prolonged use of VR devices may also cause "Virtual reality sickness," a phenomenon with symptoms comparable to motion sickness with symptoms including general discomfort, eye strain, headaches, stomach awareness, nausea, vomiting, pallor, sweating, fatigue, drowsiness, disorientation, and apathy. Various factors may be traced as causes for VR sickness, such as low frame rate, input lag and vergence-accommodation-conflict. An incorrect placement of the lenses due to an incorrect setting or due to the headset sliding off its place, may also affect VR sickness.[5] It may not be safe for people with certain conditions such as epilepsy to use VR headsets.

Studies have been performed to determine the effects of virtual reality replacing conventional physical office work. For an experiment, a traditional office setup consisting of an office desk setup with a curved display and a keyboard with integrated touchpad was replaced by a virtual reality setup. In the virtual reality setup, the curved display was replaced by a curved floating virtual display. The same keyboard was still in use with the hands being streamed into the virtual environment. The virtual reality headset used was the Meta Quest 2.

The study was performed on a relatively small group of 16 people, and intended to simulate a full work week, that is, 5 days, 8 hours each, with the participants performing actual work on the virtual reality setup, rather than specific tasks, as it was done in previous experiments. The goal was to compare certain variables such as productivity, anxiety and perceived workload in a work week using the traditional setup and a work week using the virtual reality replacement.

Of the 16 participants, 8 would spend the first week of the experiment working on the VR setup with the other 8 spending the first work working on the traditional setup. The participants had a mean age of 29.31, of which 10 were male and 6 were female. All participants had normal or corrected to normal eyesight, capable of seeing everything clearly in virtual reality. Two additional participants dropped out on the first day of the experiment due to migraines, nausea or anxiety.

The measurements that would be taken on the participants included the task load, system usability, flow, perceived productivity, frustration, positive or negative affect, wellbeing, anxiety, simulator sickness, visual fatigue, heart rate, break times and typing speed.

Additionally, the participants were given a briefing on the use of the virtual reality system at the start on the experiment to ensure that lack of experience in the virtual system would not bias the results in favor of the traditional setup.

The results of this study indicated that the participants experienced a much higher perceived workload during the virtual reality part of the experiment than on the physical work environment. The virtual reality environment was also found less usable than its conventional counterpart.

The perceived productivity and flow was also determined to be higher in the physical environment than on the virtual reality. It was also determined that participants had a higher negative affect after the virtual reality session.

A worse typing speed and longer breaks were reported in the virtual reality setup.

[5] Kolasinski, E. M. (1995). Simulator Sickness in Virtual Environments. https://doi.org/10.21236/ada295861

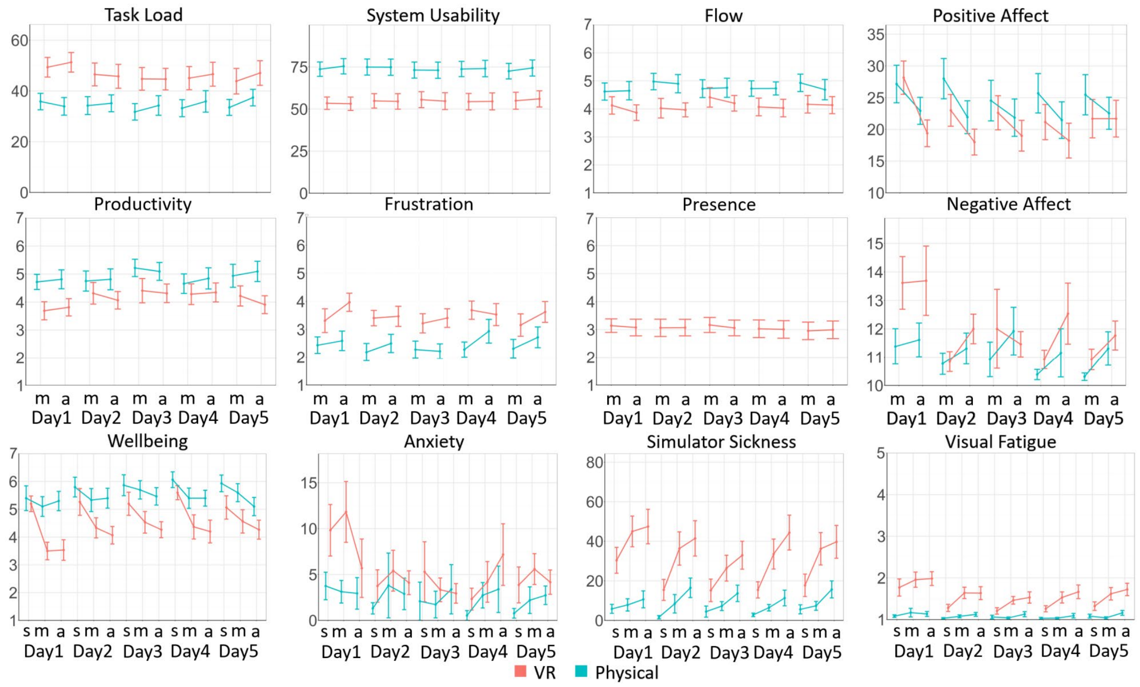

Figure 4: Average and standard error for subjective measures in the morning and afternoon.

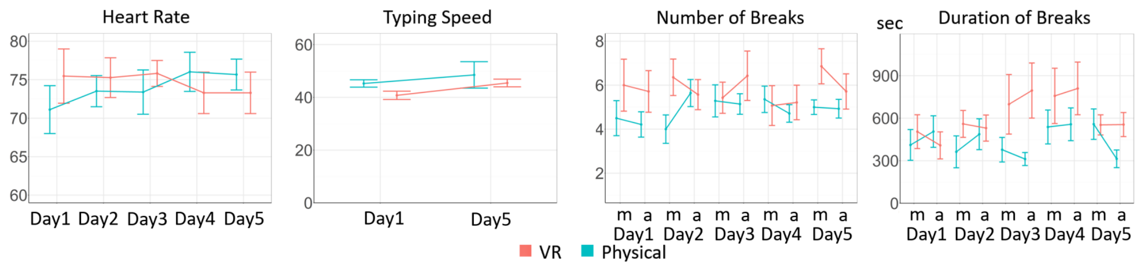

Figure 5: Average and standard error for objective measures in the morning and afternoon.

Additional issues were reported by the users during the virtual reality experience. 11 participants complained about the comfort of the headset, complaining about the weight of the headset, pressure against the face and lack of peripheral view, needing to move the head more than before. These issues were also noticed whilst performing the tests for this report.

It was also reported that the headset was also uncomfortable and prevented the users from drinking or taking notes on paper as they would if they were working on a traditional setup. Virtual reality also prevented users from looking around and taking their eyes off their screen without removing the headset completely.

Many participants liked the isolation and privacy provided by the headset with the integrated headphones allowing them to play music while working, however, some users disliked the lack of situational awareness and not knowing whatever was happening on their surroundings.

Whilst most users experience improvements in their perception of work in virtual reality, the measurements obtained during the experiment display worse than average results during the virtual reality experience and highlights the need for further research before a full implementation of virtual reality can be considered.[6]

[6] Biener, V., et al. (2022). *Quantifying the effects of working in VR for one week.* IEEE Transactions on Visualization and Computer Graphics, 28(11), 3810–3820. https://doi.org/10.1109/tvcg.2022.3203103

3 POSSIBLE APPLICATIONS

Virtual reality offers several advantages that may be suitable for several fields in the aviation industry. In this section, possible applications will be discussed.

3.1 Virtual Mockups

Physical mockups serve essential functions in the aviation industry. These mockups are used throughout the entire design and operational life of the aircraft for different purposes. In addition to other purposes such as training, these mockups are mostly used for verification during the design phases of the aircraft, as well as an aid for marketing, to display the designs and for customers to determine if their configuration is up to standard.

Mockups are full scale models of the aircraft or some of its sections that may be used for different purposes. An aircraft mockup may be designed to model sections of the aircraft such a galley, or even a full-size cabin.[7]

Mockups may be used for training. There are several types of trainings that can be performed depending on the characteristics of the mockup:

Door trainer

Door trainers are used to train cabin crews in the operation of aircraft emergency exits and doors. Such a trainer is used to train for normal, abnormal, and emergency procedures.[8]

Cabin service trainer

A cabin service trainer is a mockup modeling a full or partial fuselage, with equipment to represent the customer's aircraft layout. Such a mockup can feature functional lavatories, galleys, mood lighting and other features. Cabin service trainers can also cover door training.[9]

Cabin emergency evacuation trainer

A cabin emergency evacuation trainer adds the ability to train safety and emergency procedures. Procedures related to door and emergency exit operation, emergency evacuation, oxygen mask drop, or fire and smoke training can be simulated.[10]

Figure 6: Types of trainer mockups

[7] EDM Ltd. (2020, January 31). *Full size mockups*. https://edmgroupltd.com/civil-aviation/full-size-mockups/
[8] EDM Ltd. (2020, February 3). *Door trainers*. https://edmgroupltd.com/us/civil-aviation/door-trainers/
[9] EDM Ltd. (2020, February 3). *Cabin Service Trainers*. https://edmgroupltd.com/us/civil-aviation/cabin-service-trainers/
[10] EDM Ltd. (2020, February 9). *Cabin-trainers*. https://edmgroupltd.com/civil-aviation/cabin-trainer-cabin-emergency-evacuation-trainers/

Mockups can also be used for marketing purposes. Full scale replicas are constructed as display models to display the characteristics of a product to a potential customer. These replicas can go extremely into depth, modeling access doors or internal equipment. These mockups are often used to display interior characteristics and passenger cabin layout. Mockups can be manufactured following the customer's requirements in terms of cabin equipment and layout.[11]

Figure 7: Beechcraft Denali Mockup used for marketing at NBAA-BACE

A virtual reality setup may be used to replace traditional mockups. Virtual reality can be used to interact with elements with a realistic and true to size look. Applied to a virtual mockup of, for example, the interior of an aircraft, a realistic experience of the inside of the aircraft can be achieved with the ability to interact with all the parts and elements that make the interior.

Using a virtual reality setup offers two main advantages. Since everything is in a virtual environment, there is no downtime to wait for manufacturing and prototyping of the mockup. Additionally, a virtual reality mockup is cheaper and more environmentally friendly since there are no wastes in materials and resources. With a virtual mockup, it is possible to offer several mockups for various configurations and options at a fraction of the price of a traditional one.

[11] Pacmin Studios. (2022, November 18). *Full scale mock up & military aviation models.* https://www.pacmin.com/full-scale-mock-up/

Figure 8: Aircraft Cabin shown in Virtual Reality

Unfortunately, a virtual mockup cannot fully replace a traditional mockup in all situations since a it is not possible to simulate touch and feel of materials or mechanisms, or facts such as seat comfort. Thus, a virtual reality system may not fully replace a mockup used for training. However, a combination of virtual mockups during the earlier stages of a design phase and traditional mockups once the design is completer and more polished may offer the best experience in a cost-effective manner.

3.2 Aid in the design phase

Aircraft design is often divided into 3 different stages: Conceptual design, Preliminary design, and Detail design. The conceptual design is the very beginning of the design process, creating a rough representation of what the final product is intended to be. The next stage is preliminary design in which the initial rough model is tested and optimized to fit its intended market more accurately and to ensure that it will meet target performance. Last step is detail design, in which every aircraft component is designed at a detail enough to be manufactured.

These stages often occur in loops, designing, testing, reviewing, and if necessary, modifying the design.

Virtual reality can offer advantages that improve the efficiency of the design process and avoid the unnecessary addition of design loops.[12]

- **Visualization and conceptualization**

Virtual reality can be used to visualize accurate representations of the models with realistic textures, lighting, making the detection of errors an easier task. All the details can easily be shown, thus detecting flaws earlier in the design phase so that these are changed or repaired.

[12] Fedko, D. (2023, August 23). *How virtual reality is transforming the engineering industry.* WeAR. https://wear-studio.com/virtual-reality-in-engineering/

Using a virtual reality device, it is possible to interact with the design, rotating and moving it as needed with intuitive gestures, increasing efficiency and accuracy as well as letting engineers be more creative and innovative in their designs.[13]

- Spatial understanding

Virtual reality offers the capability to provide a sense of scale and depth, useful for understanding the sizing and relation of the parts that make up the aircraft. It is possible to walk around the virtual model of the aircraft and inspect them from different angles and perspectives. This way, it is possible to optimize the layout of the aircraft interior and exterior to ensure that all components integrate and make an efficient use of the available space.

- Ergonomics and Human Factors

Since aircraft are designed to be operated and used by humans, ergonomics and human factors are essential factors for the creation of a good design. With current design methods for aircraft components which rely on computer software displayed on flat screens, it is difficult for the designer to get a feel for the true size of the elements of the aircraft, and thus, its ergonomics.

Traditionally, to test these features, physical models of the components were built to determine if the design is correct or if a review is needed. This method is expensive and time consuming.

Since virtual reality is based on a human scale and operated with hand gestures, it is possible to immerse in a virtual representation of the aircraft design to perform initial tests on the ergonomics of the aircraft and to assess if, for example, the accessibility of switches and essential inputs in the cockpit are correct, if cabin crew control units or other cabin features, are easily reachable and usable, etc.

Unfortunately, virtual reality will not fully replace these traditional prototypes since certain features such as seat configuration and position are harder to simulate on virtual reality, however, certain necessary changes that may otherwise have been detected through the use of a prototype could be detected in the virtual environment saving time and resources.

- Testing and Simulation

With virtual reality, certain tests can be simulated under different conditions. This technology can become extremely useful in the design of the aircraft manufacturing process. It is possible to simulate all the procedures and techniques the final installer will need to follow for the installation of each component.

Doing so it is possible to assess for possible risks that may arise during the installation process that could lead to safety risks both to the operators during the time of installation or maintenance, or possible incidents that may arise later on, during the operation of the aircraft due to improper installation of the systems. The information gathered from the tests can be used to optimize the assembly process of the aircraft.

Similarly, it is possible to perform tests on the maintenance procedures. Design features such as access points, tooling requirements and safety protocols can be tested to ensure easy access, address potential issues, and minimize aircraft downtime.

[13] Engineering Management. (2023, November 28). *What are the advantages of using virtual reality in engineering design?.* How VR can boost engineering design outcomes. https://www.linkedin.com/advice/0/what-advantages-using-virtual-reality-engineering-y7vee#:~:text=One%20of%20the%20main%20benefits,optimize%20their%20performance%20and%20functionality.

Since all the tests are performed in a virtual world, all the tests are performed in a safe environment that is capable of recreating even the most extreme and risky conditions.

- Collaborative Design

Virtual reality can be used simultaneously by several people without the need for all of them being in one single location. This creates the possibility of having several people collaborate on the design of the components, collectively exploring alternatives, improving communication, providing feedback, and making informed decisions without the need for physical meetings or traveling, saving time and resources.

- Cost Reduction

Physical prototypes are commonly used for the review and testing of the designs. Even with new technologies such as additive manufacturing that can make prototyping a much faster process with less manpower required, it is still required to invest resources in terms of materials and efforts to produce these prototypes. Since the prototypes are used for testing, it is not uncommon that the prototype gets damaged, or a flaw is detected that requires a complete rebuild of the prototype with its subsequent waste of resources.

Using virtual reality applications, real-like 3d models that can be easily felt and manipulated can be used to fully evaluate them without a need for using company resources. The time required to perform any modification in a physical prototype is nowhere near the time required to perform such modification in its virtual equivalent.

