Estudo de viabilidade de desenvolvimento de um demonstrador de Realidade Virtual para as operações de servicing sobre a aeronave A-29B Super Tucano

(versão corrigida após defesa)

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Resumo

Desde o seu nascimento, a indústria aeronáutica tem vindo a vivenciar mudanças relativamente a como um operador aéreo realiza as suas atividades de manutenção e como treina os seus técnicos de modo a manter a aeronavegabilidade da sua frota, sendo que a ocorrência de incidentes/acidentes que resultem do incumprimento das regulações/procedimentos impostos pela operadora aérea sejam um foco de melhoria.

Com a evolução e surgimento de tecnologias de Realidade Virtual, foi possível a entidades formadoras aprovadas segundo a regulação EASA Part-147, incorporar e direcionar este conhecimento para o treino de técnicos de manutenção. No entanto as mesmas apenas devem ser usadas como uma ferramenta complementar ao treino prático, pois não permitem que se adquira aptidões práticas para realizar tarefas manuais como soldadura, furação, aparafusamento, entre outros.

Estas tecnologias permitem que o instruendo tenha a possibilidade de testar os seus conhecimentos teóricos a qualquer momento sem estar limitado pela disponibilidade de componentes reais para dar continuidade à sua formação. Todo este processo de treino com auxílio a aplicações de Realidade Virtual pretende melhorar a retenção de conhecimento, que necessariamente levará a um aumento nas taxas de aprovação dos instruendos.

Neste trabalho pretende-se realizar o estudo de viabilidade e desenvolvimento de um demonstrador de Realidade Virtual direcionado ao treino de manutenção, para operações de *fuel servicing* para a aeronave A-29B Super Tucano, com o objetivo de reduzir o número de relatos de incidentes/acidentes resultantes de um procedimento mal-executado.

A aplicação de Realidade Virtual desenvolvida no decorrer de este trabalho de investigação, teve por base o motor de jogo Unity, em que o utilizador pode recorrer ao hardware VR atualmente disponível, ou a rato e teclado para realizar o procedimento de *fuel servicing*. A utilização em simultâneo das opções anteriormente referidas não é possível. Para cada procedimento, três modos de realização da tarefa são possíveis, a versão guiada, não-guiada e RV.

A versão guiada fornece ao utilizador uma experiência orientada, onde qualquer desvio do manual de manutenção para o procedimento de reabastecimento escolhido não é permitido. Cada tarefa, segundo a ordem tal como surgem no manual estará destacada, de modo a fornecer uma indicação visual da tarefa a ser executada. Uma cópia exata do manual da Embraer para o procedimento escolhido é também fornecida para ser usado como um checklist.

A versão não-guiada permite desvios aos procedimentos do manual de manutenção, assim como a realização de ações erradas do procedimento. No entanto, no final do treino são fornecidos elementos para quantificar os eventuais desvios do manual que tenham ocorrido durante o procedimento. Neste caso, o manual é igualmente fornecido, mas sem checklist.

Por fim, na versão de Realidade Virtual, tal como acontece na versão guiada, os fundamentos são iguais, no entanto, a diferença que merece maior destaque é o facto de os aparelhos de input e output deixem de ser o rato, teclado e monitor e passamos a usar um HMD e *handheld controllers*.

Palavras-chave

Treino de manutenção, Servicing, Realidade Virtual, Aeronavegabilidade, Unity, Super Tucano, Embraer.

Resumo alargado

Introdução

Este resumo alargado tem como intuito expor de uma forma clara o enquadramento e os objetivos estipulados a atingir com a realização desta dissertação. São também definidos os aspetos fulcrais, assim como as conclusões relevantes que surgiram do desenvolvimento do caso de estudo.

Enquadramento

Nos dias atuais, o universo aeronáutico é fortemente controlado e legislado por entidades reguladoras, como a ICAO, EASA, FAA e pelas autoridades nacionais de cada país, que reconhecem todos os riscos que advém das operações a serem tomadas a priori para que a ocorrência de um voo seja possível sem incidentes. Estas entidades têm como objetivo primordial minimizar os erros humanos e garantir a segurança de todos os intervenientes.

Para atingir tal propósito, os objetivos principais as entidades que operam meios aéreos podem ser definidas de acordo com o seu nível de certificação emitido pela EASA nos seguintes moldes:

- Organizações Part-M que são responsáveis pelo estabelecimento das condições administrativas e critérios que os operadores têm de implementar de modo a garantir a Aeronavegabilidade continuada da aeronave;
- As organizações Part-145 que tem as condições e critérios necessários para implementar a manutenção numa aeronave;
- As organizações Part-147 que se caracterizam por serem aprovados pela autoridade aeronáutica, por cumprirem os critérios e condições necessárias, para prestar serviços de treino.

A EMPORDEF-Tecnologias de Informação apesar de não se inserir nas categorias acima expostas, tem um papel preponderante em fornecer produtos e serviços de treino e simulação que servem como ferramentas auxiliares para as organizações formadoras.

Tal como é possível averiguar pelos relatórios anuais de segurança realizados pela EASA aos seus estados-membros, constata-se que no ano de 2019, nesses mesmos Estados-Membros, foram relatados 22 incidentes e 45 acidentes não fatais devido a operações de *ground handling,* onde as operações de reabastecimento se encontram inseridos. Como tal, existe margem de melhoria para a redução de estes mesmos eventos.

A EASA considera que as operações de reabastecimento se encontram numa área de perigo denominada de *aircraft upset,* que é definido como sendo uma condição que pode resultar na perda do controlo da aeronave devido a erros cometidos.

Apesar dos técnicos necessários para a realização destas operações serem certificados e considerados qualificados para a realização das mesmas, incidentes e acidentes continuam a ser relatados, como tal novas técnicas de treino têm que ser incorporadas, pretendendo-se que a utilização de aplicações com recurso a tecnologia de Realidade Virtual sejam uma das plataformas possíveis a serem adotadas, onde qualquer erro efetuado não compromete a integridade de qualquer componente ou indivíduo.

Objetivo

Esta dissertação tem como objetivo desenvolver um demonstrador de Realidade Virtual tendo em vista a implementação de treino de manutenção aeronáutica, para operações de *fuel servicing* sobre a aeronave A-29B Super Tucano.

Caso de Estudo

Os destinatários desta investigação são os técnicos de manutenção de aeronaves que são um elo fundamental em garantir uma operação sem incidentes/acidentes para as tarefas consideradas. Para tal, as entidades formadoras necessitam constantemente de novos equipamentos e técnicas que possam ser, de modo acessível e intuitivo, utilizados como complemento de treino, de modo a aumentar os níveis de conhecimento retidos pelos mesmos, provocando um aumento de taxas de aprovação e eliminar os desafios logísticos necessários para um treino num ambiente verdadeiro e operacional e por fim dar a possibilidade de criar uma maior gama de irregularidades a que um profissional pode ser exposto ao longo da sua carreira profissional.

Em primeiro lugar, antes de ser possível proceder ao desenvolvimento do trabalho proposto foi necessário adquirir conhecimento sobre todas as disciplinas envolvidas a fim de facilitar e orientar o trabalho.

Para se estabelecer o background referido, foi realizada uma pesquisa bibliográfica sobre a evolução da tecnologia RV, assim como equipamentos complementares, software e aplicabilidade na aérea de estudo em questão. Posteriormente, foi necessário assimilar conhecimentos no motor de jogo a ser utilizado, Unity e em linguagem de programação utilizado pelo mesmo, C#.

Seguidamente foram realizadas pesquisas bibliográficas generalizadas sobre o estado atual da manutenção aeronáutica e de como novos técnicos de manutenção são treinados, permitindo averiguar dificuldades que ocupam a atualidade aeronáutica e como a tecnologia RV poderia colmatar as mesmas.

Uma pesquisa bibliográfica relativamente aos efeitos adversos que advém do uso de tecnologias de Realidade Virtual foi igualmente realizado, permitindo que a aplicação desenvolvida tenha em mente a redução dos mesmos.

Posteriormente foi necessário adquirir conhecimentos sobre os componentes e sistemas que compõem a aeronave da Embraer A-29B Super Tucano relevantes para o caso de estudo, dando de seguida um enfoque nos capítulos do manual de manutenção relativos às operações de *fuel servicing*.

Após terminadas as pesquisas bibliográficas foi necessário realizar a interligação entre os conhecimentos adquiridos de *servicing* e de Realidade Virtual, procedendo ao desenvolvimento de um demonstrador de realidade virtual de modo a satisfazer os requisitos impostos pela ETI.

Por fim, a validação dos resultados foi realizada, averiguando o cumprimento dos requisitos previamente definidos e perspetivas para trabalhos futuros.

Principais conclusões

A realização deste trabalho permitiu concluir que a incorporação desta tecnologia no treino de novos técnicos de manutenção, representa uma mais-valia que deve ser explorada e melhorada, pois representa uma ferramenta de treino *stand-alone* e sem riscos de ocorrência de danos a componentes e equipamentos utilizados no universo aeronáutico. Esta tecnologia permite também devida às suas características que se proceda à sua utilização sem os inconvenientes logísticos, tal como calendarização e disponibilidade de equipamentos, associados às técnicas de treino convencionais.

Aquando da realização do documento de especificação dos requisitos que a solução deve obedecer foi definido que teria que ser abordado as 6 tarefas de fuel servicing. No entanto, como o fornecimento dos modelos 3D por parte da equipa de design foi insuficiente para cumprir tais expectativas, apenas 1 procedimento foi abordado, que porventura se decomponha em 3 versões possíveis, modo guiado, não guiado e em Realidade Virtual.

Após testes à aplicação desenvolvida nesta dissertação para treino para *servicing* recorrendo a elementos que não possuíam conhecimento prévio de procedimentos de reabastecimento, foi possível averiguar que na versão guiada onde são facultadas como ferramentas auxiliares o manual e os highlights das tarefas a realizar, o procedimento foi realizado com sucesso e sem necessidade de ajudas externas e de conhecimento prévio da matéria em questão. Como tal, de modo a criar algum desafio e valor didático, os *highlights* das tarefas a serem realizadas foram removidas.

No entanto este hardware ainda apresenta limitações, pois as primeiras utilizações do sistema podem provocar alguns dos efeitos negativos que se encontram expostos no estado de arte desta dissertação, tal como motion sickness e cefaleias. Apesar de estes efeitos variarem de pessoa para pessoa, utilizadores afetados reportam mitigação ou eliminação dos sintomas após as primeiras utilizações.

Outra limitação presente no headset de RV utilizado é o de efeito de Screen-Door, onde a resolução de imagem percetível ao olho humano é reduzida. No entanto, esta limitação poderá ser colmatada com novos equipamentos mais atualizados e com um HMD com melhor resolução de imagem.

Por fim, devido às limitações presentes no hardware de RV utilizado e à escala do ambiente virtual, apenas foi estudada uma solução que usa um sistema de movimento com 3 graus de liberdade, pois apesar de testes feitos se comprovar que um sistema com 6 graus de liberdade, reduz ou elimina completamente os efeitos negativos que advém do uso desta tecnologias. Esta limitação deveu-se ao facto de o hardware não ser *wireless* e de não ser viável recriar um ambiente virtual a escala real.

Perspetivas de Investigação futuras

Devido a eventos recentes, nomeadamente à pandemia COVID-19 e à subsequente necessidade de confinamento em vários dos países afetados, o treino presencial mostrou-se impossível. Como tal tecnologias como a RV ganharam atração como uma solução viável para treino remoto, permitindo que o instrutor e o aluno possam ser inseridos no mesmo ambiente de treino virtual. Apesar da solução desenvolvida não possuir funcionalidades de multi-utilizador, é uma melhoria possível a ser realizada.

Como a manutenção aeronáutica é um campo de aplicação muito abrangente, não é possível, dado o tempo fornecido, abordar todo o espetro de atividades de manutenção da aeronave A-29B Super Tucano. Dado que o maior enfoque deste trabalho de dissertação está direcionado às ações de *fuel servicing*, a perspetiva a tomar para os desenvolvimentos de trabalhos futuros seria a de abordar uma maior extensão de subcapítulos inseridos no servicing e posteriormente a realização de uma abordagem a outros capítulos do manual de manutenção.

Para aplicações futuras, com o constante desenvolvimento da tecnologia de Realidade Virtual, espera-se que os efeitos indesejáveis possam ser completamente eliminados, e que os *hand-held controllers* sejam substituídos por tecnologias de *hand tracking* e que o HMD utilizado seja wireless.

Abstract

Since the birth of aviation, the industry has experienced changes on how an airline operator must perform maintenance operations and how new technicians are trained to perform them to ensure the airworthiness of the aircraft, where the reduction of human errors resulting from non-compliance to the stipulated regulations are one of the main concerns.

With the surge of new Virtual Reality technologies, EASA Part-147 approved organizations are enabled to incorporate and direct this new knowledge to the training of new EASA Part-66 approved technicians. However, Virtual Reality technologies must only be used and thought of as a complementary training tool, as it does not provide competencies to perform manual actions as welding, drilling, screwing, among others.

Virtual Reality allows the trainee to test his theoretical knowledge at any given time without being limited by the availability of real equipment/components necessary to continue his training, without creating the risk of causing any material damage. All the training performed while resorting to the use of Virtual Reality technologies aims to improve knowledge retention, resulting in better approval rates.

In this dissertation, a feasibility study and development of a Virtual Reality demonstrator directed to maintenance training for fuel servicing operations over an A-29B Super Tucano aeroplane must be performed, with the reduction of incidents/accidents reports resulting from wrongly performed procedures set as the main goal.

The Virtual Reality application was built on a game engine called Unity, where the user can choose from VR hardware currently available or a mouse and keyboard to perform a fueling procedure. For each procedure, there are three modes available, guided, unguided and VR versions.

The guided procedure will provide the user with an oriented experience, where no deviation from the maintenance manual for the fuel servicing action chosen can be performed. Each task will be highlighted in the correct order, providing a visual indication of the task to be executed. An exact copy of the Embraer maintenance manual for the designated procedure will also be provided to be used as a checklist.

The unguided procedure allows deviation from the maintenance manual and wrong actions are allowed to be performed. However, a score will be given at the end of the procedure to evaluate how accurately the manual was followed. Embraer maintenance manual will be also provided, but with no checklist.

Lastly, the VR version will follow the same fundamentals as the guided version. However, the input and output devices used on the previous 2 versions are replaced by an HMD and two handheld controllers.

Keywords

Maintenance Training, Aircraft servicing, Virtual Reality, Airworthiness, Unity, Super Tucano, Embraer.

Table Contents

List of Figures

List of Tables

List of Acronyms

CAD	Computer Assisted Design
ETI	Empordef Tecnologias e Informação S.A.
ICAO	International Civil Aviation Organization
EASA	European Aviation Safety Agency
FAA	Federal Aviation Agency
OFT	Operational Flight Trainers
CPT	Cockpit Procedures Trainers
IPT	Interactive Procedures Trainers
MT	Maintenance Trainers
CBT	Computer-Based Training
AMS	Approved Maintenance Manual
CMM	Component Maintenance Manual
MPD	Maintenance Planning Document
MRO	Maintenance, Repair, and Overhaul
EPU	External Power Unit
GSE	Ground Support Equipment
LRU	Line Replaceable Unit
AML	Aircraft Maintenance License
ATA	Air Transport Association
OJT	On the Job Training
AMC	Acceptable Means of Compliance
GM	Guidance Material
VR	Virtual Reality
AR	Augmented Reality
VT	Virtual Trainer
HMD	Head-Mounted Display
PTSD	Post-Traumatic Stress Disorder
NASA	National Aeronautics and Space Administration
FOV	Field of View
DOF	Degree of Freedom
ODT	Omni Directional Treadmill
EMG	Electromyography
SDE	Screen Door Effect
PPI	Pixels Per Inch
TUC	Time of Useful Consciousness
OBOGS	On-Board Oxygen Generating System
API	Application Programming Interface
GUI	Graphical User Interfaces
AI	Artificial Intelligence
I/O	Input/Output Devices
EICAS	Engine Indicating and Crew Alerting System

GPU	Ground Power Unit
XFR	Transfer
HYDR	Hydraulics
EXT PWR	External Power
MDP	Mission and Display Processor
EXT LT	External Lights
INRTL SEP	Inertial Separator
LDG	Landing Gear
INT LT	Internal Lights
ICE PROT	Ice Protection
LH	Left-Hand
RH	Right-Hand
AUX	Auxiliary

Main concepts

Maintenance: Maintenance means any one or combination of the following activities: overhaul, repair, inspection, replacement, modification, or defect rectification of an aircraft or component, except for pre-flight inspection (Commission Regulation (EU) No 1321/2014, 2014).

Safety: The state in which risks associated with aviation activities, related to, or in direct support of the operation of aircraft, are reduced and controlled to an acceptable level (ICAO, 2018).

Airworthiness: The status of an aircraft, engine, propeller, or part when it conforms to its approved design and is a condition for safe operation (ICAO, 2010)

Continuing Airworthiness: All the processes that ensure, at any time in its life, an aeroplane complies with the technical conditions fixed to the issue of the Certificate of Airworthiness and is in a condition for safe operation (ICAO, 2018).

Airworthiness Directives: An airworthiness directive means a document adopted by the agency which mandates actions to be performed on an aircraft to restore an acceptable level of safety when evidence shows that the safety level of this aircraft may otherwise be compromised (Commission Regulation (EU) No 748/2012, 2012).

Maintenance Planning Document: Provided by aircraft manufacturers to describe the repetitive tasks that are required to maintain their aircraft (IBM, 2020).

Service Bulletins: Advisory notices to an aircraft operator from a manufacturer informing of a product change/ improvement (Sasadmin, 2018).

Component Maintenance Manual: Formal document which details how aircraft maintenance tasks on the specified component are accomplished (SKYbrary, 2017).

Incident: An occurrence, other than an accident, associated with the operation of an aircraft that affects or could affect the safety of operation (ICAO, 2016)**.**

Accident: An occurrence associated with the operation of an aircraft that takes place between the time any person boards the aircraft with the intention of flight until all such persons have disembarked (ICAO, 2016).

Virtual Reality: The use of computer technology to create the effect of an interactive three-dimensional world in which the objects have a sense of spatial presence (NASA, 2021).

Unity: Game development framework that supports and brings together several areas of software development. Developers can import 2D and 3D graphics and resources from other software, mount them in scenes and environments and add lighting, audio, special effects, physics, animation, interactivity, and game logic (Unity, 2020).

Chapter 1 - Introduction

1.1 Motivation

Throughout the years the planning of maintenance checks and the required training of the technicians to perform them has changed as the complexity of the aeroplanes increased. So, to keep up with the growing aircraft development, government agencies and regulators had to put in place several directives, like the Commission Regulation (EU) No 1321/2014, EASA Part-145, EASA Part-147, EASA Part-66, EASA Part-CAMO, EASA Part-M, among other regulations, to be followed by airline operators, Part-147 approved organizations and Maintenance Repair and Overhaul organizations and performed by maintenance technicians in order keep aeroplanes in a safe operating condition.

“However, one of the challenges of training is that until recently the only viable way to gain practical knowledge of the necessary procedures to be taken during maintenance was through practice on real components, where trainees pass their examinations by performing repairs and maintenance under the supervision of an examiner, as described by the EASA Part-147 regulations. While effective, this portion of the training can prove to be costly as a Part-66 license pursuant with only classroom-type training, unfamiliar with the physical aspects of the work, could potentially damage aeroplane components” (Lozé, 2019).