Virtual reality also allows for recreating test in a virtual environment whose conditions may be too dangerous to perform on a physical prototype.

- Customer Feedback

An immersive and easy to interact representation of the design can be created using virtual reality, allowing people that are not specialists in the industry or potential customers, to see the design, and explore the aircraft's features and design elements before being physically built. This can help gather feedback and build interest in the product.

- Regulatory compliance

Since virtual reality can represent a vast number of situations, it may be used to show certain features to the civil aviation authority responsible for the certification of the aircraft. This is useful not only to show compliance with regulations, but to obtain feedback from the agency that could improve the final product earlier on the design phase.

3.3 Training

Training is the field in aviation in which virtual reality could excel the most.

Aviation is known for being a complex field with a vast number of different courses and qualifications needed to perform any task. This is understandable due to the nature of aviation; the safety of aviation is achieved thanks to, among other things, the training and knowledge about the field of all the people involved in air operations. Everyone's actions, from an engineer designing an aircraft, to a pilot, to ground staff can affect operational safety.

Since safety is of upmost importance, it is often the case that certain obvious improvements that may be extremely helpful in terms of training suffer delays due to the need for testing before regulator's approval. This can mean that certain technologies that could ease the training process may not be available and in turn make the training process more difficult and expensive than needed.

EASA ED Decision 2023/019/R is an excellent example that highlights all the issues found in training that might benefit from new technologies and the delay in the implementation of these. This decision amends continuing airworthiness Part 66, Part 147, and Part-CAO regulation. The changes mentioned in this decision will become effective the 12th of June 2024 with a transition period for all trainings started before the 12th of June 2024 under the previous regulation needing to be finished by the 12th of June 2026. [14]

Certain points indicated in the amendments will be analyzed to mention the importance of the changes and how it could open the regulation up for the possibility of implementing VR based systems:

- **AMC1 147.A.115(a) Instructional equipment**

In the consolidated version published in December 2022, the Implementing Rule "147.A.115 Instructional equipment" does not mention computer-based training[15], the new AMC1 147.A.115(a) mentions computer-based training, distance learning or multimedia-based training.[16]

- **Implementing Rule 147.A.145 Privileges of the maintenance training organization**

The new amendment introduces new acceptable means of compliance: "AMC1 147.A.145(c) Distance learning via uniform resource locator (URL) addresses". This new AMC allows for the delivery of training and examinations online via URL addresses. This is extremely beneficial to the trainee since it offers better flexibility and cost savings.[17]

- **AMC 147.A.200(f) The approved basic training course**

The rule available on the consolidated version published in December 2022 mentions the requirement to issue a certificate of recognition (CoR) of reaching at least 90% of the tuition hours. The amended version includes an alternative of 95% completion of the content for the issue of a CoR in cases of student-centered methods, such as those based on online training or virtual reality.[18]

- **AMC1 Appendix III Aircraft type training and type evaluation standard – on-the-job training (OJT) Section 6**

Whilst the Part 66 amendment is the most extensive out of the 4 amendments released with the ED, the changes in this acceptable mean of compliance is the most significant in terms of the use of virtual reality for training.

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[14] Agencia Estatal de Seguridad Aérea. (November 2023). AC-TRAN-ETI02-GU01. *Guía Transición Parte 147.* https://www.seguridadaerea.gob.es/es/ambitos/aeronaves/aeronavegabilidad-continuada/organizaciones/organizaciones-de-formacion-de-mantenimiento-parte-147

[15] EASA. (December 2022). *Easy Access Rules for Continuing Airworthiness - 147.A.115 Instructional equipment.* https://www.easa.europa.eu/en/document-library/easy-access-rules/online-publications/easy-access-rules-continuing-airworthiness?page=35#_DxCrossRefBm550195039

[16] EASA. (2023, November 2). *AMC & GM to Part-147 — Issue 2, Amendment 3 - AMC1 147.A.115(a) Instructional equipment.* https://www.easa.europa.eu/en/document-library/agency-decisions/ed-decision-2023019r

[17] EASA. (2023, November 2). *AMC & GM to Part-147 — Issue 2, Amendment 3 - AMC1 147.A.145(c) Distance learning via uniform resource locator (URL) addresses.* https://www.easa.europa.eu/en/document-library/agency-decisions/ed-decision-2023019r

[18] EASA. (2023, November 2). *AMC & GM to Part-147 — Issue 2, Amendment 3 - AMC1 147.A.200(f) Approved basic training course.* https://www.easa.europa.eu/en/document-library/agency-decisions/ed-decision-2023019r

There are several changes related to the flexibility in the planning of on-the-job training. The new amendment adds the option to perform OJT on several approved maintenance organizations (AMO) under the supervision of the evaluating AMO, as well as opens the possibility to perform OJT on similar components of different aircraft types for the type training of one aircraft.

The most significant amendment in this AMC in terms of introduction of Virtual Reality is the approval of the use of MSTDs (Maintenance Simulation Training Device) and MTDs (Maintenance Training Device) during OJT. The previous edition mentioned: "The use of simulators for OJT should not be allowed."[19]

As it can be seen in the agency decision mentioned, education and training in aviation is being subject to intense changes to keep up to date with higher standards whilst still trying to be accessible.

Additionally, looking at examples of documentation used for training, it is clear that those documents may benefit from a redesign, even better with the use of virtual reality.

3.3.1 Analysis of current training methods

To take as an example, and, since the goal of the last step of this project is the creation of a demonstrator for ground personnel training, an analysis on AENA's Platform Safety Regulation ("Normativa de Seguridad en Plataforma") manual will be performed. This manual is the basis for all the training ground personnel need.[20]

To perform any work in an airport air-side in Spanish territory, it is necessary to have both AVSEC and AVSAF certificates. These certificates are given after performing training in certain fields. There are two AVSAF trainings, AVSAF-P (Pedestrians) for access on foot, and AVSAF-C for drivers.

After completing AVSEC and AVSAF-P training, and passing an AESA exam, the student will be given an airport access accreditation restricted to the areas strictly necessary for performing the tasks required in his work position and its employer's limitations. I.e., an employee does not need to access the passenger terminal but needs to access the platform, the employee will get a yellow accreditation. For drivers, it is needed to have completed AVSEC and AVSAF-C training, and pass an AESA exam to be granted a PCP (Platform Driving Permit).[21]

AVSEC is related to security. The contents of this course include:

- Security procedures.
- Enforcing agents.
- Regulating bodies.
- Types of accreditations and its limitations.
- Use of the accreditation and access to the airport.
- Reasons for the withdrawal of the accreditation.

[19] EASA. (2023, November 2). *AMC & GM to Part-66 — Issue 2, Amendment 8 - • AMC1 Appendix III Aircraft type training and type evaluation standard – on-the-job training (OJT) Section 6.* https://www.easa.europa.eu/en/document-library/agency-decisions/ed-decision-2023019r

[20] *Normativa de Seguridad en plataforma: Edición 2021* (11th ed.). (2021). AENA S.M.E., S.A. Retrieved from: https://tramitesyreclamaciones.aena.es/sites/Satellite?blobcol=urldata&blobkey=id&blobtable=MungoBlobs&blobwhere=1576864774111&ssbinary=true

[21] *Diferencia entre Avsec y AVSAF.* Avsaf. (2022, January 20). https://avsaf.es/post/diferencia-avsec-avsaf/

- Procedures in case of risky events or suspicious objects.

AVSAF is related to operational safety. The contents include:

- Operational security policies.
- Regulations.
- Operational Safety Surveillance Plans (PVSOs).
- Notification and action in case of incidents and accidents.
- Safety during aircraft refueling.
- Low Visibility Procedures (LVPs).
- Documentation (personal and vehicle) needed to perform certain tasks.

Most of the procedures related to the training in the AVSAF section depends on the rules published on the AENA Platform Safety Regulation. This manual is divided in 4 sections:

- **Operational Regulations**

Explains all the regulations related to airside work and operations, signaling in use in the airport airside and specific rules during certain situations.

- **Vehicle access**

This section explains the procedures and the required documentation and paperwork for the entry of a vehicle into the airport air side.

- **Driving permit**

This section explains the requirements for driving vehicles inside the airport security zone and all the conditions to perform those related tasks.

- **Supervision**

This final section explains supervising and enforcing agents, as well as explains possible non-compliances that may be caused by personnel during ground operations and its related sanction.

3.3.1.1 Issues in the training methods

Out of these sections, the first is the one that will be analyzed since this section could easily be replaced or, at least, aided by a virtual reality system to improve the quality of the training given to all the personnel involved in ground operations. There are various characteristics on the design of this manual that could lead to future non-compliances, incidents or accidents. Among those:

- **Lack of on-site pictures or images.**

The manual shows absolutely no on site image or actual representation of all the images and signals explained in the manual as displayed on a real airport. Whilst there are several illustrations that show all the signaling used inside the airport, this lack of actual images may lead to difficulties in relating what is taught in the manual to whatever is found in a real airport.

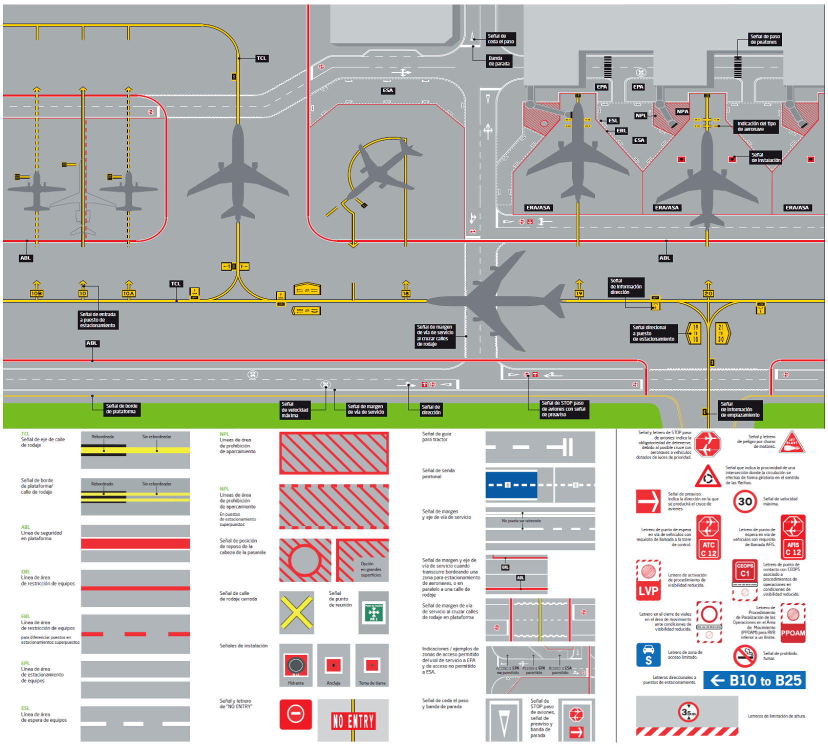

Figure 9: Signals as shown on the manual

Virtual reality may definitely be an advantage and help in solving this issue. A virtual recreation, either a digital twin of a real airport or a non-existing airport created merely for the purpose of training may be used to display all of the signs taught on the manual inside an environment that closely mimics what is found on real airports.

- **Lack of training in certain fields**

Whilst there is definitely enough training in certain areas such as signaling, the manual is lacking in certain extremely relevant areas such as Foreign Object Debris (FOD). The manual does define what FOD is, however, the manual does not explain at any point the risks that may arise from FOD such as Foreign Object Damage, the elements that may be considered FOD and the processes for its removal or notification.

AVSAF and AVSEC training is commonly taught by external companies that provide trainees with their own material that often cover the issues mentioned in more depth and may help alleviate these issues, however, depending on the training company used, the employee may not have access to the manuals during operations for consulting the appropriate procedure since certain training providers offer the trainings with an expiration date and thus, documentation may not be accessible. Because of this, the manual that the worker will most likely use is AENA's NSP.

AENA's NSP is printed in a small booklet that is comfortable to carry on at all times. It is also easily accessible on the internet and thus, editing the manual to cover the areas mentioned may be beneficial.

The manual's contents may also be more thoroughly explained using virtual reality simulations or software to ensure that the employee has adequate knowledge of the regulations.

Additionally, for the issue of an airport access accreditation or a platform driving permit, it is necessary to perform a "practice" or on-site familiarization with the airport environment. This familiarization needs to be proven to the accreditation issuing agency. Using Virtual Reality, it may be possible to perform those familiarizations in a safe and controlled environment without the need for entering an airport.

3.3.1.2 Importance of training

Even if training for ground service personnel is based on relatively basic documentation, its responsibilities and associated risks are relatively high with a large history of incidents caused due to malpractice during ground servicing, maintenance or lack of FOD identification. These incidents range from small crashes between cars on ground, to airplanes crashing with no survivors.

3.3.1.2.1 Barajas, August 1st 2019 service vehicles crash

One example of crashes during ground movements is the crash between a ground service van and a follow-me car in Barajas on august 1st, 2019.[22]

Figure 10: Barajas 1 august 2019 incident shots

This incident is a clear example of contents the platform safety regulation may be considered to be lacking on. On the incident, it can be seen the follow-me car driving on a taxiway rather than on a service road. The van is indeed crossing the taxiway correctly through a service road.

The platform safety regulation clearly indicates that it is forbidden to begin the crossing of a taxiway whenever an aircraft is taxiing or in an unpowered pushback at 200m or less from the crossing. However, from the recorded images, it seems that no aircraft is behind the follow-me car.

At no point in the regulation defines the procedure for the crossing of two non-flying vehicles in crossings other than safety road crossings or roundabouts.

A report regarding this incident, which would indicate the actual reason behind the incident, is not available.

[22] González, J. (2019, August 9). *El Impactante choque entre dos furgonetas en la Pista de Aterrizaje del Aeropuerto de Barajas*. El Español. https://www.elespanol.com/sociedad/sucesos/20190809/impactante-choque-furgonetas-pista-aterrizaje-aeropuerto-barajas/420208118_0.html

3.3.1.2.2 Pushback incidents

It is, unfortunately, relatively common to have incidents during the pushback process. These incidents are mostly divided into two. Towbar failures or collisions.

Collisions are whenever an aircraft performing a pushback is driven against another aircraft, another service vehicle or any other airport utility light a light post or building. These collisions may occur due to improper operation of the pushback vehicle, improperly parked or signaled service vehicles, or performing two incompatible maneuvers at the same time, as is the case of the 28th of May 2018 incident in Tel Aviv Ben Gurion airport.[23]

Figure 11: Collision between two aircraft during pushback

Towbar failures are another reason for pushback incident. The towbar connecting the pushback tug to the aircraft may fail. This may lead to the aircraft being left moving backwards, with no pushback tug to controlled and with the bypass pin in place preventing the pilots from operating the nosewheel tiller.

Towbar failures can occur both due to lack of maintenance and inspections on the pushback equipment, as well as due to incorrect procedures while performing the pushback maneuver, such as turning the nose wheel more degrees than certified. This may lead to the aircraft jackknifing and the pushback tug colliding against the fuselage of the aircraft, causing major damage, as it was the case on the 6th of December 2015 incident in Singapore Changi Airport.[24]

Figure 12: Aircraft damage due to towbar failure

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[23] Aviation Accidents and Incidents Investigation, *Safety Investigation Report – Final Accident File No. 31-18* (2019) Retrieved April 7, 2024, from https://www.gov.il/BlobFolder/dynamiccollectorresultitem/31_18-en/en/31-18-E.pdf

[24] Transport Safety Investigation Bureau, *B737-800, REGISTRATION 9V-MGM PUSHBACK INCIDENT* (2017). Retrieved April 7, 2024, from https://www.caa.co.uk/media/slpbs1p3/tsib-pushback-b737-06-12-15.pdf

These issues may occur due to a ground controller's, ground crew or maintenance personnel's fault. However, it is appropriate that everyone involved has knowledge in the prevention, detection and action in case of such an issue. The platform safety regulation manual does not include any instruction related to performing pushbacks.