“In response, the aviation industry has been taking a hard look at how new technologies like Virtual Reality can help to train mechanics and ground crew” by providing accessibility to a multitude of training scenarios without the risk of damaging equipment. “So, VR gives personnel a safe environment to hone their skills, letting them run through a maintenance scenario multiple times until the trainee is capable of performing those same tasks on an error-free procedure” (Lozé, 2019).

“However, VR or any simulation-based training cannot be eligible as a sole training or assessment tool for basic hand skills such as wiring, welding, drilling, filling, wire locking, riveting, bonding, or any other skills, where competence may only be achievable by performing a hands-on activity” (EASA, 2020).

As VR technology evolves, the ability to respond to the aviation industry's needs increases. As such it is expected that VR will be increasingly incorporated in the industry as a tool to be used in training to optimize aeroplane maintenance procedures, cabin crew procedures, and ground crew procedures.

1.2 Objective

The objective of this dissertation is to study the feasibility regarding the implementation of a Virtual Reality solution applied on maintenance operations training, mainly, fuel servicing on an A-29B Super Tucano thus improving the standard training process in place.

1.3 Requirements

In general terms, EMPORDEF-Tecnologias de Informação, S.A. (ETI), a company with experience in the development of training tools used mainly on military airplanes, wants to develop a VR solution to be used on the military airplane manufactured by Embraer, the A-29B Super Tucano, regarding fuel servicing procedures training.

To this end, ETI established the requirements that were the basis of this research work which allowed to conduct the state of the art but also to conduct the process in view of establishing a solution.

Also, the requirements are essential for the validation of the solution, meaning that the solution needs to be assessed to determine if it responds to what is required by ETI.

Table 1 exhibits the various requirements defined by ETI for what was denominated Virtual Trainer (VT). Each requirement was identified with a reference that was defined as SR-HLV-XXX.

ID	Requirement
SR-HLV-001	Hardware by Vive[1]
SR-HLV-002	The solution must be built on Unity
SR-HLV-003	VT shall allow fuelling procedures
SR-HLV-004	VT shall allow access to the refuelling ports
SR-HLV-005	VT shall allow safety procedures
SR-HLV-006	VT shall allow grounding procedures
SR-HLV-007	VT shall allow external energy powering
SR-HLV-008	VT shall allow the operation of the external fuel panels
SR-HLV-009	VT shall allow the operation of the internal fuel panels
SR-HLV-010	VT shall allow the operation of the fuel hose

Table 1 VR application High-Level requirements.

1.4 Methodology

This work was conducted using the following approach:

- Document research related to maintenance training and VR solutions;
- The use of specific standards to assist the design and development process;
- The use of specific software tools to construct the solution;
- The integration of 3D models relevant to the solution;
- The test and approval of the solution.

1.5 Work Limits

Given the human resources assigned, defined timeframe, and requirements established by ETI the present research was limited as follows:

- The training process only covered the pressure refuelling procedure without EPU;
- Training process restricted to only 1 user;

[1] HTC Vive pro is a solution provided by Vive company whose main characteristics is to enable VR applications development, with the use of an HMD and hand-held controllers.

1.6 Work organization

This dissertation is structured in nine chapters as follows:

1. Introduction;
2. ETI brief presentation;
3. State-of-the-Art of maintenance training and VR;
4. A-29 Super Tucano servicing tasks;
5. Unity editor tool;
6. Maintenance training requirements;
7. Maintenance training solution;
8. Validation;
9. Conclusion and future work.

The first chapter (the present) approaches the motivation, objectives, scope of work, methodology work limits, and work organization of the dissertation.

The second chapter describes ETI in terms of history, area of expertise, capabilities, market target, and former performed work.

The third chapter addresses the state-of-start relevance for the topic defined to be studied during this dissertation. This includes a description of the aeroplane maintenance training processes, a discussion on virtual reality technology, and the subsequent applicability in the aviation industry.

The fourth chapter covers the specific aspects of the A-29 Super Tucano servicing tasks with a focus on the fuel system.

The fifth chapter has a brief introduction to the Unity editor, the tool used for the development of the solution, its structure, and its functionalities.

The sixth chapter addresses the requirements defined by ETI concerning the training process associated with the servicing of the fuel system of the A-29 Super Tucano.

The seventh and eighth chapters describe the solution developed with the training of the servicing process of the A-29 Super Tucano and the results of the validation, respectively.

The last chapter approaches the conclusion of the work, as well as recommendations for future research activities.

Chapter 2 - EMPORDEF-Tecnologias de Informação

2.1 Company profile

ETI is a Portuguese company working in Integrated Logistics Support (ILS) that offers training and simulation solutions as well as engineering services for supporting AeroSpace and Defence platforms (ETI, 2020).

The company is specialized in providing solutions and services in the areas of interactive learning, advanced simulation, and has an extensive background and references in Operational Flight Trainers (OFT), Cockpit Procedures Trainers (CPT), Interactive Procedures Trainers (IPT), Maintenance Trainers (MT) and Computer Based Training (CBT) systems in the aeronautics and defence industries (ETI, 2020).

2.2 History

The History of EMPOREDF - Tecnologias de Informação, S.A. (ETI) starts with the creation of the Development Engineering Division, within OGMA - Indústria Aeronáutica de Portugal, S.A., back in 1984 that went through a spin-off process, becoming ETI in august 2004. ETI is owned entirely by idD – Portugal Defense S.A., the State´s holding for the Portuguese Defense Industry. Located near Lisbon-Portugal at the Lazarim Technological Pole (ETI, 2020). Former work performed by ETI is shown in Figure 1.

Figure 1: CAD version of Embraer KC-390 (ETI, 2020).

2.2 Ownership structure

"Under the umbrella of the Portuguese National Defence Ministry, a new society formed over the old idD, adopted the designation of idD – Portugal Defence and is responsible for the implementation of a strategy for the national and international promotion of the Base Tecnológica e industrial de Defesa, BTID, as a way of developing the national capabilities on this field, having Portugal as a producer and exporter of technology and services within the scope of the Defence sector" - see Figure 2 (idD, 2021).

Under the terms of statutes approved by the government, it is responsible for (idD, 2021):

- Maintaining an interface between the Defence sector and the centres of investigation and development of the Portuguese universities.
- The management of the social participations assigned to the society (OGMA – Indústria Aeronáutica de Portugal, S.A., Arsenal do Alfeite, S.A., Navalrocha – Sociedade de Construção e Reparações Navais, S.A., EEN – Empordef Engenharia Naval, S.A., EID – Empresa de Investigação e Desenvolvimento de Eletrónica, S.A., EMPORDEF – Tecnologias de Informação, S.A. (ETI), EDISOFT – Empresa de Serviços e Desenvolvimento de Software, S.A. (EDISOFT, S. A.), Extra – Explosivos da Trafaria, S.A.) ;

- The support of operations for the profitability of assets in the area of national defence, namely within the scope of the implementation of the respective infrastructure law;
- Advising on military equipment transactions, specifically in the context of the execution of the military programming law.

Figure 2 idD logo (idD, 2021).

2.3 Clients

Today, ETI exports 80% of its production, where almost 90% of ETI sales have as end goal user military staff. ETI has in the Portuguese Air Force, at the national level, its most important customer (ETI, 2020).

ETI also holds as key costumers, at the international level, Airbus, Embraer, Leonardo, General Dynamics, Austrian Armed Forces and Belgian defence (ETI, 2020).

2.4 Capabilities

“ETI has been accumulating experience since 1984 in the areas of testing software, synthetic training systems, and research and development projects that have exposed and prompted ETI to the development processes, technologies competencies and tooling”, such as (ETI, 2020):

- Systems modelling and simulation;
- Distributed and tactical simulation;
- Mechanical design;
- I/O System design;
- Instructor and debriefing station;
- Maintenance of training devices.

The preceding competencies sustain the simulation activity area that ETI offers to the Aerospace and Defence market (ETI, 2020).

ETI also offers turn-key solutions in visual systems. These solutions range from simple visual applications for PC based flight trainers to high-end visual systems for full-flight simulators (ETI, 2020).

“ETI is working towards the edification of a solid prestige, bolstering more and more the capabilities deemed relevant to the engineering of innovative and technologically advanced systems, which uphold the accumulated skills and expertise in” (ETI, 2020):

- Aircraft engine test benches;
- Vibration monitoring & vibration spectrum analysis;
- Aircraft engine automated diagnostics;

Chapter 3 - State-of-Art of maintenance activities and of the Virtual Reality

This chapter approaches the state of the art on the training of Aircraft Maintenance Technicians - (AMT). Also includes a historical background of Virtual Reality development, adverse health effects, the current state of the art of VR hardware and how it is starting to be incorporated in the aviation industry as a complementary training tool. VR technology already in effect on the diverse areas that the aviation industry encompasses, namely in the ground crew, cabin crew, AMT, and pilots' procedures, will also be addressed.

3.1 Aircraft maintenance

The European Union Commission Regulation (EU) No 1321/2014 defines aircraft maintenance:

> "Maintenance means any one or combination of the following activities: overhaul, repair, inspection, replacement, modification or defect rectification of an aircraft or component, except for pre-flight inspection" (Commission Regulation (EU) No 1321/2014, 2014).

Also, it "states that organizations involved in the maintenance of large aircraft or aircraft used for commercial air transport, and components intended for fitment thereto, shall be approved under the provisions of Annex II (Part-145)" (Commission Regulation (EU) No 1321/2014, 2014).

3.1.1 Relevance of maintenance

Throughout the years, aeroplanes structures and components evolved drastically in complexity, however from an engineering standpoint, it is not possible to design a system with the following characteristics:

- Will not fail during its life cycle;
- Will not need to be modified;
- Will never need to be replaced;
- Will withstand operation related degradation.