3.3.1.2.3 Foreign Object Debris/Damage

Foreign object debris (FOD) is the denomination given to every object that may be at risk of being ingested by an engine. FOD ranges from aircraft parts such as screws, broken debris from airport surface, rocks, grass, trash left by passengers, birds…

Several incidents have occurred due to ingestion of foreign objects. An example that takes FOD ingestion to the extreme, even if no casualties occurred, occurred on an Airbus A320 registered 9M-AHA at Singapore Change Airport the 28th of February, 2010.

After the arrival of the aircraft to the gate, ground personnel started the procedure for docking and signaling the aircraft whilst engine 2 was still running. As a result, the cone placed in front of this engine was ingested, with the cone being shredded into pieces by the engine. After an inspection of the engine, it was deemed that no significant damage had occurred.

Figure 13: Ingested cone

The investigation determined that, despite of knowing the procedure, requiring all ground personnel to wait until the beacon light of the aircraft is switched off and a confirmation is received from the flight supervisor, the operator proceeded with the placement of this cone, disregarding the procedure, ignoring the beacon light still on and without waiting for the approval of the supervisor.[25]

In the platform safety regulation, whilst there is clear indication of when and how to approach the aircraft, there is no additional information regarding management of potential FOD that may be found, indicating how to proceed with its removal or notification.

[25] Air Accident Investigation Bureau of Singapore, *AIRBUS A320, REGISTRATION 9M-AHA FOREIGN OBJECT INGESTION INCIDENT AT SINGAPORE CHANGI AIRPORT ON 28 FEBRUARY 2010* (2010). Retrieved April 7, 2024, from https://www.mot.gov.sg/docs/default-source/about-mot/investigation-report/final-2010-feb-28.pdf

4 STATE OF THE ART

Even if virtual reality is a relatively new technology, there are already companies dedicated to the creation of aviation specific applications of virtual reality technology.

4.1 Aviar B.V.

Aviar is a dutch company dedicated to the creation of virtual reality aviation training software. Currently, the company is developing professional software for industry training applications, however, home use versions are available for the enthusiast to check.

As of now, AVIAR has published two apps for Ground Handling Training and Cabin Crew Training.

The advantages stated by the company include:[26]

- Costs saving

The company claims that a part of the trainings that would otherwise be performed in practical situations could be replaced by virtual reality sessions, saving in costs related to preparation and organization of the conventional practice.

- Reduction in unnecessary travel costs

Aviar claims that the software, since conventional practices can be replaced by virtual reality sessions that can be performed inside an office without the need to travel to an airport or any location with equipment suitable for performing the conventional practice, saving time costs related to the displacements.

- Flexible training

Since the practice sessions are performed purely in virtual reality with the capacity to simulate any condition independent to the conditions present in a real airport, issues that would prevent completing a conventional practice session such as current equipment loads or responsible personnel available no longer affect the practices.

- Useful in low seasons or stopovers

During normal airline operations, it is common to have low seasons or stops through which there is not a need to have all the personnel working. This can lead to these employees not staying up to date with the procedures or needing refreshments when coming back to work. Since VR can offer cheap training sessions, it might be possible to keep every employee up to date with procedures and regulations regardless of the changes or events that may affect the company's operations.

Out of the software created by this company, there are two products that are commercially available for a home user and will be analyzed. The software is published as "Airport Ground Handling Simulator" and "Airline Flight Attendant Simulator." Both programs can be purchased on the steam store and are designed for use only with a virtual reality headset inside the "SteamVR" virtual reality environment, making it easier for the home user to access and use the software.

[26] *Aviar platform*. AVIAR PLATFORM. (n.d.). https://aviar.nl/

4.1.1 Airport Ground Handling Simulator

As part of this report, the software "Airport Ground Handling Simulator" will be tested to see the possibilities that may be achieved with this software and determine the ability to implement it into airline or ground handling companies personnel training procedures.

The different available training scenarios were tested on the simulator. At the time of writing, the simulator offers training modules for:

- Pre-arrival checks
- Aircraft Marshalling
- Ground Service Equipment Connection
- Cargo doors operation
- Pre-departure checks

The simulator indicates that pushback training will be coming soon, however, that feature was already indicated as such in 2022 and so far no further update has been published regarding that or any other feature.

Figure 14: Marshalling training in Airport Ground Handling Simulator

The simulator offers two modes of use. Training and exam modes.

The training mode has an instructor that explains all the instruction for the completion of that task. For example, in the case of marshalling training, the instructor explains both procedures during normal operations as well as procedures during an emergency such as: Identifying the gate, proceeding straight ahead, slowing down, turning right, turning left, emergency stop, holding position, indicating of an engine fire or a normal stop.

The simulator uses a menu to provide with all the information related to the training being performed. This menu can be accessed by clicking on the wristwatch on the left hand of the user. This menu not only offers information regarding whatever training is being performed at the moment, it also lets the user configure other conditions, weather, time of day or events that may occur during the training.

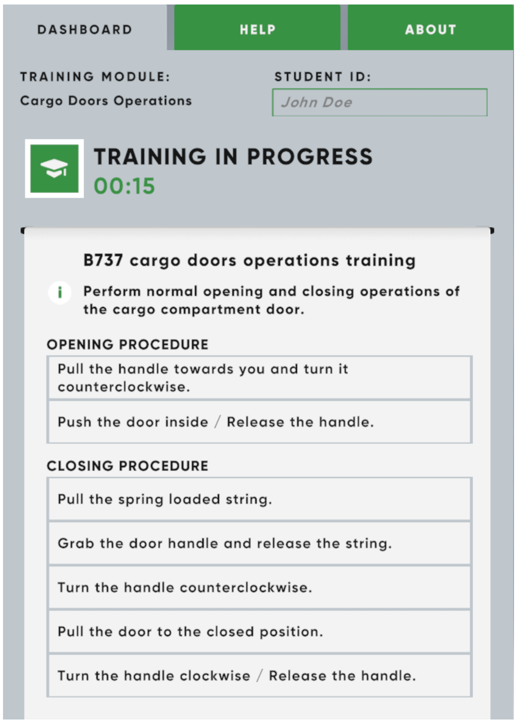

Figure 15: Example of tasks in training mode

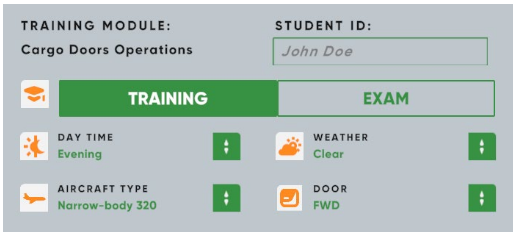

Figure 16: Events and conditions configurator

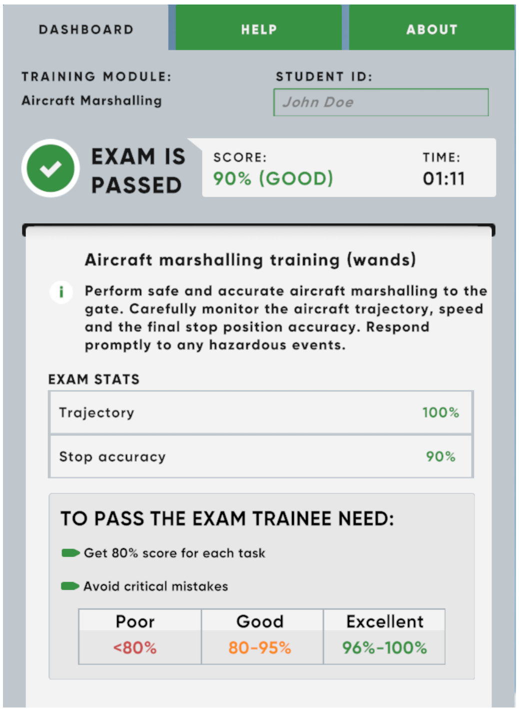

Figure 17: Exam results menu

This menu is also displayed on the computer screen and can be operated with the mouse at any given time. The view of the user, as displayed on the VR headset is also shown on the computer screen. This can be useful in airport worker training since the computer may be operated by an instructor to select whatever conditions the student will be exposed to without previous notification, ensuring that the student is capable of performing tasks in unexpected situations.

The same training may be performed in the simulator in good weather condition at midday with no emergencies, or may be performed at night, raining, in foggy low visibility conditions with an engine fire.

The exam mode menu setup offers similar settings to those provided in training mode in which the aircraft, weather conditions or other events can be defined.

In exam mode, there is no instructor to determine and guide the user through the tasks, the user must complete the tasks correctly following the explanations previously presented in the training mode alone. At the completion of the exam or, if the exam is failed for whatever reason, such as stopping the aircraft early when marshalling for no given reason or failing to notify an emergency, a report is shown on the menu.

Unfortunately, certain features were missing in this software. There is a lack of scenarios. As of now, only 5 scenarios can be performed on the simulator, nowhere near the knowledge needed for an operator to consider the implementation of a virtual reality training system. In online advertisements, the company states the scenarios included in the home version of the software is just a selection of those used commercially. However, the full list of scenarios the software may be capable to simulate is nowhere to be found.

Certain relevant tasks such as baggage loading and securing, jet bridge operation or the operation of ground vehicles are not present in the software.

4.1.2 Airline Flight Attendant Simulator

This software was also tested to determine its suitability for its use as training for actual cabin crew personnel. This software is similar to its ground crew training counterpart. There are several things that are identical. There is a menu that can be accessed both from the computer so it can be used as an instructor station, as well as from the virtual reality headset.

There is training in several aspects cabin crew may face:

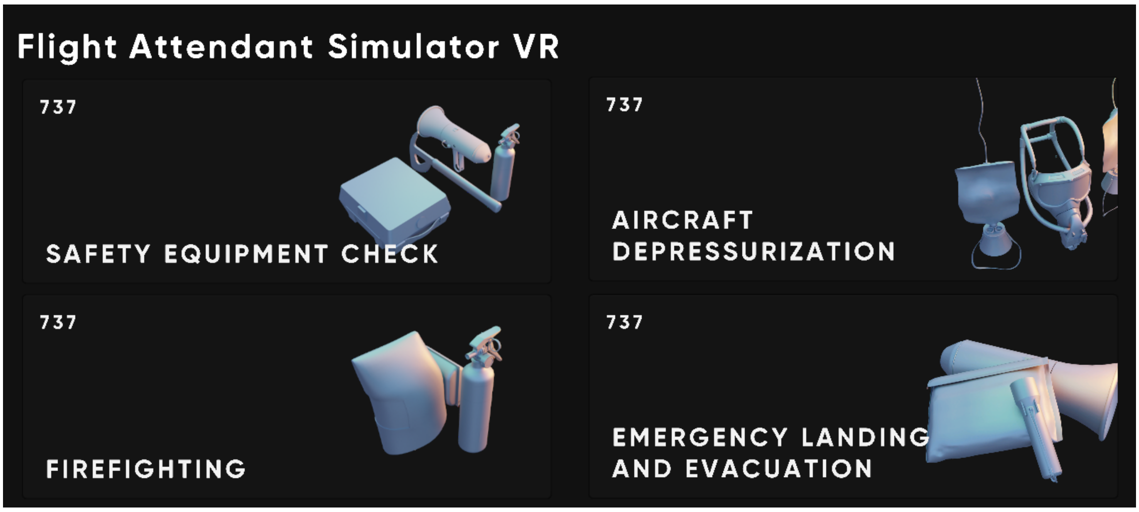

Figure 18: Training modules offered on airline flight attendant simulator.

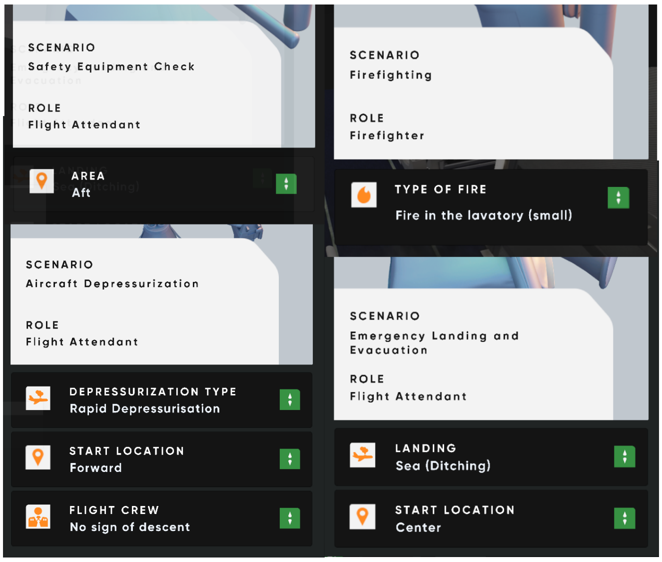

Figure 19: Different Condition selector

Similar to its ground crew training counterpart, each of the training modules lets the user choose between different conditions or events on each of the training modules.

The configuration of these conditions can also be done through the menu, accessible on the virtual reality headset, as well as on the instructor menu accessible form the computer or instructor station. This way it is possible to train cabin crew in their response to unexpected situations.

Out of the conditions that can be selected through this menu are the type of event that will occur, i.e., a toilet small fire or passenger seat fire, the initial location of the cabin crew at the start, or in the case of depressurization training, the response given by the flight crew to the situation.

There are significant differences between Airport Ground Handling Simulator and Airline Flight Attendant simulator in terms of how the training is given on each software. Whilst airport ground handling simulator gives the user a guided training, with a prerecorded instructor guiding the student through the steps required to perform certain tasks, in the case of airline flight attendant simulator, this training is given in videos or

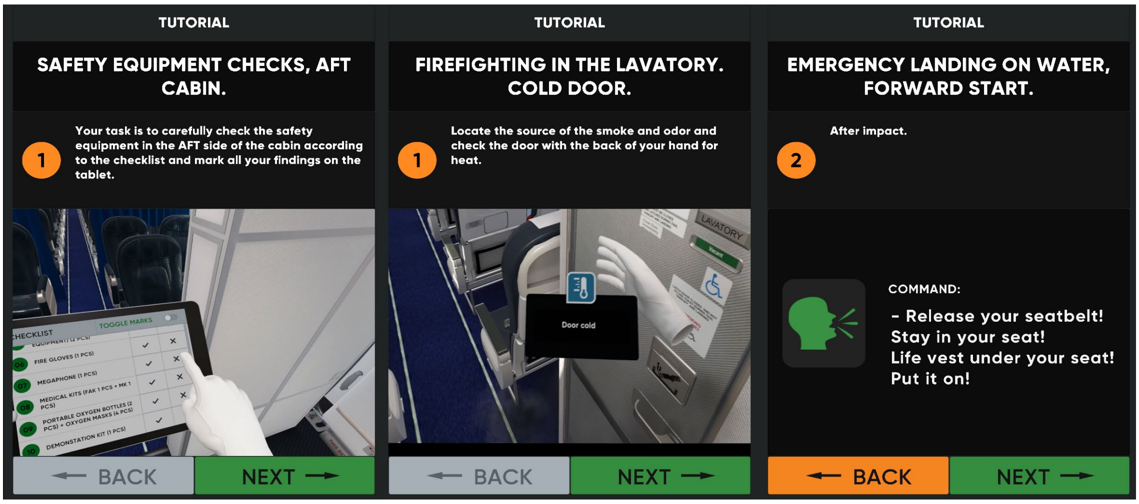

Figure 20: Tutorial as seen on airline flight attendant simulator

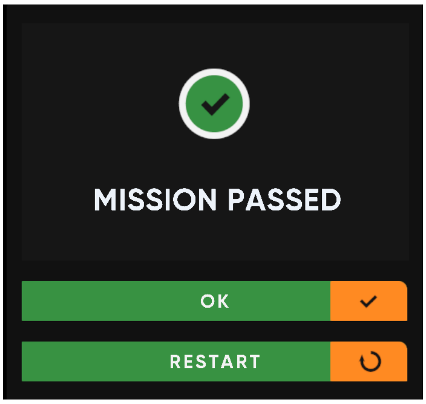

Figure 21: Message given if the task is passed

As it can be seen on the screenshot from the tutorial, this software is a clear downgrade compared to its ground handling training counterpart. Whilst the tutorials are clear and can be easily understood, the guided training is far easier to understand and to perfect procedures before beginning with the exam provided by the simulator.

There is also significant difference in the way both simulators present exam results. In the case of the ground crew trainer, a detailed report of all the tasks done correctly and those done incorrectly is presented. In the case of the flight attendant simulator, this report is less detailed. If the exam is passed correctly, with all the required tasks done adequately, the only statement is just an exam passed indication. Additional indications only appear if the exam has not been passed.

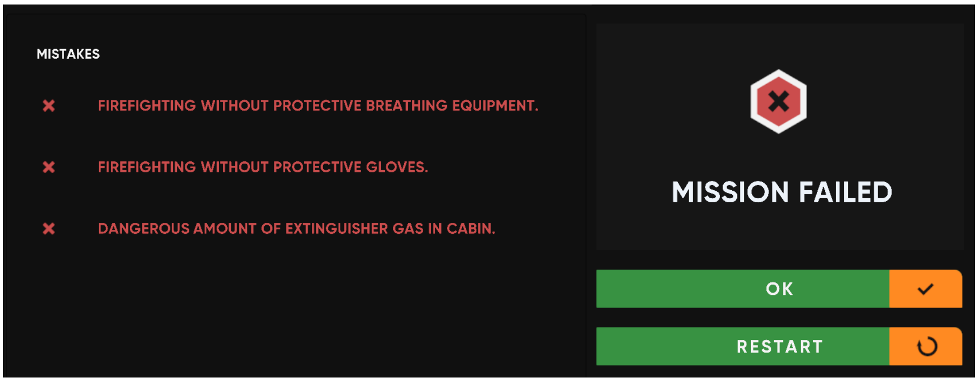

Figure 22: Message given if the task was failed

Overall, this software suffers from the same issues the ground handling counterpart does. At the time of writing the amount of training this software can provide is somewhat limited and with no news from the developer for over one year, this fact seems unlikely to change. The training however is still somewhat detailed and can already be useful since the software lets the trainee make mistakes without being exposed to risks. However, more development is needed before this tool can be considered suitable for actual training.

Figure 23: Screenshot taken during airline flight attendant simulator testing

4.1.3 Lack of updates

Even if the software published by this company definitely shows a huge potential in what can be achieved with virtual reality in for aviation personnel training, unfortunately there has been an important lack of updates and further development in the software.

The last post created by this company was a post on Facebook the 29th of April, 2023. Since then, no more news or updates have been published for any of the two home use simulators. There has not been any additional information regarding the professional software either.[27]

Additionally, looking at the store pages for both simulators and its community posts found both on the Steam store, and on the developer's Discord show users worry regarding the lack of updates on this project.[28]

This is somewhat worrying in terms of the possible future of virtual reality in aviation training, since there is no real alternative capable of what this simulator offers, leaving a huge gap in the market.

There are other companies developing similar software that simulate ground operations, such as AirportSIM[29] however, none of these reach the level of detail and extensive simulation offered by the Aviar platform that makes it suitable for aviation training use or are not even intended for virtual reality use. Most of these are intended for the home user only.

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[27] AVIAR (2023, April 29). *New content is coming to AGHS VR.* Facebook. https://www.facebook.com/reel/251378233916709

[28] Steam User "planesarecool" (2024, March 18). *State of the game (do`s any one know if the developers are still working on this game)* https://steamcommunity.com/app/2088630/discussions/0/7056650139344702941/

[29] *Airport Ground Operations Simulator.* AirportSIM. (2023, October 5). https://airportsim.com/

5 DEVELOPMENT OF A VIRTUAL REALITY AIRPORT ENVIRONMENT

To highlight the possibilities that may be achieved with virtual reality, a fully functional representation of an airport will be created. This demonstrator will show the capabilities of virtual reality in fields such as training of ground handling personnel.

Based on over 6 years of experience in the development of airport sceneries for flight simulators with 15 products released for customers such as Microsoft, a new scenery will be created to be used as a demonstrator for this project. Among those 15 products, are Vitoria Foronda airport, being the first of the 15, released in 2019 and the latest being Marseille.

Figure 24: Vitoria airport in the simulator.

Figure 25: Marseille airport in the simulator.

The objective of this section is to, starting from the knowledge obtained from the previous projects, develop a completely new scenery, and perform the necessary additional steps to have a fully functional and interactive VR representation of an airport environment that could act as a demonstrator for the capabilities of VR in the aviation sector mentioned earlier.

While it would be ideal for the demonstrator to run standalone, based on a dedicated graphics engine such as Unity or Unreal Engine, without depending on additional software, that feat would only be achievable if an entire team were working on this project.

As an alternative, the final demonstrator will run on the X-Plane 12 flight simulator. In order to use a software created for the simulation of aircraft for simulating the movement and operation of a tug, clever use of the existing tools provided by the simulator such as Plane Maker and tweaking the simulator settings will be needed.

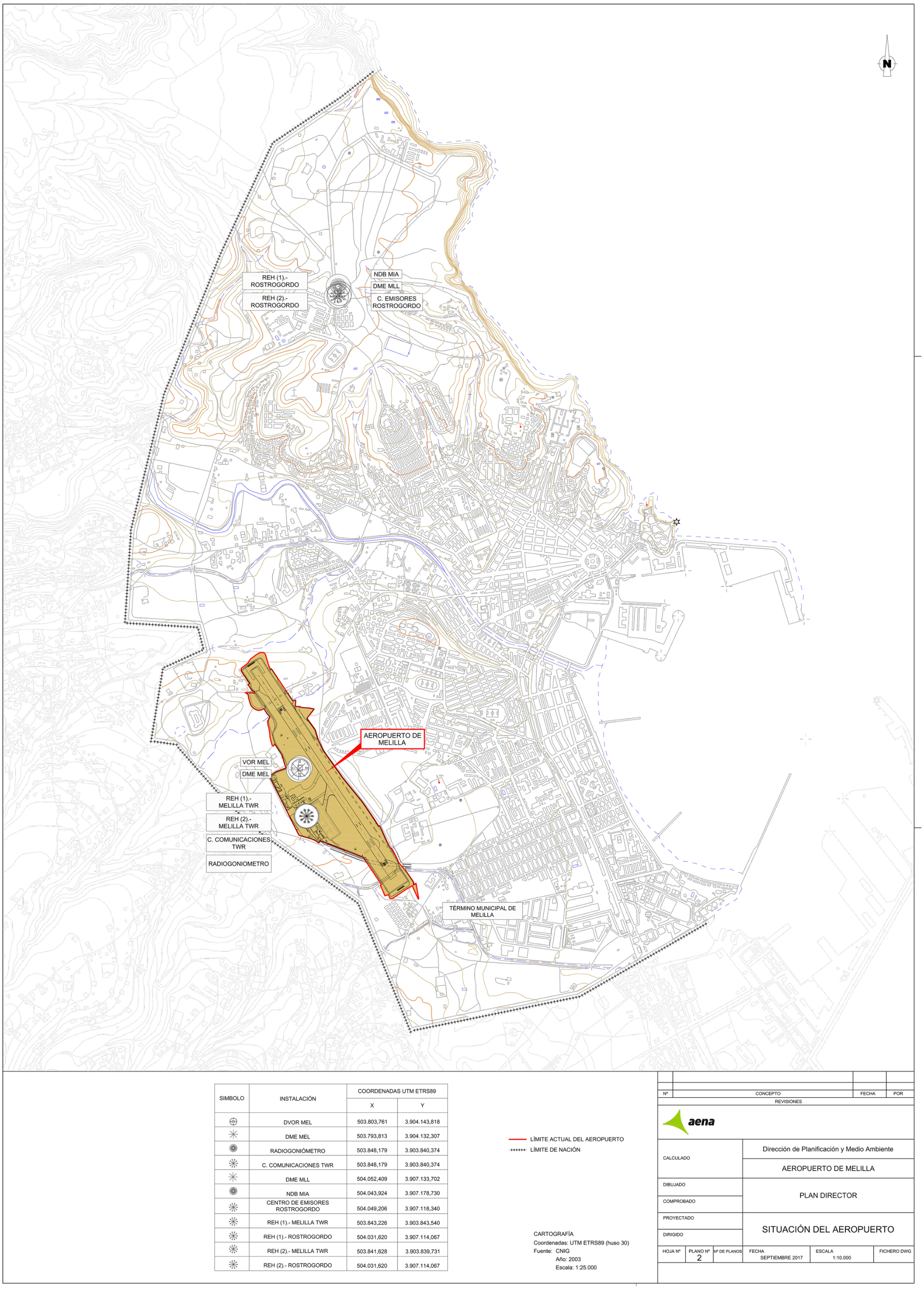
5.1 Current situation of the airport

The airport serves the autonomous city of Melilla, in the north of Africa. The airport was opened in 1969, replacing the former Tauima Aerodrome, located in the former Spanish protectorate in Morocco. The airport is essential in communicating the island of Melilla with the peninsula.

Operations in the airport are relatively special. The airport has a short runway (15-33) of 1433 M and is located next to the border with Morocco. The airport has no precision approach system or procedure, the two VOR instrument approaches require a visual final approach, following a curve to avoid Moroccan airspace, thus, it is only possible to operate in VMC (Visual Meteorological Conditions).

Whilst the airport is rated for the operation of aircraft as large as the Airbus A318 or Embraer E195, no aircraft larger than the ATR72 operates there.

The airport is divided in two areas, each with its own platform, each serving military or civil aircraft. The civil apron can hold 5 aircraft with two additional general aviation stands. All the stands are taxi-out, not requiring pushback, and can be used facing towards and away from the terminal building.



SIMBOLO	INSTALACIÓN	COORDENADAS UTM ETRS89	
		X	Y
	DVOR MEL	503.803,761	3.904.143,818
	DME MEL	503.793,813	3.904.132,307
	RADIOGONIÓMETRO	503.848,179	3.903.840,374
	C. COMUNICACIONES TWR	503.848,179	3.903.840,374
	DME MLL	504.052,409	3.907.133,702
	NDB MIA	504.043,924	3.907.178,730
	CENTRO DE EMISORES ROSTROGORDO	504.049,206	3.907.118,340
	REH (1).- MELILLA TWR	503.843,226	3.903.843,540
	REH (1).- ROSTROGORDO	504.031,620	3.907.114,067
	REH (2).- MELILLA TWR	503.841,628	3.903.839,731
	REH (2).- ROSTROGORDO	504.031,620	3.907.114,067

Figure 26: Current situation of the airport

30

[30] AENA. (2017, September). *Plan director Del Aeropuerto de Melilla*. Ministerio de Transportes y Movilidad Sostenible. https://www.transportes.gob.es/areas-de-actividad/aviacion-civil/politicas-aeroportuarias/integracion-territorial-aeroportuaria/planes-directores/plan-director-del-aeropuerto-de-melilla

5.2 Obtention of references

For the development of the airport, a wide variety of sources of information and references need to be used. Whist on-site visits for taking pictures would be ideal, this is often not a possibility and open-source documentation on the internet is the only option.

Different types of sources are used and the uses and treatment for each is completely different. The types of sources may be divided into three:

5.2.1 Blueprints, schematics, aeronautical publications

For this project, two main sources of schematics and documentation were used: AENA's Master plan[31] and airport charts, released in the ENAIRE AIP (AD2 GEML)[32].

These documents act as a starting point for the development. These documents have extremely valuable data, dimensions and maps that can both act as a reference for the recreation of the airport building as well as explain the correct names, terms and references related to each of the airport's characteristics. It is easier to find further references of a building online if its name or use is known.

Airport charts released in the aeronautical information publication (AIP) include characteristics of the airport that affect both operations and performance that need to be modeled inside the simulator. The charts used are the Aerodrome Data which provides:

- Runway length and width
- Runway material
- PAPI light angles
- Runway elevation profile
- Coordinates of the thresholds
- Lighting types

The Aerodrome Chart (ADC) which provides:

- Taxiway names and locations
- Location and types of ground markings
- Location of navigational aids in the airport area

And the Parking/Docking Chart (PDC), shown on the figure below[33] which provides:

- Stand location and name
- Stand markings
- Largest aircraft compatible with the stand

[31] AENA. (2017, September). *Plan director Del Aeropuerto de Melilla*. Ministerio de Transportes y Movilidad Sostenible. https://www.transportes.gob.es/areas-de-actividad/aviacion-civil/politicas-aeroportuarias/integracion-territorial-aeroportuaria/planes-directores/plan-director-del-aeropuerto-de-melilla
[32] División AIS - ENAIRE. (2023, November 2). *GEML - Melilla*. AIP España. https://aip.enaire.es/AIP/#GEML
[33] División AIS - ENAIRE (2023, September 07). *AD 2-GEML PDC 1.1. - PLANO DE ESTACIONAMIENTO Y ATRAQUE DE AERONAVES-OACI* https://aip.enaire.es/AIP/contenido_AIP/AD/AD2/GEML/LE_AD_2_GEML_PDC_1_en.pdf