As such maintenance is of paramount importance to maintain the aeroplane systems, necessary for operation, at a safe operating state and prevent their degradation beyond a certain point that could jeopardize the aircraft integrity and its users.

3.1.2 Initial Airworthiness

During the development of an aeroplane, before the manufacturer can enter into series production for future sales, a Type Certificate must be granted by an aeronautical Authority (normally a national agency), which includes all the technical and administrative criteria to be complied for the aeroplane to be on an airworthy state and to be operated.

As the aircraft enters into service, it is subjected to operational degradation, so it is required to establish Instructions for Continued Airworthiness to assure all components remain in a safe operation throughout their life cycle, as mandated by EASA CS-25 Appendix H (in the case of large aircraft).

The Instructions for Continued Airworthiness include some the following elements (EASA, 2007):

- Aeroplane maintenance manual or section;

- Maintenance Instruction;
- Diagrams of structural access plates and information needed to gain access for inspections;
- Details for the application of special inspection techniques including radiographic and ultrasonic testing;
- Information needed to apply protective treatments to the structure after inspection;
- All data relative to structural fasteners such as identification, discard recommendations, and torque values;
- A list of special tools needed.

3.1.3 Maintenance programme

Based on the above, the necessity to perform maintenance must be done in compliance with already established regulations. As such, aeronautical regulations in response to ICAO standards have implemented a mandatory need for a maintenance plan for an aircraft.

This plan will give an extensive list of tasks to be performed on the aeroplane after certain flight hours, flight time or calendar time including repair and modifications.

Every aeroplane system is placed under different levels of structural fatigue and degradation during operation, as such, they need to be regulated under different types of maintenance intervals.

In general terms, "the intervals of maintenance are parameters set within the Approved Maintenance Schedule (AMS) which is in turn are based on the Maintenance Planning Document (MPD). These will be set according to different criteria, mainly using the methodology defined under MSG-3[2], mostly depending on how well damage can be detected and failure predicted" (CAA, 2017) the following concepts of maintenance applicable to the various aircraft items:

> **Hard time** "is the preventive process in which known deterioration of an item is limited to an acceptable level by the maintenance actions. Carried out at periods related to time in service (e.g., calendar time, number of cycles, number of landings)" (Commission Regulation (EU) No 1321/2014, 2014). It includes components belonging to engines, propellers, landing gears, among others.
>
> **On-condition** "is the preventive process in which items are inspected or tested, at specific periods, to an appropriate standard to determine whether they can continue in service. The purpose is to remove the component before its failure" (Commission Regulation (EU) No 1321/2014, 2014).
>
> **"Condition monitoring** is a process mainly for systems that have neither HT nor OC maintenance as their primary maintenance process". In practical terms, it involves (in the case of engines) permanent monitoring of performance parameters. "It is accomplished by appropriate means available to an operator for finding and solving problem areas. The user must control the reliability of systems or equipment based on knowledge gained by analysis of failures or other indications of deterioration" (Schoolcraft, 2020).

[2] Maintenance Steering Group.

3.1.4 Levels of maintenance

In the civil [3]segment aircraft maintenance is divided into two main categories:

- Line maintenance;
- Base maintenance.

Line maintenance is considered as any maintenance that is carried out before flight to ensure that the aircraft is fit for the intended flight. Line maintenance may include (EASA, 2014):

- Trouble shooting;
- Defect rectification;
- Component replacement with use of external test equipment;
- Scheduled maintenance and/or checks including visual inspections that will detect obvious unsatisfactory conditions;
- Minor repairs and modifications which do not require extensive disassembly.

Maintenance tasks falling outside these criteria are considered to be base maintenance (EASA, 2014).

"For temporary or occasional cases (Airworthiness Directives, Service Bulletins) the Quality Manager may accept base maintenance tasks to be performed by a line maintenance organization provided all requirements are fulfilled as defined by the competent authority" (EASA, 2014).

Base maintenance consists of tasks that are generally more in-depth and long-lasting than those above but are performed less frequently. A Maintenance, Repair, and Overhaul (MRO) company will have to have large facilities and specialized equipment and staff to undertake base maintenance (SKYbrary, 2019).

The different activities may include (EASA, 2018):

- Maintenance tasks or replacement of any major component, either scheduled or unscheduled, where the related maintenance procedures address the need of a hangar environment requiring special ground support equipment and/or complex and lengthy maintenance;
- Major repairs and/or major modifications;
- Troubleshooting and/or defect rectification requiring special ground support;
- Scheduled maintenance event, which in the planning phase has been already identified as significant in terms of duration and/or man-hours;
- A work package requiring a complex team composition in terms of high number & categories of staff involved per shift.

[3] In the defence sector the approach may include other terminology such as 1st level, 2 level and Depot. This terminology is not universal but it is the most common adopted (author note).

3.1.5 EASA Part-66 License

EASA Part 66 Aircraft Maintenance License is a document issued on the standard EASA Form 26 which permits the holder to exercise privileges to issue Certificates of Release to Service following aircraft maintenance (EASA, 2008).

Figure 3 Part - 66 License issued by the Portuguese National Aviation Authority (ANAC).

This license (see Figure 3) is issued by a competent authority, where the competent authority is typically a national aviation authority, or in the case of the “European Union, any aviation body designated by the Member State and located within that Member State. A Member State may also designate more than one competent authority to cover different areas of responsibility” (EASA, 2014).

“Individual aircraft maintenance license holders need not be restricted to a single category. Provided that each qualification requirement is satisfied, any combination of categories may be granted” (EASA, 2014).

There are 4 categories within the Aircraft Maintenance License for civil aviation (Commission Regulation (EU) No 1321/2014, 2014):

- Category A – Line Maintenance Certifying Mechanic;
- Category B1 – Maintenance Certifying Technician - Mechanical;
- Category B2 – Maintenance Certifying Technician - Avionic;
- Category C – Base Maintenance Certifying Engineer.

In addition, the Aircraft Maintenance License categories A and B1 are subdivided into subcategories relative to combinations of aeroplanes, helicopters, turbine and piston engines as follows (Commission Regulation (EU) No 1321/2014, 2014)

- A1 and B1.1 Aeroplane Turbine;
- A2 and B1.2 Aeroplane Piston;
- A3 and B1.3 Helicopters Turbine;
- A4 and B1.4 Helicopters Piston.

The holder of an aircraft maintenance license depending on the category, as described on 66.A.20 Privileges, have the following Privileges (Figure 4) (EASA, 2014):

- A category C licence permits certification of scheduled base maintenance by the issue of a single certificate of release to service for the complete aircraft after the completion of all such maintenance;

- A category B1 permits certification privileges on aircraft structure, powerplant and mechanical and electrical systems. Also, replacement of avionic Line Replaceable Units (LRUs) requiring simple tests to prove their serviceability;
- A category B2 permits certification privileges on avionic and electrical systems;
- A category A permits certification privileges on scheduled line maintenance tasks.

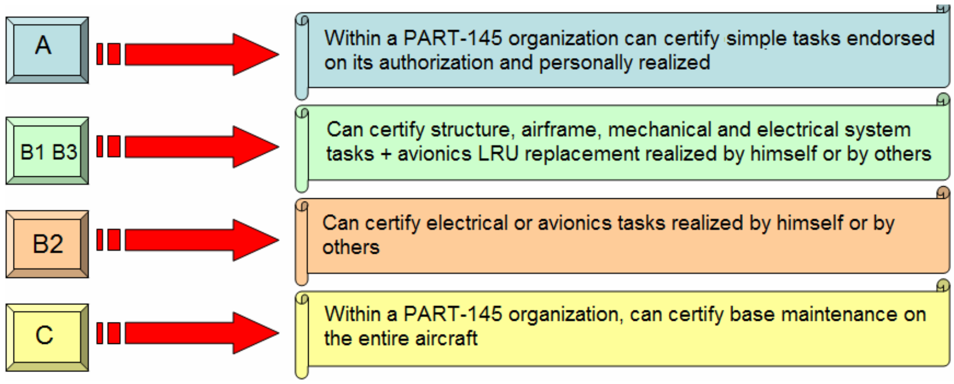


Figure 4 Certification privileges of each AML category (Elearnstation, 2014).

Before a Part-66 AML can start aircraft type training, a basic training course must be completed. Where basic training courses shall consist of (Commission Regulation (EU) No 1321/2014, 2014):

- Knowledge training;
- Knowledge examination;
- Practical training;
- Practical assessment.

"The knowledge training shall cover the subject matter for the category or subcategory aircraft maintenance licence as specified in Annex III (Part-66)" (Commission Regulation (EU) No 1321/2014, 2014).

The knowledge examination shall cover a representative cross-section of the subject of matter for the category or subcategory of the aircraft maintenance licence (Commission Regulation (EU) No 1321/2014, 2014).

"The practical training element shall cover the practical use of common tooling/equipment, the disassembly/assembly of a representative selection of aircraft's parts and the participation in the representative maintenance activities being carried out relevant to the Part-66 complete module" (Commission Regulation (EU) No 1321/2014, 2014).

"The practical assessment shall cover the practical training and determine whether the student is competent at using tools and equipment and working under maintenance manuals" (Commission Regulation (EU) No 1321/2014, 2014).

The basic knowledge that must be acquired throughout the basic training courses for each license category is directly related to the complexity of the certifications related to the corresponding license category, which means that category A should demonstrate a limited but adequate level of knowledge, whereas category B1 and B2 should demonstrate a complete level of knowledge in the appropriate subject modules (EASA, 2014).

"For a category C applicant holding an academic degree, the representative selection of tasks should include the observation of hangar maintenance, maintenance planning, quality assurance, record-keeping, approved spare parts control and engineering development" (EASA, 2014).

"While an applicant to a category C license may be qualified by having 3 years' experience as a B1 or B2 certifying staff only in line maintenance, it is however recommended that any applicant to a category C holding a B1 or B2 license demonstrate at least 12 months experience as a B1 or B2 support staff" (EASA, 2014).