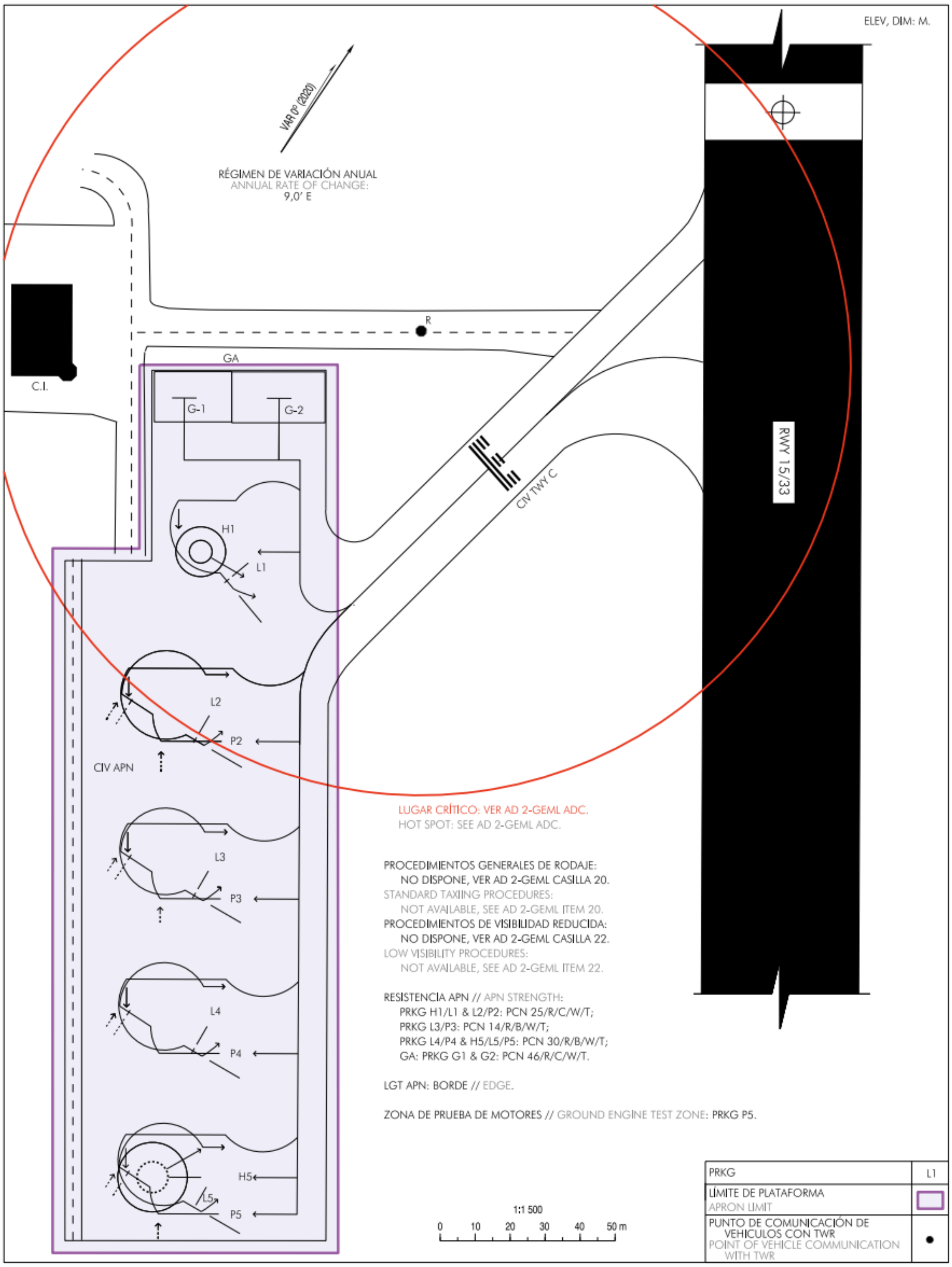


Figure 27: GEML PDC

5.2.2 Satellite orthoimagery

Two sources are used for satellite orthoimagery. Google Earth offers a wide variety of tools to obtain data from satellite imagery such as distances and elevations. In certain areas, a Photogrammetry scan of the area is provided which allows 3d measurements and can be extremely useful for calculating building heights. Unfortunately, photogrammetry is not available in Melilla.

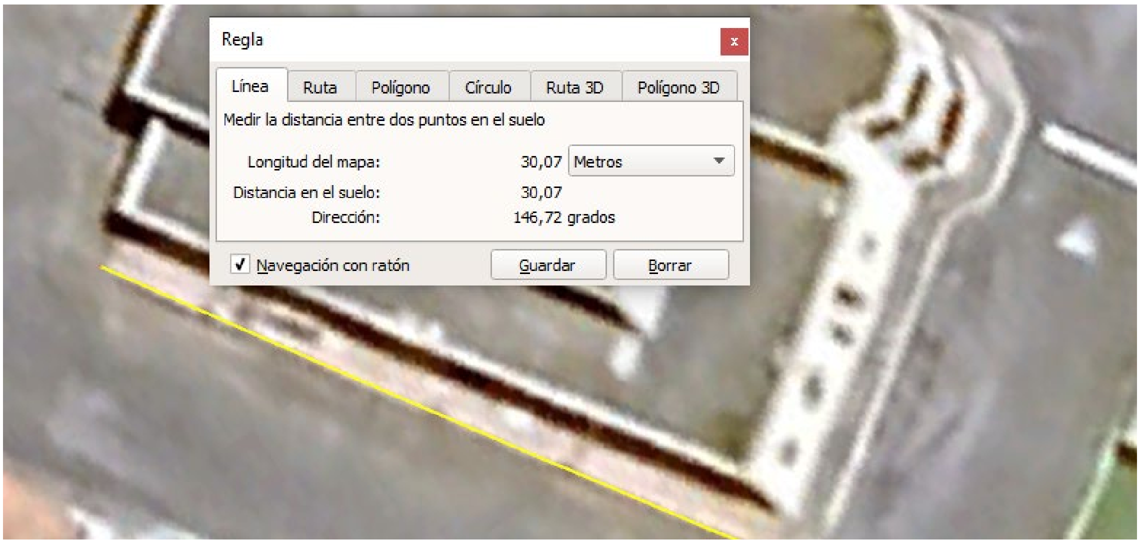


Figure 28: Demonstration of Google Earths measurement tools.

Whilst Google Earth acted as an aid in the obtention of measurements, the main orthoimagery source was the National Aerial Orthophotography Plan (PNOA)[34] of the National Geographic Institute (IGN), which has an extremely high-quality data set of aerial photography and orthophotography that covers all Spanish territories. The database has an up-to-date orthophoto set with a high resolution of at least 25 cm per pixel, as well as historic photography dating back to 1929.

Figure 29: High Resolution Orthoimagery from PNOA

[34] Instituto Geográfico Nacional, (n.d.) *Plan Nacional de Ortofotografía Aérea*. https://pnoa.ign.es/web/portal/pnoa-imagen

Imagery obtained from the PNOA will be used as a reference for the placement of all the buildings and ground markings. Additionally, the imagery from the area will be color corrected, split into tiles that the simulator can load and used as the base for the scenery.

Figure 30: Orthoimagery ready for the simulator

5.2.3 Photographic references

Photographic references may be used for finding text or details that may not otherwise be seen, or for calculating proportions or heights. Unfortunately, there was not a huge variety of images available for Melilla, therefore, unusual sources were needed. Pictures were obtained from, among others, blogs[35][36], Instagram[37], YouTube videos and "trip reports," Google Reviews and Google Street View, as well as from the aforementioned airport master plan.

The technique used for obtaining accurate dimensions from reference images is based on scaling and comparing from objects of known size such as bins, benches, or cars. Shown on the figure below is an example of the process using a bin of known height 885 mm.

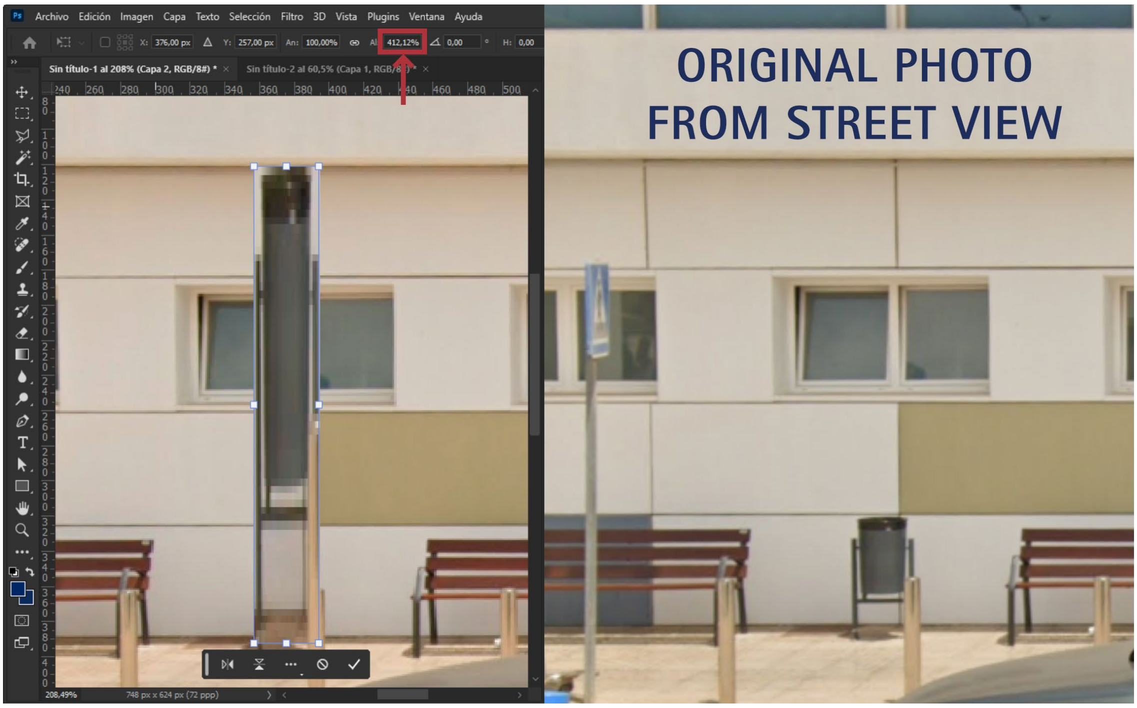


Figure 31: Obtaining dimensions in Photoshop

Photoshop is one of the most widely used graphics editing tools. Among its vast amount of uses, photoshop is capable of scaling and showing the relationship between original scale and final scale in a percentage. The percentage has been highlighted on the picture with the red rectangle. This percentage is extremely useful to calculate distances. Using the example shown in the figure, the height of the wall behind can be estimated:

$$Height\ of\ the\ Wall = Height\ of\ the\ Bin \cdot Scale$$

$$885 * 4.1212 = 3647\ mm$$

To ensure that the estimation is as accurate as possible, various measurements should be taken.

[35] *Siempre en nuestro corazón: GEML (Aeropuerto de Melilla-España).* el sitio de "jactres." (2012, April 30). https://elsitiodejactres.blogspot.com/2012/04/

[36] El Aeropuerto de Melilla Remodela el Edificio de Cocheras y el acceso a la cubierta del edificio terminal de pasajeros. El Informal de Fran. (2011, February 17). http://www.elinformaldefran.com/2011/02/el-aeropuerto-de-melilla-remodela-el.html

[37] *Asoc. AeroSpotters Melilla.* Instagram. (n.d.). https://www.instagram.com/spottersmelilla/

5.3 Development of the environment

Once all the necessary references and dimensions are obtained, development can begin. The airport is built in layers, each providing different characteristics. In the case of the simulator used, there is a layer hierarchy that needs to be followed to ensure that objects are displayed correctly.

The hierarchy used can be summarized in the figure below:

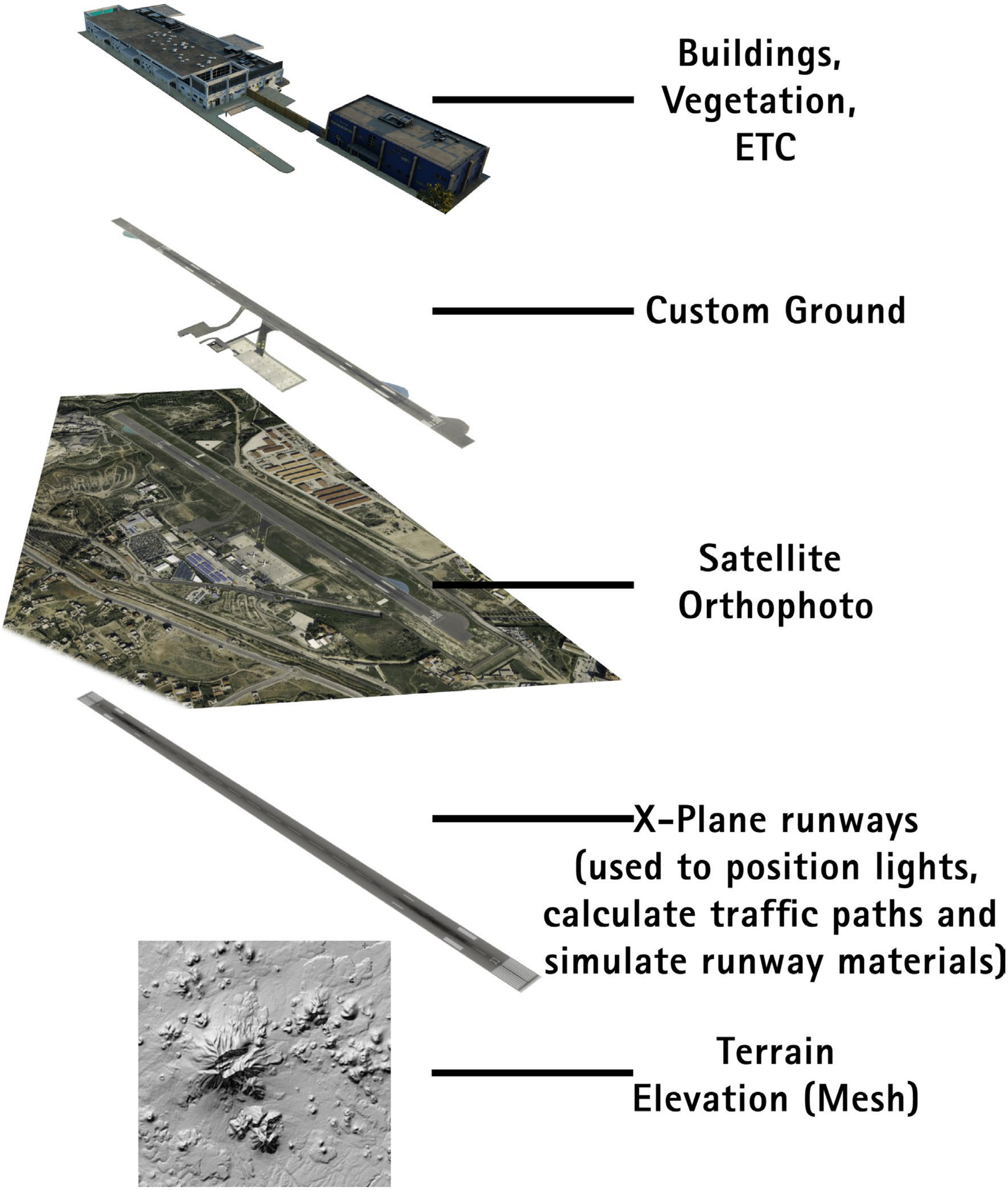


Figure 32: Scenery layer hierarchy

5.3.1 X-Plane runways

Whilst these are not shown, it is necessary to define runway and taxiway positions to:

- Generate runway and taxiway lighting.
- Generate taxi paths for X-Plane's air traffic control.
- Display airport charts in the X-Plane map.
- Make the terrain "hard;" define ground surfaces as asphalt, concrete, etc.

In this process, other features such as taxiway centerline and edge lights, holding point "wig-wags," PAPI lights and parking spots are placed at its right locations.

Part of this step is the definition of other features such as airport frequencies, largest allowable aircraft on each stand, taxiway names and many other values to ensure that operating in the airport in the simulator exactly matches what is described in airport charts.

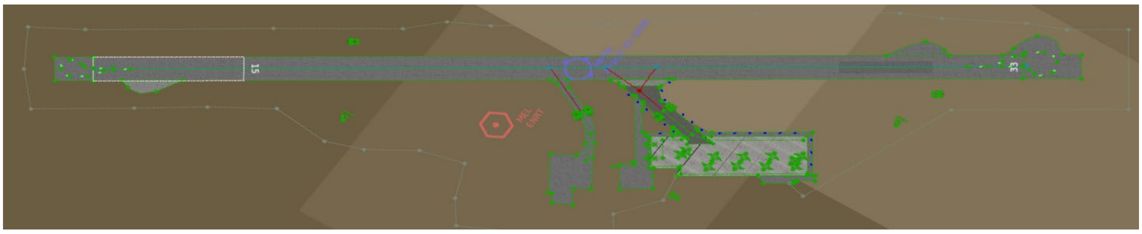


Figure 33: WED ground layout

5.3.2 Ground orthophoto

As it was mentioned before, the orthophoto was color corrected and split into tiles. The split tiles were placed in the simulator. To do so, a ".pol" file was needed for each tile. Each file contained the code:

```
A
850
DRAPED_POLYGON

LAYER_GROUP taxiways +2
TEXTURE_NOWRAP TILENAME.png
SCALE 5 5
DECAL_PARAMS_PROJ   5   5   0.0  -30   35  -8  0   0   0.0  0   0   0   0   0   0.0  GrassDec.png
DECAL_PARAMS_PROJ   5   5   0.0   30  -35  10  0   0   0.0  0   0   0   0   0   0.0  DirtDec.png
```

The ".pol" file for each tile had the appropriate tile specific texture name, with the portion of code shown in italics being changed. The last two lines of the code generate a grainy/grassy effect for when the ortho is seen from up close.

Shown in the figure is a sample of the ortho being displayed on top of the custom mesh.

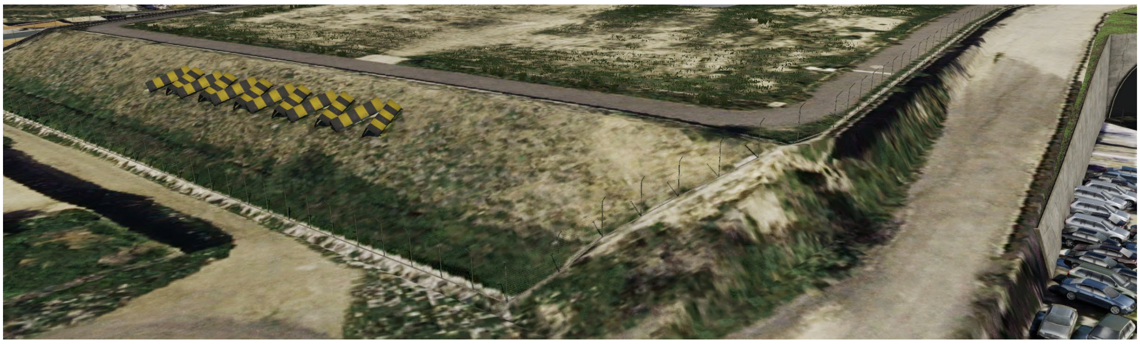


Figure 34: Ortho in the simulator

Figure 35: Grass effect up close

5.3.3 Terrain (Mesh)

X-Plane does not have a native method for editing the terrain mesh, but Melilla needed a handmade terrain mesh to simulate the elevation profile of both runway and platform, and the falls around the airport boundary.

To create the custom terrain with third party software, a KML file with the elevation information was needed. This file was created by hand. The red polygons define areas into polygons (flat areas at a fixed elevation) and ramps, which need the elevation input from 3 place markers (Yellow pins).

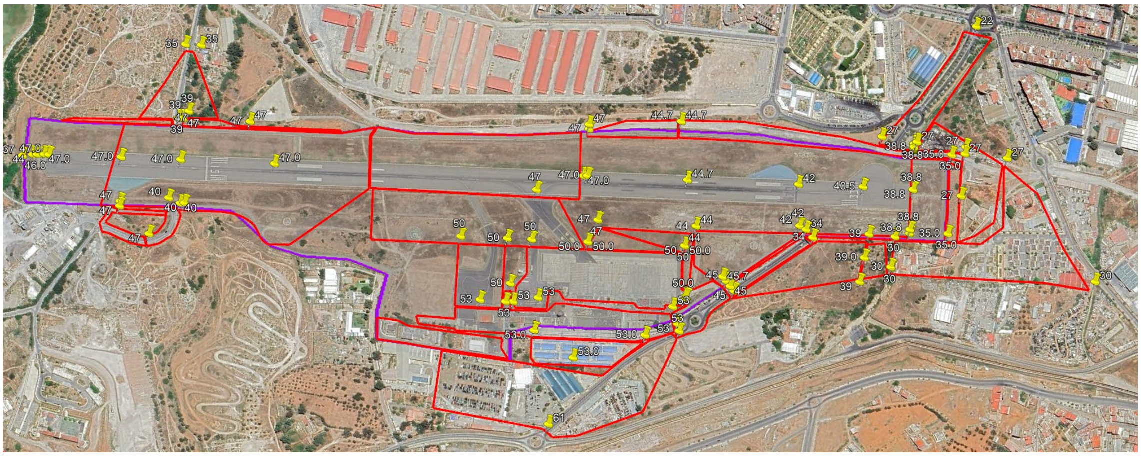


Figure 36: Terrain "KML"

Using the third-party software Mesh Updater X-Plane (MUXP)[38], the KML is interpreted and used to modify the terrain mesh inside X-Plane. The resulting mesh follows all the intricate shapes found in real life so that aircraft performance and behavior is as close as possible to its real-life counterparts.

[38] *Mesh updater X-plane (MUXP).* XPLANE ORG. (2021, May 27). https://forums.x-plane.org/index.php?%2Ffiles%2Ffile%2F67230-mesh-updater-x-plane-muxp%2F

5.3.4 Custom ground

The custom ground was modeled in 3ds MAX. This ground is made of separate layers, each add different details and features, among those are, base asphalt, markings, wear and tear, etc. These layers are superimposed when shown on the simulator. The layers used are shown in the table below, the layers are named following X-Plane's standards[39]:

Layer (From lowest to highest)	**Content**
Runways +2	Asphalt base, Concrete base
Runways +3	Concrete dirt
Runways +4	Asphalt edges (Transition between different shades, asphalt to grass transition). Taxi lines (Centerline black borders)
Runways +5	Taxi lines. Damage from old markings.
Markings +1	Taxi markings
Markings +2, +3	Dirt, skid marks
Markings +4	Concrete tile edges.

Shown on the figure is a screenshot of the taxi line 3d model in 3ds Max. On the screenshot, 3ds max is set in the "Edged Faces" mode, to show the edges of all the separate 3d objects used to recreate all the different layers and details mentioned on the table above.

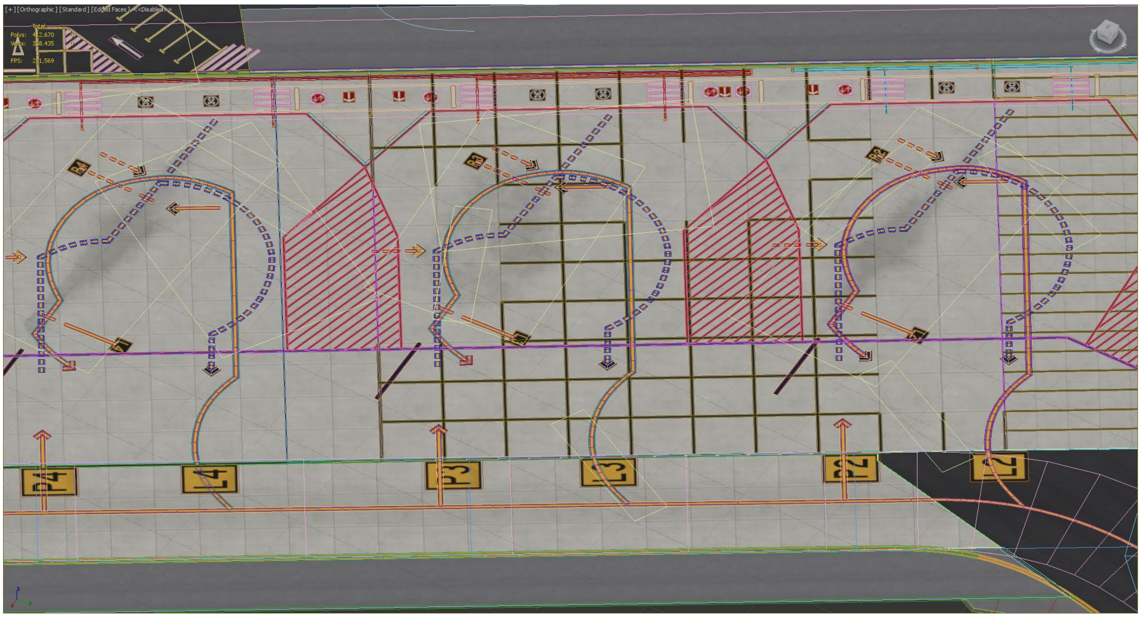


Figure 37: Taxi line 3d model

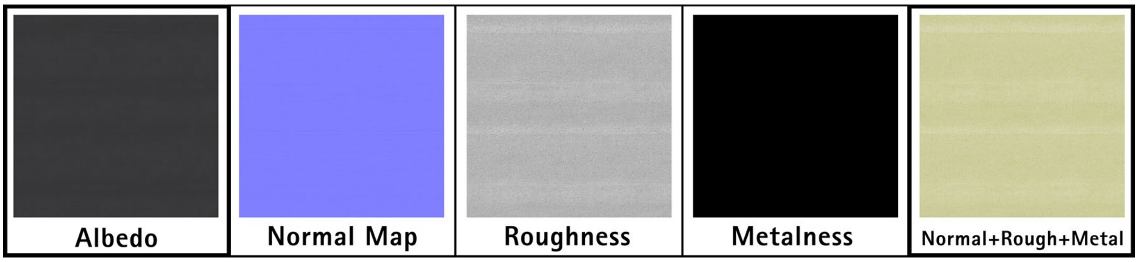
For the creation of the different objects, references from both satellite images and airport charts were imported into 3ds Max and were followed to ensure that both markings and damage are placed in the correct location to ensure that the layout accurately matches real life and may be used as a digital twin.

[39] *Controlling draw order.* X-plane developer. (2015, September 23). https://developer.x-plane.com/article/controlling-draw-order/

5.3.4.1 PBR

PBR stands for Physically based rendering. In real life, the sun casts shadows and reflections that may even affect visibility during operations in certain times of the day. One of the advantages of virtual reality is the ability to simulate different weather conditions and thus, these reflections needed to be simulated. This was achieved through PBR. PBR uses additional maps that simulate glossiness, roughness or bumps in surfaces that are used to calculate how the rays of light would interact with these surfaces.[40]

Several maps are needed to recreate PBR surfaces:



Of which:

- Albedo provides the base color for the texture.
- Normal map acts as a height map and creates bumps in the surface.
- Roughness map sets the glossiness of the surface and how much light it reflects.
- Metalness map creates a reflective mirror-like effect of polished metals (specularity).
- Normal, Roughness and Metalness are combined in one map that the simulator uses.

Shown below is an example of PBR in action in Melilla.

Figure 38: PBR in Melilla

[40] Russel, J. (2020, November 5). *Basic theory of physically-based rendering.* Marmoset. https://marmoset.co/posts/basic-theory-of-physically-based-rendering/

5.3.5 3d Buildings

For this project, the decision was to create all the buildings in one 3d model, the same that was used to model the ground, to ensure perfect integration of all the buildings, details, and ground.

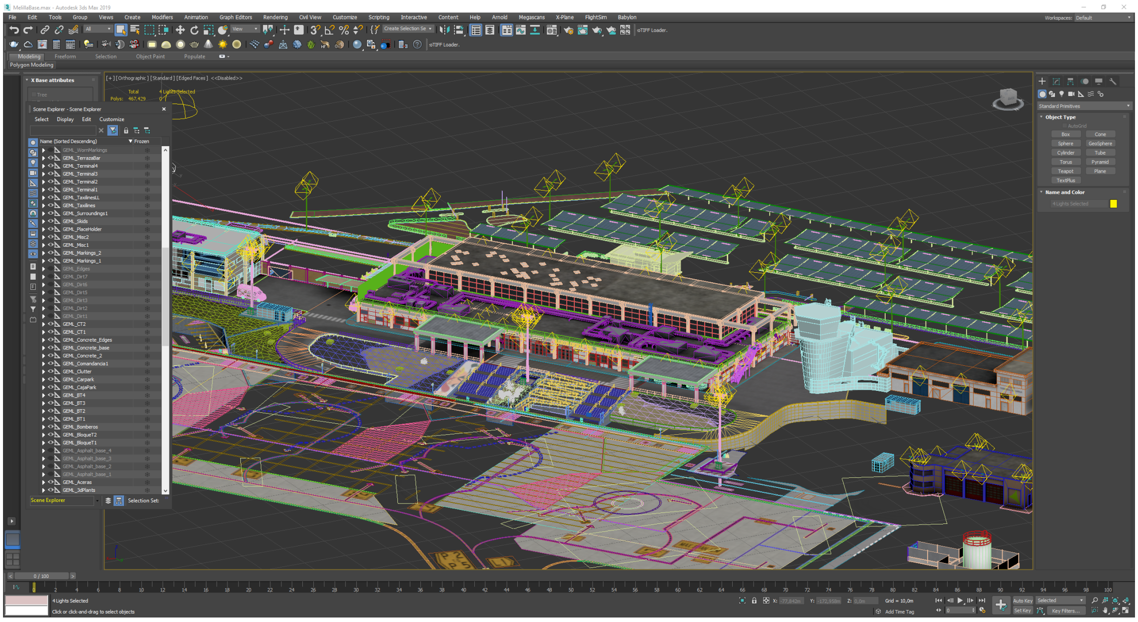


Figure 39: View of the airport mesh in the 3d modeling software.

Figure 40: Buildings in the simulator

Since the goal was a recreation of the airport that could be usable for training or airport familiarization, it was essential to ensure that all the signs in use in the airport in real life are present, correct and perfectly readable.

For the creation of a 3d building, an initial basic 3d model was created from the references obtained through the methods mentioned previously. This basic 3d model consisted of boxes of the size of the final building, columns or other significant features of the buildings that would accurately represent the final size of the complete 3d model. This model was shaded blue, to ensure that all unfinished buildings were easy to detect, and imported into X-Plane to determine if the dimensions were accurate and to verify that the buildings, the ground layout and the ortho image were all compatible.

Figure 41: Example of the terminal building in the early stages of the development. Note the blue interior box.

With the dimensions set, the entire building can be modeled entirely:

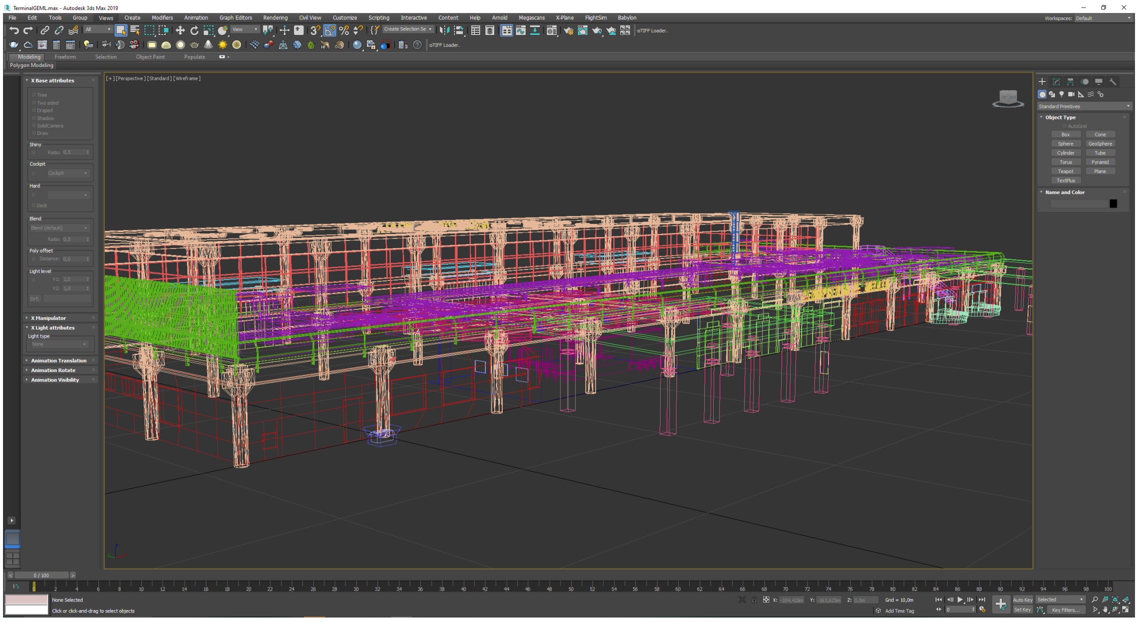


Figure 42: Wireframe view of the terminal in the 3d modeling software.