“An applicant to an aircraft maintenance license must demonstrate an experience appropriate to the category. That means a minimum of one year of recent experience should be gained in the aircraft category. Depending on the category of the aircraft maintenance licence, the following activities are considered relevant for maintenance experience” (EASA, 2014):

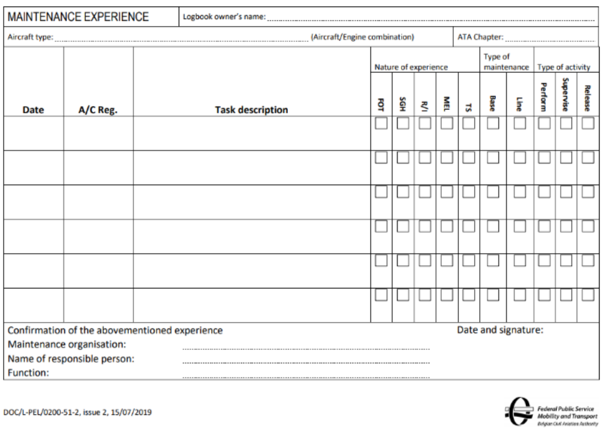
- Servicing;
- Inspection;
- Operational and functional testing;
- Trouble-shooting;
- Repairing;
- Modifying;
- Changing component;
- Supervising these activities;
- Releasing aircraft to service.

To be considered as recent experience, at least 50% of the required 12-month recent experience should be gained within the 12 months before the date of application for the aircraft maintenance license. The remainder of the recent experience should have been gained within the 7 years before application (EASA, 2014).

“For category A the additional experience of civil aircraft maintenance should be a minimum of 6 months. For category B1, B2 or B3 the additional experience of civil aircraft maintenance should be a minimum of 12 months. Aircraft maintenance experience gained outside a civil aircraft maintenance environment may include aircraft maintenance experience gained in armed forces, coast guards and police or in aircraft manufacturing” (EASA, 2014).

The experience should be documented in an individual logbook (see Figure 5 as an example) or any other recording system containing the following data (EASA, 2014):

- Date;
- Aircraft identification i.e. registration;
- ATA/ISPEC 2200 chapter (optional);
- Operation performed;
- Type of maintenance;
- Type of activity;
- Category used A, B1, B2, B3 or C;
- Duration in days or partial days.


MAINTENANCE EXPERIENCE — Logbook owner's name: ....

Aircraft type: .... (Aircraft/Engine combination) — ATA Chapter: ....

Date	A/C Reg.	Task description	Nature of experience: FOT	SGH	R/I	MEL	TS	Type of maintenance: Base	Line	Type of activity: Perform	Supervise	Release
			☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
			☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
			☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
			☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
			☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
			☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Confirmation of the abovementioned experience — Date and signature:
Maintenance organisation: ....
Name of responsible person: ....
Function: ....

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Federal Public Service Mobility and Transport
Belgian Civil Aviation Authority

Figure 5 Logbook Template of the Belgian Civil Aviation Authority (Federal Public Service Mobility and Transport, 2019).

After the pursuant completes the preceding steps, described in EASA AMC 66.A.25 and in EASA AMC 66.A.30, a "Blank" AML, without type rating certification, may be issued by the competent authority. To obtain a Type rating endorsed on the AML, the applicant must complete Type Training (Theory Exam and Practical Assessment), as described by EASA Part-66 Appendix III and Part 66.A.45 (b), and complete On the Job Training (OJT). As shown in Figure 6.

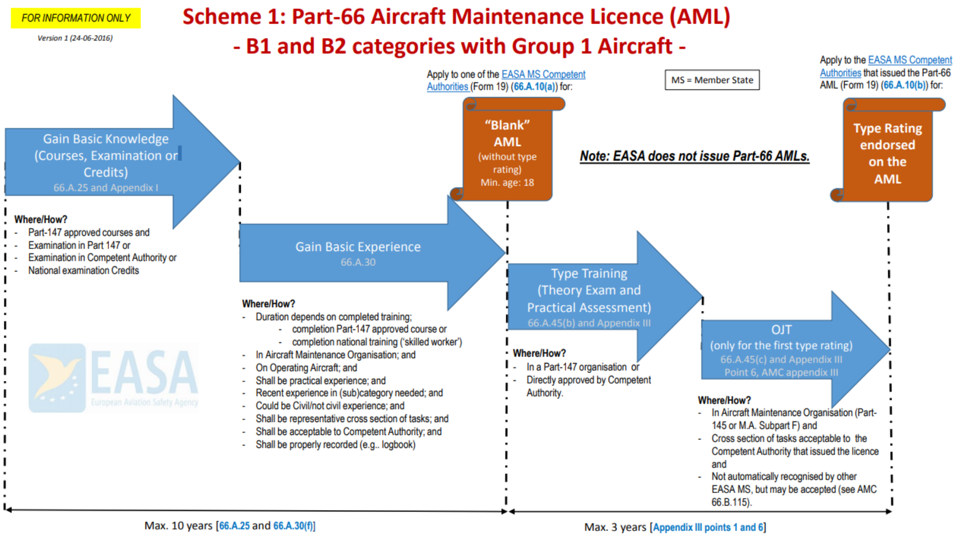

Figure 6 EASA Part-66 Aircraft Maintenance Licence Scheme (EASA, 2021).

On the Job Training must be performed on an approved maintenance organization. Where a maintenance organization appropriately approved for the maintenance of the aircraft type means an EASA Part-145, EASA PART M.A Subpart F or Part-CAO approved maintenance organization holding an A rating for such aircraft (EASA, 2020).

The procedures for OJT of an EASA Part-145 organization should be included in the Exposition Manual[4] of the approved maintenance organization. However, since these procedures are approved by the competent authority of the maintenance organization, and providing training is not one of the privileges of a maintenance organization, they can only be used when the licensing authority is the same as the competent authority of the maintenance organization. In other cases, it is up to the licensing authority to decide whether it accepts such procedures to approve the OJT (EASA, 2020).

3.1.6 EASA Part 147 Approved Organisations

EASA establishes the requirements to be met by an organization seeking approval to conduct training and examination as specified in EASA Part-66. A maintenance organization shall be approved to carry out Part-66 aircraft type and/or type training in compliance with the standard specified in EASA PART 66.A.45 (Sasadmin, 2016). The application should contain all the information specified in the EASA Form 12.

To be considered approved for basic maintenance training courses means holding and ensuring reasonable access to examples of aircraft parts and national aviation legislation, examples of typical aircraft maintenance manuals and service bulletins, Airworthiness Directives, aircraft and component records, release documentation, procedures manuals and aircraft maintenance programs (EASA, 2014).

[4] Manual responsible to set forth the procedures, means and methods of the organisation. (EASA, Acceptable Means of Compliance and Guidance Material to Annex II (PART-145) to Regulation (EU) No 1321/2014, 2014)

“Except for the aircraft parts and national aviation regulations, the remainder of the documentation should represent typical examples for both large and small aircraft and cover both aeroplanes and helicopters as appropriate. Avionic documentation should cover a representative range of available equipment” (EASA, 2014).

A larger maintenance training organization should appoint a training manager with the responsibility of managing the training organization on a day-to-day basis. In addition, the organization should appoint a quality manager with the responsibility of managing the quality system and an examination manager with the responsibility of managing the relevant EASA Part-147 subpart C or Subpart D examination system (EASA, 2014).

“An appropriate selection of aircraft parts must be available to the subject module or sub-module of EASA Part-66 being instructed. For example, the turbine engine should require the provision of sufficient parts from different types of a turbine engine to show what such parts look like, what the critical areas are from a maintenance viewpoint and to enable disassembly/assembly exercises to be completed” (EASA, 2014).

An appropriate aircraft, engines, aircraft parts and avionics equipment must be selected to the subject module or sub-module of EASA Part-66 being instructed. For example, category B2 avionic training should require amongst other equipment, at least one type of installed autopilot and flight director system such that maintenance and system functioning can be observed and therefore more fully understood by the student in the working environment (EASA, 2014).

Each license category or subcategory basic training course may be subdivided into modules or sub-modules of knowledge and may be intermixed with the practical training elements subject to the required time elements of EASA PART 147.A.200 (f) and (g) being satisfied. If a holder of an aircraft maintenance license wishes to qualify for conversion for another category the following requirements must be met (EASA, 2014):

- Conversion from holding an EASA Part-66 aircraft maintenance licence in subcategory A1 to subcategory B1.1 or B2 should not be less than 1600 training hours;
- Conversion from holding an EASA Part-66 aircraft maintenance licence in subcategory A1 to subcategory B1.1 combined with B2 should not be less than 2200 training hours;
- Conversion from holding an EASA Part-66 aircraft maintenance licence in subcategory B1.1 to B2 or category B2 to B1.1 should not be less than 600 training hours;
- Conversion from holding an EASA Part-66 aircraft maintenance licence in subcategory B1.2 to subcategory B1.1 should not be less than 400 training hours;
- Conversion from holding an EASA Part-66 aircraft maintenance licence in one subcategory A to another subcategory A should not be less than 70 training hours.

Aeroplane type training may be sub-divided into airframe and/or powerplant and/or avionics/electrical systems type training courses. A maintenance training organization approved under EASA Part-147 may be approved to conduct airframe type training only, powerplant type training only, avionics/electrical systems type training only or any combination thereof (EASA, 2014).

Airframe type training course means a type training course including all relevant aircraft structure and electrical and mechanical systems excluding the powerplant (EASA, 2014).

Powerplant type training course means a type training course on the bare engine, including the build-up to a quick engine change unit (EASA, 2014).

“The interface of the engine/airframe systems should be addressed by either airframe or powerplant type training. In some cases, such as for general aviation, it may be more appropriate to cover the interface during the airframe course due to the large variety of aircraft that can have the same engine type installed” (EASA, 2014).