With the finished 3d model the textures can be created. In the case of the terminal building, a set of 4 texture sheets was required. This set was created using both Substance Painter and Photoshop. The buildings are also PBR, meaning that windows are reflective, bumps found in the materials, such as the concrete in the wall, rust and wear in metallic surfaces and many more effects are present in the finished model.

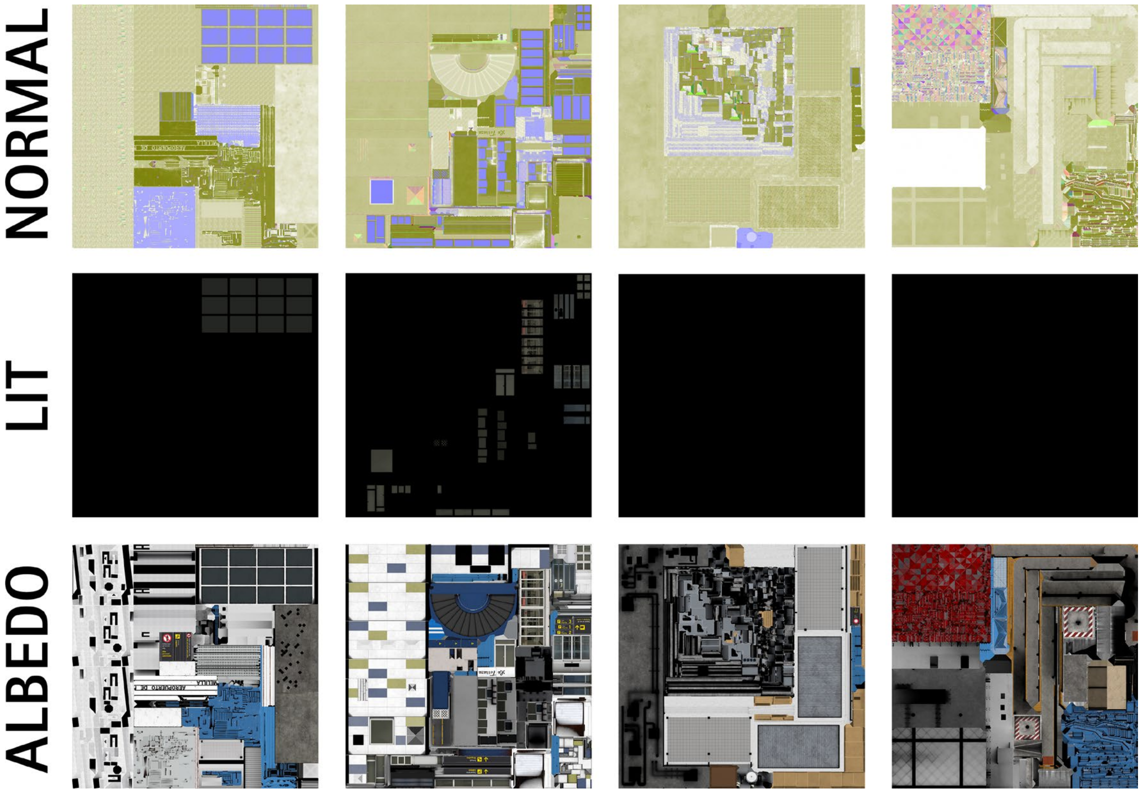


Figure 43: Texture set used for the terminal building.

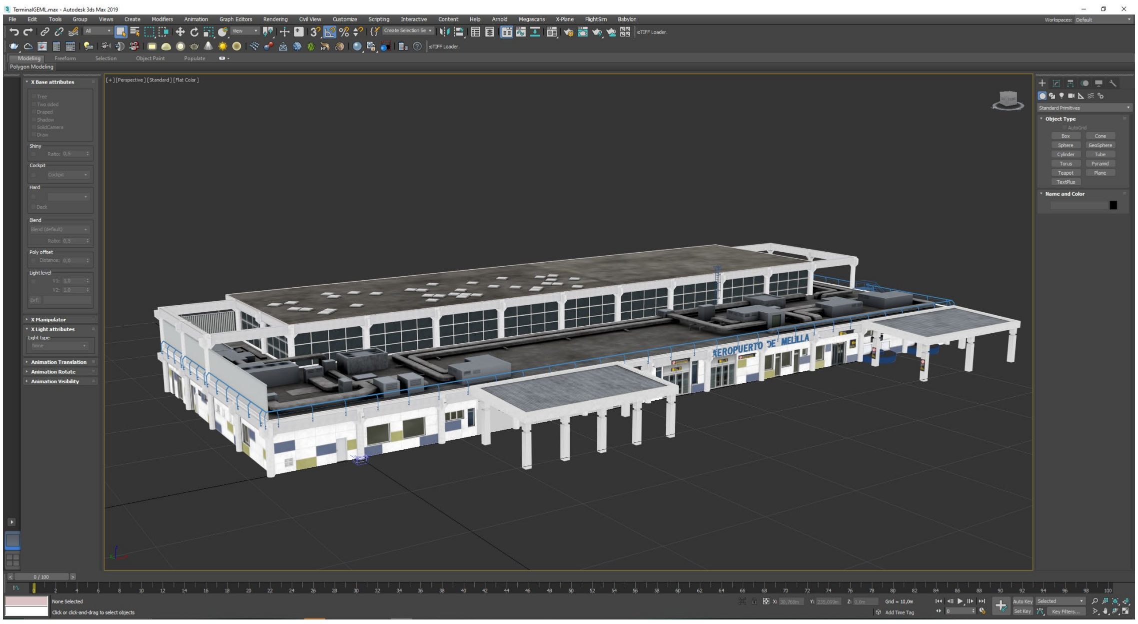


Figure 44: Finished and textured terminal in the 3d modeling software

Figure 45: Finished and textured terminal in the simulator.

5.4 Development of the drivable tug

The Tug model is based on the Charlatte T135 NEO[41]. This was originally modeled as a "static" model for the airport. Using the same 3d model, a drivable tug will be made:

Figure 46: Drivable Tug model

[41] *T135 NEO / neo L.* Charlatte Manutention. (2023, November 24). https://charlattemanutention.fayat.com/en/products/t135-neo-neo-l

5.4.1 Tug programming

The programming of the Tug was performed inside Plane Maker, a tool included with X-Plane used for the design of aircraft for the simulator. The tug will be detected in the simulator as an aircraft with wing and control surfaces of area=0. This is to ensure that, even if the tug is detected as an aircraft, it will not fly and will only operate on ground.

5.4.1.1 Traction

X-Plane is unable to simulate tire traction. Tire traction was simulated with jet engines simulated to produce thrust at the exact point of contact between the ground and the rear tires. It is most definitely not an ideal solution and produces certain unwanted results such as an extremely high maximum speed for the tug, however, it is the closest option to simulate tire traction with a simulator designed to simulate aeroengines only. The power of the engines was determined through trial and error to ensure that it was the minimum enough to climb the slopes present in the airport.

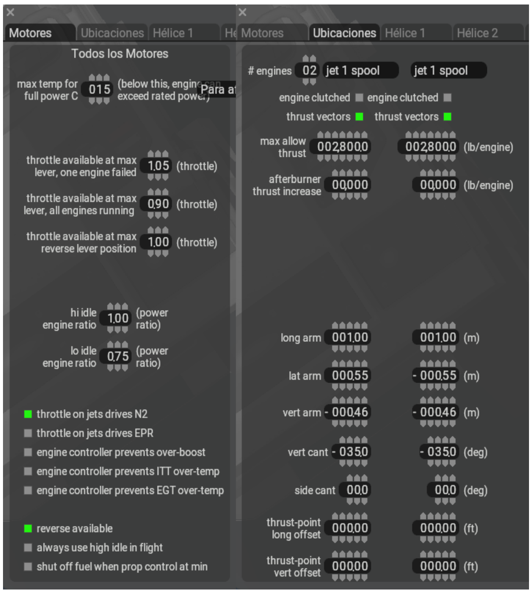


Figure 47: Engine settings

The jet engines were set to have thrust reversers to model the reverse gear of the tug. Initially the goal was to reduce the maximum thrust available when operating in reverse to around 70% of the thrust available going forward to simulate a restriction in maximum speed. However, testing this feature it was determined that it would cause significant problems and this reduction in thrust would stop the tug from getting moving, even in flat terrain. Therefore, in the end, the thrust available when operating in reverse is 100% of the thrust available going forward.

5.4.1.2 Wheels

The wheels were simulated as a landing gear. Tire characteristics were defined to match real life characteristics. The coordinates of each wheel were obtained from the 3d model. The suspension was also configured with the travel significantly reduced to match the characteristics of the tug. Other data, such as tire pressure, taken from both the tug datasheet and online listings of the vehicle were used to define all characteristics of the tug to ensure it behaves and rolls in an accurate way, compared to the original.[42]

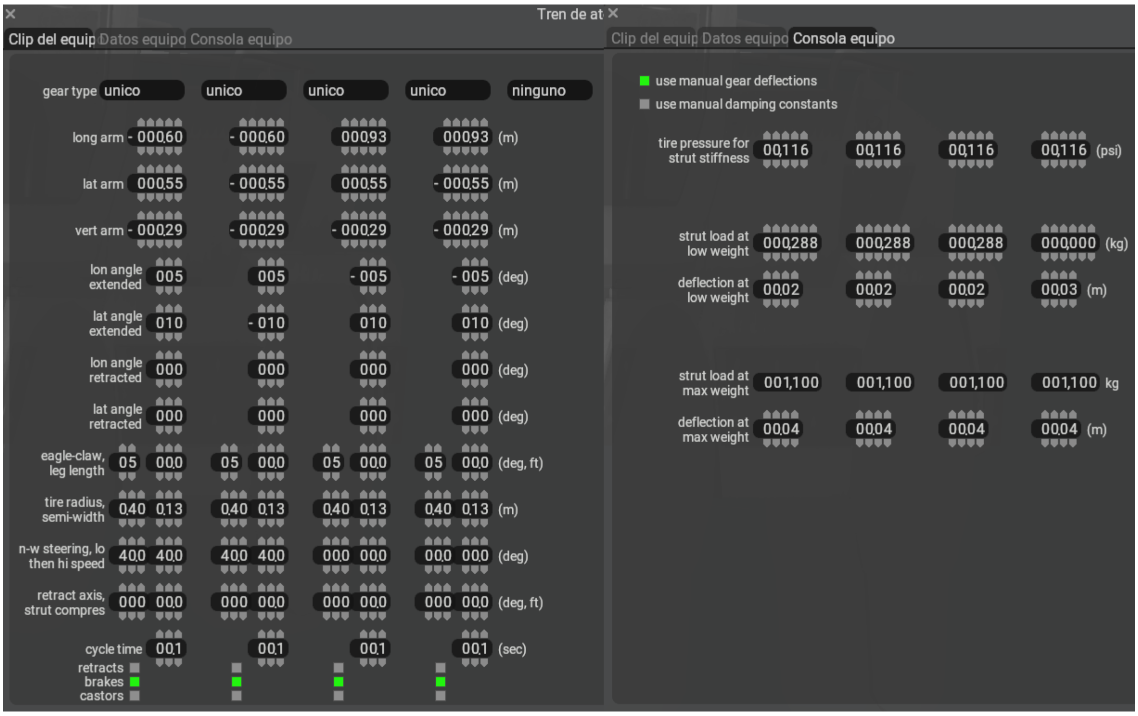


Figure 48: Wheels configuration

5.4.1.3 Weight

The weight was set to the 4450kg, following the data indicated in the tug datasheet.[43]

5.4.1.4 Driver position

The driver position is the point in which the camera will be located inside the simulator. This camera will represent the eyes of the operator inside the simulator. An accurate camera placement is especially important since the goal is to use the tug in virtual reality and therefore, camera position must closely match the actual head position of an operator of that vehicle in real life.

The horizontal and lateral coordinates of the camera position were determined by measuring seat location in the 3d model. The vertical coordinate was approximately estimated. A correct horizontal and lateral settings are fundamental during this setup, however, the vertical coordinate did not need such accurate measurements since, once the simulator is used with the virtual reality headset, the vertical location of the camera will vary based on different factors such as user height or how the user sits, just like in real life.

[42] *Industrial tractor Charlatte T135*. CAPM Europe SA. (n.d.). https://www.capmeurope.eu/materiel/tractor-130/industrial-tractor.1283/charlatte-697/t135-6579/16968-YCOWBU6q.gxxMH0H
[43] *T135 NEO / neo L*. Charlatte Manutention. (2023, November 24). https://charlattemanutention.fayat.com/en/products/t135-neo-neo-l

5.4.2 X-Plane setup

With the tug and the airport finished and already imported into X-Plane, it is necessary to set up and configure the ability to control and operate the tug with the necessary hardware.

5.4.2.1 Steering wheel hardware setup

The goal is to operate the tug with a Logitech G27 wheel or a similar device. Since X-Plane setup system is designed for aircraft, changes in the settings were needed to use the steering wheel.

Throttle setup is straightforward, the throttle variable from X-Plane is linked to the throttle pedal on the steering wheel. Steering is also straightforward; the steering wheel is linked to the rudder or nosewheel tiller in X-Plane.

Braking was more problematic. Since aircraft are designed for differential braking, the simulator did not allow linking both left and right brake variables to one single pedal. In the end, the brake pedal slider from the steering wheel was set to operate as two simple buttons based on how much pressure is applied to the pedal. If a small pressure is applied, the simulator applies medium strength braking. If more pressure is applied reaching near the end of the travel of the brake pedal, maximum braking strength will be applied. Releasing the pedal stops applying braking in the simulator. This is not ideal since the brake is not linear but rather has two notches, however, it was the only option.

The reverse gear was also programmed to the Logitech steering wheel. Since X-Plane is not intended for using a standard gear shifter, the shifter in the Logitech G27 is set with 4th gear programmed as "Toggle thrust reversers". Moving the gear shifter into 4th and back into neutral engages reverse gear. Forward gear can be engaged again by moving the gear shifter back into 4th and back into neutral.