Avionics/electrical systems type training course means type training on avionics and electrical systems covered by but not necessarily limited to ATA ISPEC 2200 chapters (EASA, 2014).

The traditional approach mainly used for training lessons is the teacher lecturing the students. Commonly the training tools are a blackboard and training manuals. New technologies make it possible to develop new training methods and use other training tools, e.g., multimedia-based training and virtual reality. A combination of several training methods/tools is recommended to increase the overall effectiveness of the training (EASA, 2014). Where overall effectiveness can be thought of as the increase of knowledge retention from training, resulting in better approval rates.

The teacher, as described on Annex IV to ED Decision 2020/002/R Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Annex IV (Part-147) to Commission Regulation (EU) No 1321/2014 Issue 2 — Amendment 2, can select a variety of training tools ranging from the classical approach of a slideshow presentation, manuals, videos, mock-up, and real aircraft to the use of new emerging technologies like Augmented Reality and Virtual Reality. The combination of various tools is authorized and recommended.

However, simulation-based training cannot be eligible as a sole training assessment tool for basic hand skills such as wiring, welding, drilling, filling, wire locking, riveting, bonding, or any other skill where competence may only be achievable by performing a hands-on activity (EASA, 2020).
As far as training methods go, EASA states that the possible training methods to be used on basic training are as follows (EASA, 2020):

- Assisted learning (mentoring);
- Computer-based training (CBT);
- Demonstration;
- Distance learning asynchronous;
- Distance learning synchronous;
- e-learning;
- Lecturing (Instructor-led/face to face);
- Mobile learning (M-learning);
- Multimedia based training;
- Simulation;
- Web-based training (WBT).

The next paragraphs explain what consists of each of the training methods referred.

<u>Computer-based training</u> (CBT) (Figure 7) is any interactive means of structured training using a computer to deliver content (EASA, 2020). This training method can be implemented in one of the following options, that is, Instructor-centred[5], student-centred[6] or blended training[7].

[5] The instructor is responsible for the student learning progress.
[6] The student is responsible for the learning progress.
[7] Includes different instructional methods and tools, different delivery methods, different scheduling, or different levels of guidance.

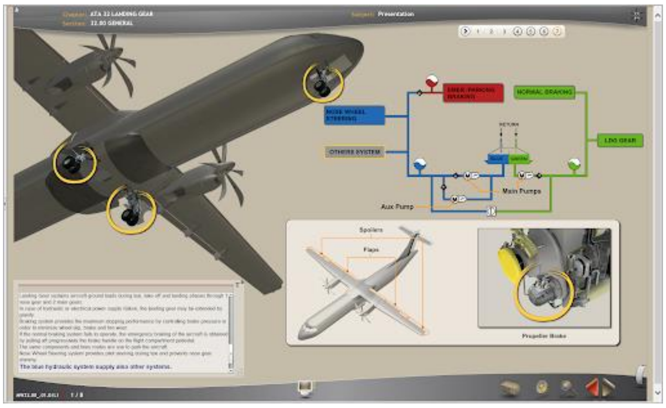

Figure 7 Computer Based Training example (ATR, 2020).

Assisted learning or mentorship represents an ongoing, close relationship of dialogue and learning between an instructor and a student to develop the experience/knowledge of students (EASA, 2020). This training method can either be Instructor-centred, student-centred, or Blended training.

Demonstration is a method of teaching by example rather than explanation (EASA, 2020). This training method can either be Instructor-centred or blended training.

Distance learning asynchronous is the type of training that reflects situations in which instructors and students are physically separated. It is synchronous if the teacher and students interact at the same time (real-time) (EASA, 2020). This training method can either be instructor-centred or blended training.

E-learning is training processed via a computer network or electronic means, with or without the support of instructors (EASA, 2020). This type of training can either be instructor-centred, student-centred, or blended training.

Lecturing (instructor-led/face to face) is a practice of delivery of training involving[8] an instructor and students, either individuals or groups (EASA, 2020). This type of training can either be instructor-centred or blended training.

Mobile learning is any sort of learning that happens when the student is not at a fixed, predetermined location, using mobile technologies (EASA, 2020). This type of training can either be instructor-centred or blended training.

Simulation is any type of training that normally uses technology to represent a real-world process or system (EASA, 2020). This type of training can either be instructor-centred, student-centred, or blended training.

Web-based training is a generic term for training delivered over the internet or an intranet using a web browser (EASA, 2020). This type of training can either be instructor-centred, student-centred, or blended training.

In summary, this subchapter addressed, in brief, the methodology regarding how it is possible to obtain an EASA Part-66 licence, their privileges depending on their licence category, how EASA Part-147 organizations need to be structured and a list of tools to be used as complementary training tools. The next subchapter addresses the state of art of the Virtual Reality technologies and its progressive introduction in the aviation industry.

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[8] The education process in general terms does not impose the existence of an instructor rather the availability of the subject to be learned and a student (note of the author).

3.2 VR technology

The term Virtual Reality (VR) has no established definition or meaning. So, it has been changing throughout the years as new VR technologies emerge and a better grasp of the capabilities of VR is obtained.

Virtual can be defined as “being in essence or effect, but not in fact” [9] and Reality as “the state or quality of being real. Something that exists independently of ideas concerning it. Something that constitutes a real or actual thing as distinguished from something merely apparent” [9] (Jerald, 2016).

In 2015, Virtual Reality was defined as “an artificial environment which is experienced through sensory stimuli (as sights and sounds) provided by a computer and in which one´s actions partially determine what happens in the environment”[10].

In 2020, Virtual Reality has been defined as “a set of images and sounds produced by a computer that seems to represent a real place or situation”[11].

There is a term often confused with VR (Figure 8), known as Augmented Reality (AR) (Figure 9). While Augmented Reality is characterized by the insertion of virtual objects in real-world environments, VR introduces the user to a simulated 3D environment allowing the user to experience the sound and images of the 3D scene while creating an illusion of reality (Mittal, 2020).

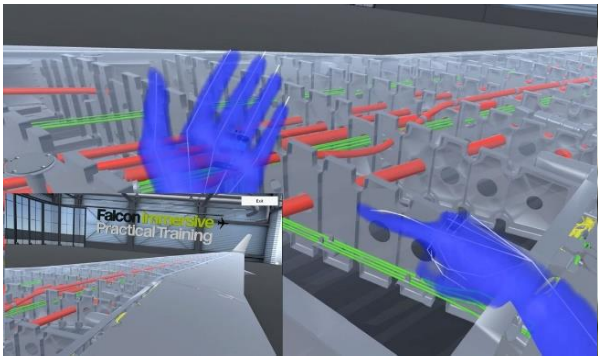


Figure 8 VR based Training (Dassault Falcon, 2017).

Figure 9 AR based training (Fade, 2019).

To create a VR application for the user, the professionals tasked with the development of the solution shall have in consideration five key development focus points, which in turn must be converted to functional requirements that the application shall comply with. Those key focus points are:

- Virtual world;
- Immersion;
- Feedback;
- Interactivity;
- User.

The next paragraphs address the relevant aspects associated with the five key development elements.

“The virtual world is a computer-simulated environment that may be populated by many users who can create a personal avatar and simultaneously and independently explore the virtual world, participate in its activities, and communicate with others” (Aichner, 2015).

[9] Definitions from Webster´s New Universal Unabridged Dictionary, 1989.
[10] Definition from Merriam-Webster.com, 2015.
[11] Definition from Cambridge dictionary, 2020.

Immersion in the psychology context refers to being completely involved in something while in action. In other words, it is a state in which a participant becomes attracted and involved in a virtual space of an activity to an extension that his or her mind is separated from the physical space he or she is being active in (Muhanna, 2015).

“Physical immersion, another type of immersion, can be experienced when the participant becomes physically involved in an experience. In a flight simulator, for example, the trainee must go inside a simulated cockpit to be able to interact with different objects to fly a virtual aeroplane” (Muhanna, 2015).

Mental immersion, on the other hand, corresponds to a different level of immersion in a virtual reality experience. Such experience can have a partial mental immersing or a complete one, although it is worthwhile noting that reaching a mental immersion in a virtual reality experience is still an active challenge to be reached effectively (Muhanna, 2015).

Feedback is a key factor in VR that_gives participants the ability to observe the results of their activities. The head, hands, the orientation of the torso, or other parts of the participant, are tracked to provide feedback in several forms, such as visual, haptic[12] and aural[13] feedback (Muhanna, 2015).

Interactivity in Virtual Reality gives the participant the ability to interact with and modify the virtual *world.* Interactivity is achieved through the use of sensors and other devices that allow users to dynamically interact with virtual objects through navigation, direct manipulation, and other forms of interaction. (Muhanna, 2015).

The User as with any other computer system is an essential element in any virtual reality experience. Every user needs to be studied to fulfil his/her needs. A new user to a VR system, for example, needs an easy-to-use experience. On the other hand, a user with previous experience needs an efficient system in terms of getting to his/her goals with the help of shortcuts and command aggregations (Muhanna, 2015). In the next subchapter, a brief history of VR systems is addressed.

3.2.1 History

In this state of the art on Virtual Reality, we look at how technology has evolved and how key pioneers have paved the path for virtual reality as we know it today (VRS, 2017).

1838 - Sir Charles Wheatstone was the first to describe stereopsis in 1838, a research that led him to construct the stereoscope. The research demonstrated that the brain combines two photographs of the same object taken from different points to make one image appear to have a sense of depth and immersion (3-Dimensional) (Barnard, 2019). Even though this is not considered Virtual Reality it laid out the foundations for future development on VR technology, more specifically on Head-Mounted Displays (HMD), see Figure 10.

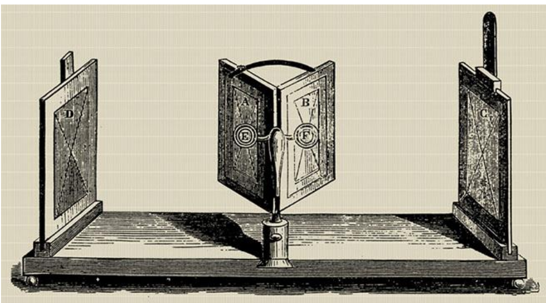


Figure 10 The Wheatstone mirror stereoscope (Dom Barnard, 2019).

[12] Haptic feedback is a form of feedback between the system and a user through touch and vibration.

[13] Aural feedback is a form of feedback between the system and a user through sound.

1956 - Cinematographer Morton Heilig created Sensorama, the first VR machine if taken into consideration the VR definition of 2015 previously referred. It combined multiple technologies to stimulate all the senses: there was a combined full-colour 3D video, audio, vibrations, smell, and atmospheric effects, such as wind. This was done using scent, a vibrating chair, stereo speakers, and a stereoscopic 3D screen (Barnard, 2019).

1960 - Heilig patented the Telesphere Mask which was the first Head-Mounted Display (HMD). This provided stereoscopic 3D images with wide vision and stereo sound. There was no motion tracking in the headset at this point (Barnard, 2019).

1961 - Headsight was created by Comeau and Bryan. Headsight was the first motion tracking HMD. It had built-in video screens for each eye and a head-tracking system (Barnard, 2019).

1966 - Thomas Furness, a military engineer, created the first flight simulator (Barnard, 2019).

1968 - Sutherland created the first virtual reality HMD, named “The Sword of Damocles”. This head-mount connected to a computer rather than a camera and was quite primitive as it could only show simple virtual wire-frame shapes (Barnard, 2019), see Figure 11.

Figure 11 The Sword of Damocles (Don Barnard, 2019).

1979 - McDonnell-Douglas Corporation integrated VR into its HMD, the VITAL helmet, for military use. A head tracker in the HMD followed the pilot´s eye movements to match computer-generated images (Barnard, 2019).

1982 – The Sayre Gloves were created by Sandin and Defanti. These gloves were the first wired gloves. They monitored hand movements by using light emitters and photocells in the fingers. This may have been the beginning of gesture recognition (Barnard, 2019).

1985 - Jaron Lanier and Thomas Zimmerman founded VPL Research, Inc. This company is known as the first company to sell VR goggles and gloves. They developed a range of VR equipment, such as, the DataGlove, EyePhone HMD and the Audio Sphere (Barnard, 2019), see Figure 12.

Figure 12 VPL Research VR equipment (Don Barnard, 2019).

1989 - Scott Foster founded Crystal River Engineering Inc. after receiving a contract from NASA to develop the audio element of the Virtual Environment Workstation Project (VIEW), a virtual training simulator for astronauts. Through this company, real-time binaural[14] 3D audio processing was developed (Barnard, 2019).

1997 - Georgia Tech and Emory University researchers used VR to create war zone scenarios for veterans receiving exposure therapy for PTSD. This was known as Virtual Vietnam (Barnard, 2019).

2012 - Luckey launched a Kickstarter campaign for the Oculus Rift which raised 2.4 million dollars (Barnard, 2019).

2015 - VR possibilities started to become widely available to the public, for example (Barnard, 2019):

- The Wall Street Journal launched a VR roller coaster that followed the ups and downs of the Nasdaq Stock Market;
- The BBC created a 360-degree video where users view a migrant camp;
- The Washington Post released a VR experience of the Oval Office;
- RYOT, a media company, exhibited Confinement, a short VR film about solitary confinement in US prisons.

2016 - By 2016 hundreds of companies were developing VR products. Most of the headsets had dynamic audio and haptic interfaces were underdeveloped. HTC released its HTC VIVE SteamVR headset. This was the first commercial release of a headset with sensor-based tracking which allowed users to move freely in space (Barnard, 2019), see Figure 13.

Figure 13 HTC VIVE SteamVR (HTC, 2016).

2018 - Oculus released a new headset prototype, the Half Dome. This is a varifocal headset with a 140 degrees field of vision. (Barnard, 2019).

3.2.2 Taxonomy of current VR hardware

When providing a taxonomy of the current VR hardware developments, the following input/output devices to be approached often exist only in a prototype state. Most of them are not yet commercially available and may never be (Anthes, 2017).

The traditional approach of separating VR hardware into the two main categories of input and output devices is taken. In most cases, the addressed devices can be hybrid devices as for example an HMD which provides both input and output data (Anthes, 2017).

3.2.2.1 Output devices

The main category in the current output devices technology are the visual displays, followed by haptic and multi-sensory devices (Anthes, 2017) , see Figure 14.

[14] 3D stereo sound.

Mobile HMDs have the property of being wireless and are used without an additional PC. In most cases, the application areas lie in entertainment – displaying 360º movies or panoramas rendered from a stationary point of view or interactive walkthroughs based on gaze (Fuhrmann, 1998).

Wired HMDs have the feature list of the wired HMDs and differentiation is beyond the traditional quality factors like resolution, Field of View (FOV) or weight. Some are equipped with cameras to allow for AR applications and can be used as video see-through displays, while others include eye-tracking (Anthes, 2017).

Haptic devices cross different areas. Several approaches exist in form of vests including vibrating elements, while others are hybrid since they are implemented as a controller. All these approaches are either body-worn or carried (Anthes, 2017).

Multi-Sensory Devices are additional displays stimulating other senses, which generate tactile or olfactory feedback. The suggested olfactory displays for the consumer market are body-worn, either as an add-on to upcoming HMD solutions, or combined with the display component of the HMD (Nakaizumi, 2006).

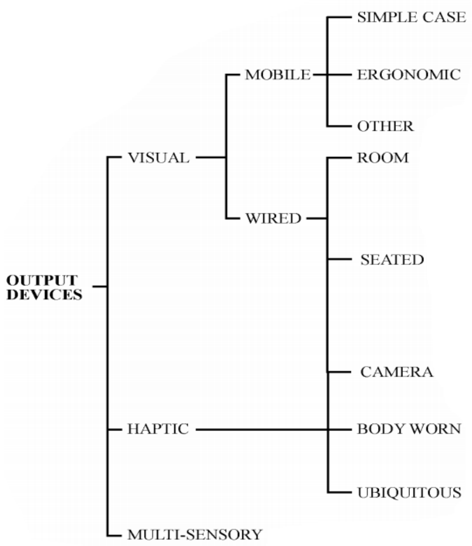


Figure 14 Output devices taxonomy (Anthes, 2017).

3.2.2.2 Input devices

In the category of input devices, three different subcategories focused on input provision for HMD users can be identified. This category is constituted by navigation devices, controller input devices and hand or full-body tracking devices (Anthes, 2017), see Figure 15.

Controllers for HMDs are handheld and provide discrete input in the form of buttons and continuous input by top-mounted joysticks or touchpads with an additional 6 DOF[15] (Degree of Freedom) tracking information. They are wired or wireless (Anthes, 2017).

Navigation Devices are used to give the user the illusion of moving through endless spaces and act as an input source for travelling through the virtual environment. While traditional treadmills allow motion in one direction (Forward/Backwards), the current developments in VR support motion on a two-dimensional plane (Backwards/Forward or/and Left/Right), by using an omnidirectional Treadmill (ODTs). (Anthes, 2017)

[15] The 6 degrees of freedom are: Roll, Pitch, Yaw, Surge, Sway and Heave.

Body Tracking is the posture estimation focus on the actual posture of the user´s full body or only upper body. The posture estimation in consumer VR can become a critical feature to provide a reasonable self-representation required in HMDs (Badler, 1993).

Gesture Tracking devices are multiple and range from data gloves, with strain gauges or fibre optics, which are equipped over the hands, like a glove, over fully contact-free technologies using optical tracking with Electromyography (EMG) measurement technology (Anthes, 2017).

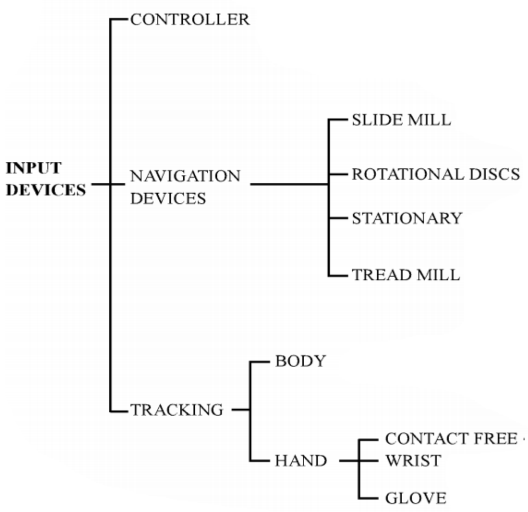


Figure 15 Input devices taxonomy (Anthes, 2017).

3.2.3 Current VR hardware

This subchapter addresses currently available VR headsets on the market. Before discussing the HMD currently available, some technical definitions are given to provide a better understanding of HMDs hardware specifications.

Field of view (FOV) is the amount of an environment that is visible for an observer. In VR used to play games, it is the extent of the game world that is visible in the displays. A broader FOV in an integral headset provides a feeling of immersion (Wickens, 2020).

Inside-out tracking is the system used to track a user movement in VR that originate in the headset, as opposed to outside-in tracking, where external sensors are used to track movement. Tracking, and the method used, is crucial to enable either 3 degrees of freedom or 6 degrees of freedom (Wickens, 2020).

“Latency is the delay between an input and a response, in VR, the delay between user input through a controller, moving your head, or other methods, and the response on the headset displays. Low latency is vital to reducing nausea in VR, which is most intense when there is a delay or stuttering between moving or looking and the display reacting” (Wickens, 2020).

“Resolution is the measurement in pixels, horizontal and vertical, of an image or display. Higher resolution in VR is essential because the displays are so close to the user eyes, which emphasizes jagged lines, and the screen door effect” (Wickens, 2020).