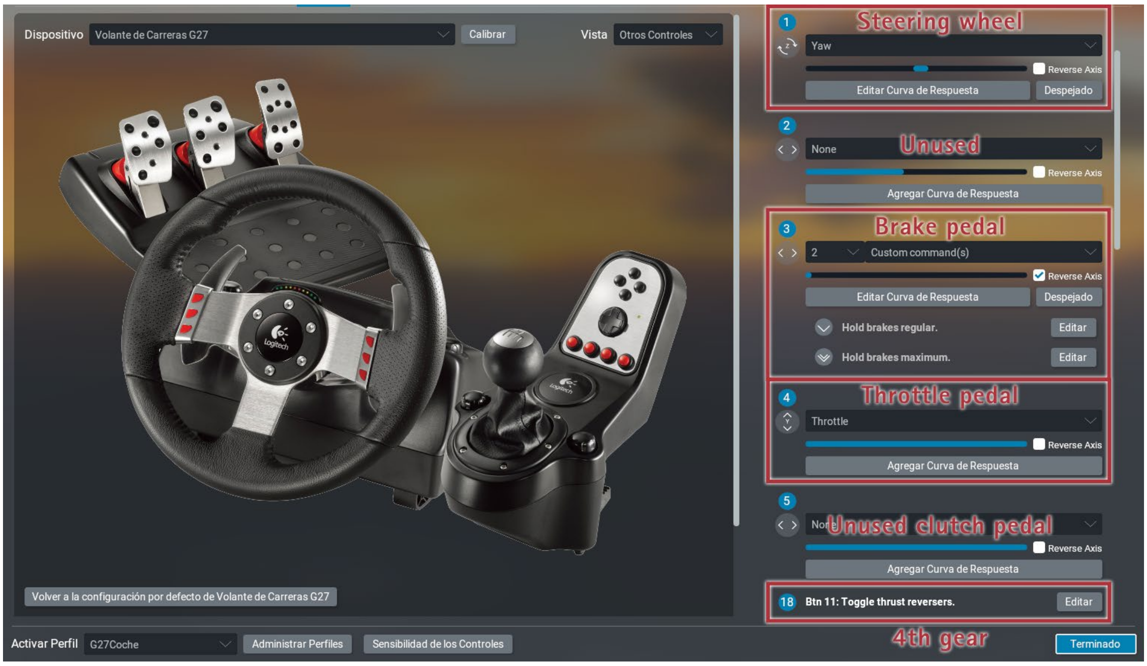


Figure 49: Steering wheel settings

With the Logitech G27 wheel set up, severe testing was performed to ensure that the tug performed as intended. Plane Maker tug settings needed several changes to improve a more realistic and accurate performance and behavior.

5.4.2.2 Virtual reality hardware setup

The virtual reality hardware, in this case, the virtual reality headset used for the development of the project was an HTC VIVE PRO 2, also needed to be set up and configured to operate with the simulator.

The HTC VIVE link box needs to be set up as indicated in the manual, connected to the PC using a DisplayPort video output and USB. The link box is also connected to a power supply. The VR headset is connected to the link box and needs calibration with SteamVR.[44]

SteamVR is the software that will act as a link between the virtual reality headset and the simulator. Once SteamVR is installed, and all VR hardware (Hand controllers and base stations) detected and calibrated in SteamVR, X-Plane can be launched and in settings, VR hardware enabled. Once this is done, the simulator will automatically start transmitting images and being controlled by the VR headset.

5.5 Demonstration

After performing all the steps mentioned before, the demonstrator is ready to be used. X-Plane can be launched and after selecting the tug and the starting point in Melilla, the simulation can begin:

Figure 50: Tug being driven in Melilla in the simulator

5.5.1 Use

As the final step in the development of the demonstrator comes the testing. For this, several drives around the airport were performed both in virtual reality and running the simulator in a conventional screen.

[44] Valve corporation. (2024). *SteamVR.* https://www.steamvr.com/en/

Figure 51: View of the airport in the demonstrator

The setup that would be used for the testing is as shown in the figure:

Figure 52: Setup used for testing

On one of these tests, the display was recorded: https://youtu.be/Vo4y4aRoi6Q

This test consisted of a test drive around the airport in good weather, including, taking the tug from its parking next to the airport's technical block, climb to the terminal and drive through its service road, driving the entire service road down to the fuel tank, return through the service road to the same parking as in the beginning and reverse parking.

Through the drive, the user looks at different features and details present in the demonstrator such as a stationed ATR72, all the services in the terminal and all the signals indicating the different stands or warning about jet blast. It needs to be noted that the ATR72 is randomly placed, sometimes, the demonstrator may show no aircraft parked, on other occasions it may show all of the stands used by different aircraft. However, the demonstrator has been programmed so that only aircraft that operate there in real life appear. The placement of the aircraft is completely random, the demonstrator does not track which aircraft is operating in Melilla in real time.

Several things were noticed throughout the testing. So far, the demonstrator is extremely bare-bones and limited in its capabilities, however, during its use, it was clear that X-Plane's virtual reality system is much better optimized than AVIAR's system, with higher framerates, leading to a smoother experience. Both programs rely on SteamVR to transmit images to the headset and, even if AVIAR's was purchased, launched and every interaction with the software was either through Steam or SteamVR, X-Plane, purchased and launched from outside the Steam environment provided a much smoother user experience.

This lack of optimization in AVIAR's software became even more clear the longer the session was. The computer used to perform these tests uses a Ryzen 9 5950X 16 core GPU, a NVIDIA RTX 3080TI and 64 GB of RAM. Well above the recommended system requirements for AVIAR's software. The computer was cleaned before performing all these tests to ensure that no dust was present that would affect the computer's performance. Both Airline Flight Attendant Simulator and Airport Ground Handling Simulator were run at reduced graphic settings, with all of the computer's fans set to 100%. Even so, stutters throughout the session were constant, with computer temperatures rising to abnormal levels, leading to loss of immersion and a headache after all of the sessions.

Using the demonstrator, the experience was, surprisingly, much smoother, with almost no stutters, the image on the headset at no point froze, and the physical feeling of the user after the session was significantly better. Throughout the testing of the demonstrator, the graphic settings were set to its maximum, yet performance was significantly better, maintaining a constant of 25 frames per second.

Another advantage of the simulator that is not present on AVIAR's software is the recreation of an entire airport. Whilst AVIAR's makes a high fidelity representation of one stand on an airport, in this demonstrator the entire airport of Melilla is recreated, and the user is free to travel throughout the entire airport. It is even possible to exit the airport and drive through land-side.

Even if the demonstrator has certain improvements compared to AVIAR's software, it is barely usable, only capable of driving the tug. It is not possible to get out and walk or perform any other tasks that are otherwise capable on AVIAR's such as marshalling or interacting with any items from the surroundings. At its current state, the only interaction possible with any item in the surrounding is crashing against it.

Looking at the only thing the demonstrator is capable of, that is, driving, there are many factors that need improvements and polishing. Everything in the driving feels incorrect. Steering wheel controllers such as the one used are capable of transmitting forces from bumps felt in the terrain or make the direction stiffer as the vehicle gains speed. The demonstrator is not capable of doing so.

The throttle and braking is not that good either. Since traction is simulated with two aeroengines configured to behave as the wheels, smooth controls on the throttle pedal have almost no output in the simulator. This is even worse when using the reverse gear. It can be seen in the video that, to reverse back to its parking position, a lot of power is needed with the throttle pedal being flat-out to do so.

Braking is also bad and clunky, instead of being smooth, there are only two notches, making a smooth stop impossible, as it can be seen in the video when stopping at the stop sign. To make matters worse, due to the impossibility of simulating an electric engine sound, the tug sounds diesel.

Nonetheless, the demonstrator aims to show the possibilities that may be achieved in representing actual airport environments in a virtual world, the relative ease in this process in which, a small team or even one person can achieve convincing results, and hint on the almost limitless possibilities that may be achieved with these technologies if proper teams, with enough expertise, invest enough efforts into the development of these technologies.

5.5.2 Adaptability

As it was mentioned, one of the capabilities of virtual reality is high adaptability. This advantage can be used both commercially, since previously created elements, vehicles and environments may be modified and adapted to fit other customer needs, and to provide a more in depth simulation experience with the capacity of recreating different conditions, events, or weather.

5.5.2.1 Weather conditions

As it was mentioned, one of the capabilities of virtual reality is high adaptability. The demonstrator can simulate every weather condition to be able to provide a far more thorough training. Different conditions can be defined in terms of:

- Visibility and fog
- Precipitation
- Temperature (May affect, among other things, the performance of the vehicles and engine start)
- Water and snow buildup in the terrain
- Icing and slippery pavement
- Clouds
- Time of the day

Figure 53: Demonstration of different meteorological conditions in Melilla

5.5.2.2 Adapting to customer's needs

One of the advantages of performing training on software-based platforms is the ease to adapt one product to other customer's demands. Whether that may be changing the environment location, changing the vehicles used or simply changing logos, plenty of the assets developed for one customer can be reusable and reduce development times and costs. As an example, the tug was adapted for another company, Aviapartner, and was set in Marseille airport for simulation. This whole process took only 10 minutes.

Figure 54: Tug adapted to operate in another environment

Whilst it is true that this adaptation took so little time thanks to Marseille being an airport done in a past project, based on previous experience, a fully new airport environment at very high level of detail may be developed by a team of just 4 in in around 2 or 3 months, sometimes even less, and if subcontracted, cost would be between 8,000 to 50,000€ depending on the size of the airport to be modeled. This proves the cost effectiveness of virtual reality.

6 FUTURE DEVELOPMENTS

There are plenty of developments that may be performed in the future to further the implementation of virtual reality in aviation.

6.1 Training

As it was mentioned before, virtual reality may be used for personnel training in aviation. There are several fields it may be used in.

6.1.1 Ground Crews

As it can be seen in the tests and the demonstrator developed for this project, a virtual reality trainer for ground crew is definitely a possibility that companies should explore and try to implement into its procedures. It offers the possibility for a more in-depth, safe and cost effective training for all the personnel that assist aircraft from the ground. Especially with the recent changes in regulation, which have been mentioned, that offer better flexibility for the implementation of these methods.

The only issue that may prevent the implementation of these technologies is the lack of development. The only company with known progress in the development of software suitable for these applications is AVIAR BV, which, as it was mentioned, has gone silent with no news about its development for over a year and, the current status of their product is definitely nowhere near where it needs to be to reach the level required to make its implementation into actual airline operations a possibility. Either a new company needs to start developing to fill this market or AVIAR needs to get back to work to make their software reach the level needed.

6.1.2 Cabin Crews

As it was seen during the tests, virtual reality can offer plenty of advantages in the field of cabin crew training, with the possibility of giving a more in-depth training, simulating more dangerous events and situations that previously were no possible or not safe in mockup based training.

However, just like with ground crew training, there is not much development and effort being put into this field. There are several companies that promised a virtual reality based cabin crew training, however, there is not any proposal at a level of development good enough to make its implementation a reality. The only project whose completion and application seemed feasible was AVIAR BV's proposal, which, as it was mentioned, has gone silent for over one year.

6.1.3 Flight Crews

Unfortunately, it seems that virtual reality may not be an ideal solution for flight crew training. During the development of this report, certain tests were performed in flight simulators, using them in virtual reality, and, whilst it may be an interesting technology for the home user, it may be difficult to implement in professional settings and it is unlikely that it will fully replace current flight simulator setups.

Figure 55: Screenshot taken during one of the tests performed in VR. Starting the APU.

There are several aspects of the nature of VR that need to be noted from these tests.

- VR may replace a flat panel training device.

Flat panel trainers are used for flight crew and maintenance personnel training, based on flat screens set to display the panels found in the actual aircraft. Virtual reality lets the user interact with all the buttons and switches present in the flight compartment and allows for the simulation of procedures in the cockpit.

- VR will never replace a full motion simulator. It most likely will not replace full cockpit flight simulators.

During testing, it was easy to notice difficulty in manipulating inputs other than switches with a limited number of positions or buttons. When moving controls such as the yoke, throttles or nose wheel tiller, it was extremely difficult to make precise inputs on these controls. A physical control offers a certain friction which virtual reality is unable to simulate. Whilst haptic sensors may help in simulating these, it does not resemble an actual control and makes controlling the aircraft using just a virtual reality headset and hand controllers impossible.

Figure 56: Generic Flight Simulator Yoke

There may be several possibilities to solve this issue, such as the use of a generic setup covering the basic controls needed for flight (Yoke, Throttles, Rudder, Tiller) and make every other control be accessible with a virtual reality hand controller. However, there are several issues with this approach.

The user will not be able to see the controls he is intended to touch since the user will only be seeing the virtual world. This makes the use of such a setup extremely tedious and may destroy the immersiveness VR aims to achieve.

With all the additional disadvantages of virtual reality such as the additional fatigue related to having a relatively heavy screen hanging from the head, 2 centimeters away from the eyes, the computationally intensive processes required for the use of virtual reality, making an extremely powerful computer a necessity, and the fact that it still needs physical controllers for its use means that VR doesn't seem to be a feasible competitor to current flight simulators.

Especially in full motion simulators, the hydraulic base used to simulate all the forces and accelerations will still be needed. A traditional full cockpit simulator will probably provide a better experience, be more dependable and, most likely, more cost effective than any VR approach to this issue.

6.2 Virtual Reality in the design phase

As it was studied in this report, virtual reality can offer advantages compared to traditional screen based design solutions. There already are several solutions such as CATIA 3DEXPERIENCE[45] that already offer the possibility of integrating virtual reality into design workflows.

There are several drawbacks and issues related to the possible introduction of virtual reality. First of all, not all computers powerful enough to run design software will be powerful enough to run virtual reality software, meaning that, if a company intended to introduce VR throughout its entire operation, it would require a significant investment in the purchase of VR equipment and the replacement of, most likely, fully functional computers, generating significant expenses and waste.

There are additional issues related to the users of VR devices. Certain users may be skeptical or unwilling to adapt to the changes required to introduce VR, which is completely understandable. Using a computer based VR device, which are the only ones capable of running software such as CATIA or equivalents required for design, requires significant tweaking and setup. Additionally, certain users may be unfit for the use of VR because of certain health conditions but may be completely capable of performing the tasks their jobs require. These employees will never be able to introduce VR into their workflows.

It is clear that virtual reality can offer advantages compared to traditional design methods, however, VR will only be used by those users willing to spend the time and effort to introduce these new technologies into their processes. The new technology will not replace conventional screen based design processes but will have to live with them.

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6.3 Virtual Mockups

At the time of writing this report there is not much information regarding efforts being put into the development of software that may be used for the display of aviation mockups on virtual reality. This is somewhat surprising since this application is probably the easiest to introduce out of all the ones mentioned throughout this report.

Either for design or marketing purposes, this field would require the least efforts for any kind of certification or agency approval. In the case of mockups during the design phase, these are produced either before or for the purpose of certification. In the case of marketing, since the mockups' use is completely outside air operations, no certification should be required.

The required development efforts would also be insignificant compared to the other proposed applications for virtual reality. Since there already existing 3d models of all the CAD designs, importing these models into a VR software for visualizing the 3d model would be the only necessary step.

Lastly, since the VR headset would only be used for short periods of time, as required to see and experience whatever needs to be displayed, certain issues that may arise due to the use of a virtual reality device through long periods of time may not be an issue with this application.

6.4 Conclusion

As it can be seen with the tests and the demonstrator created in this report, Virtual Reality can offer significant advantages in several fields of the aviation industry, leading to improvements in efficiency, quality and cost savings.

There are several issues that need to be accounted for its introduction in the aviation sector. Some of which may be solved with further investment and efforts in the development of these technologies, but others may not have a possible solution such as those related to limitations in the users' health or will to adapt to change.

However, current technologies and developments already allow for a certain level of implementation of virtual reality into the aviation sector without significant difficulties. Especially now that several regulation changes are being released making the regulation more permissive with the introduction of newer technologies in certain fields.

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7.1 Images

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