Refresh rate is the number of images a display can display per second, measured in hertz. The high refresh rate is essential for VR similarity to latency, as a low refresh rate can cause stuttering (or even the appearance of freezing), which can cause nausea (Wickens, 2020).

The screen door effect (SDE) is the fine mesh-like effect of viewing an image rendered in pixels at close range, where the grid between pixels is visible. Higher resolutions mitigate this effect (Wickens, 2020).

The first hardware to be approached is the Oculus Quest (Figure 16), a wireless HMD, with a built-in sensor to translate user movements in VR and provide room-scale tracking. The oculus touch controllers provide hand position and gestures in the VR world. Some games support controller-free features by hand-tracking (Oculus, 2020).

The Oculus Quest main specifications are as follows (Oculus, 2020):

- **Display:** OLED;
- **Resolution:** 2880x1600;
- **Refresh Rate:** 72 Hz;
- **FOV:** 100 degrees;
- **Controller:** Oculus Touch;
- **Connections:** Standalone (USB-C to charge, 3.5mm jack for 3rd party headphones).

Figure 16 Oculus Quest headset and controllers (Oculus, 2020).

The second product discussed is the PlayStation VR (Figure 17), which possesses a six-axis motion sensing system (6 DOF) and built-in stereo headphones. The main specifications are as follows (Playstation, 2020):

- **Display:** OLED;
- **Resolution:** 1920 x1080;
- **Refresh Rate:** 90 Hz;
- **FOV:** 100 degrees;
- **Controller:** PlayStation Move;
- **Connections:** HDMI, USB 3.0, AUX port.

Figure 17 PlaystationVR (Playstation, 2020).

The third HMD addressed is the HTC Vive Pro (Figure 18), released in 2018, which uses room-scale tracking technology, allowing the user to move in 3D space and use motion-tracked handheld controllers to interact with the environment (Savov, 2015).

The main specifications are as follows (Developers, 2020):

- **Display:** Dual AMOLED ;
- **Resolution:** 2880 x 1600;
- **Refresh Rate:** 90 Hz;
- **FOV:** 110 degrees;
- **Controller:** Vive Controllers;
- **Connections:** USB-C 3.0, DP 1.2, Bluetooth.

Figure 18 HTC Vive Pro (Developers, 2020).

3.2.4 Adverse VR health effects

This subchapter focuses on the adverse health effects of VR and its causes. An adverse health effect is any problem caused by a VR system or application that disturbs user well-being, inducing various problems such as nausea, eye strain, headache, vertigo, and physical injury (Jerald, 2016).

The causes associated with the said problems include perceived self-motion through the environment, incorrect calibration, latency, physical hazards. The VR users in response to these situations might adapt their behaviour to avoid becoming sick, resulting in incorrect training for real-world tasks (Jerald, 2016).

Motion sickness "refers to adverse symptoms and visible signs that are associated with exposure to real and/or apparent motion". Motion sickness resulting from apparent motion (also known as cybersickness) is the most common negative health effect resulting from VR usage (Jerald, 2016).

Non-moving visual stimuli can also cause discomfort and adverse health effects. Known problems include accommodation-vergence conflict, binocular-occlusion conflict, and flicker. After-effects are also discussed, which can indirectly result from scene motion as well as non-moving visual stimuli (Jerald, 2016).

The HMD accommodation-vergence conflict occurs due to the conflict between accommodation[16] and vergence[17] not being consistent with what occurs in the real world. Overriding the physiologically coupled oculomotor process of vergence and accommodation can result in eye fatigue and discomfort (Jerald, 2016).

Binocular-occlusion conflict occurs when occlusion cues do not match binocular cues, for example, when text is visible but appears at a distance behind a closer opaque object. Many desktop first-person shooter games contain a 2D overlay display to provide information to users. If such games are ported to VR, then such

[16] Is the process of focusing on a virtual image as distance changes.
[17] Is the simultaneous movement of both eyes in opposite directions to obtain or maintain binocular vision.

information must be deleted or given an appropriate depth so that information is occluded properly when behind scene geometry (Jerald, 2016).

Flicker (Figure 19) is the flashing or repetition of alternating visual intensities. Retinal receptors respond to flickering light at up to several hundred cycles per second, although sensitivity in the visual cortex is much less. Perception of flicker covers a wide range depending on many factors including dark adaptation, light intensity, retinal location, stimulus size, blanking time between stimuli, among others (Jerald, 2016). Not all VR HMD on the market are currently Flicker-free.

Figure 19 Flickering effects on a computer screen (BenQ APAC, 2013).

VR after effect of VR usage is any adverse effect that occurs after VR usage but was not present during the gameplay. Such aftereffects include perceptual instability of the world, disorientations, and flashbacks (Jerald, 2016).

Nowadays, it is not possible to eliminate all the negative effects of VR for all users, but by understanding the problems and why they occur, newly developed VR systems and application can minimize their severity and duration (Jerald, 2016).

3.3 VR on the aviation industry

"In recent years, the aviation industry has been taking a hard look at how new emerging technologies like Virtual Reality can complement and improve the training experience of professionals entering the aviation industry. VR gives personnel a safe environment to hone their skills, letting them run through scenarios multiple times until the process is familiar" (Lozé, 2019). As such there are 4 key areas where VR knowledge can be applied to improve aviation safety.

Figure 20 Forecasted demand of new personnel (Boeing, 2020).

3.3.1 Pilot training[18]

Air traffic demand and operator flight hours have declined significantly over the past year, resulting in large numbers of pilot furloughs and layoffs. Given the current oversupply of pilots, labour shortages may seem a distant memory. However, as the industry positions itself for recovery, sufficient pilot supply remains an

[18] The referred projected growth on the different areas of the aviation industry was performed on October of 2020, as such the impact of the COVID-19 outbreak is taken in consideration.

important consideration as a large contingent of the workforce approaches the mandatory retirement age (Boeing, 2020).

“An advantage of today's data-rich environment is the ability to assess knowledge gaps as they occur, enabling new training solutions to produce pilots. With the availability of historical data, evidence and competency-based training programmes are increasingly being adopted to change how pilots are trained and assessed” (Boeing, 2020).

“The goal is to ensure pilots are effectively trained on procedures to address today's most common operational risks and assessed based on key skills and competencies that all pilots should possess” (Boeing, 2020).

To attend to the forecasted need for new pilots in the next 20 years (Figure 20), new ways to make flight training more efficient, more flexible, and more attractive must be developed. Virtual Reality (VR) stood out as the most appropriate technology to meet all these objectives (Airbus, 2019).

Airbus’s VR new flight training solution focused on the A320 aeroplane aims to provide a portable training solution with a ‘study & practice tool’ for pilots to be able to train remotely or to be used as a complement of the full flight simulator training sessions (Airbus, 2019) see Figure 21.

The virtual package consists of a PC, a VR headset, and a pair of hand controllers. The software will run on off-the-shelf[19] equipment, including the VR hardware. Airbus claims the new flight simulator will be used in airbus training centres to make it an integral part of the Airbus type rating curriculum (Airbus, 2019).

Figure 21 Airbus new flight simulator resorting to VR technology (Airbus, 2019).

3.3.2 Ground crew training

Before a plane takes off, the pilots and ground crew need to perform a pre-flight check, to spot any malfunction. On-the-job is the most efficient way to train crews for these roles. As mentioned, On-the-Job-Training is often impractical because of the lack of access to working aircraft (Leon, 2020).

According to Boeing’s data (“Statistical Summary of Commercial Jet Airplane Accidents Worldwide Operations 1959-2017”), over 15% of the total number of deadly accidents from 1959 to 2017, account for ground handling operations. If taking into consideration only data from 2016, EASA reported 10,697 incidents and 7 accidents linked to ground handling operations. As such ground handling safety must be improved (AVIAR, 2020).

“The International Air Transport Association (IATA) is a provider for the aviation industry and an advocate for the use of immersive technology in operational training. Determined to improve ground handling operations safety, IATA has been working on a VR training system for airline ground crew since 2016” (Leon, 2020).

[19] Software or hardware that exists in the market meaning that there was no need to design and develop specific items thus avoiding additional costs (note of the author).

RampVR is a simulation where trainees can undertake immersive training scenarios, practising on a range of different aircraft type, in various weather conditions, learning key aspects of ground control, such as marshalling and turnaround inspections (Leon, 2020) see Figure 22.

Figure 22 IATA RampVR Training (IATA, 2019).

3.3.3 Aircraft maintenance[18]

"As the new generation of aeroplanes become more prominent in the global fleet, advances in aeroplane technology will drive demand for a new set of skills, such as digital troubleshooting and composites repair. Concurrently, operators and MROs will be challenged to ensure technicians continue to maintain the skills and capability necessary to service the large fleet of older generation aeroplanes. These two skills set often differ, creating opportunities for the industry to enhance its standard training curriculum" (Boeing, 2020).

"Mobile and distance learning solutions are supplementing traditional classroom instruction and allow students to continue their studies outside of traditional instructor-led classes. New technologies, such as Virtual Reality solutions, are also being tested to improve student engagement, quality of instruction, and knowledge retention" (Boeing, 2020).

Competency-based maintenance training continues to evolve as the industry focuses on addressing individual student needs and knowledge gaps (Boeing, 2020). The forecasted need for new technicians to be trained is shown in Figure 20.

A USA-based VR/AR company, Inlusion, collaborated with aviation service companies Baltic Ground Services and FL Technics to develop new virtual reality training experiences on aircraft repair and maintenance (Lozé, 2019).

The result of Inlusion's collaboration with FL Technics is a VR training system for the Boeing 737, where maintenance technicians can practice, for example, thrust reverser opening actions using procedures from a self-created checklist based on the Boeing 737 maintenance manual (Lozé, 2019) - see Figure 23.

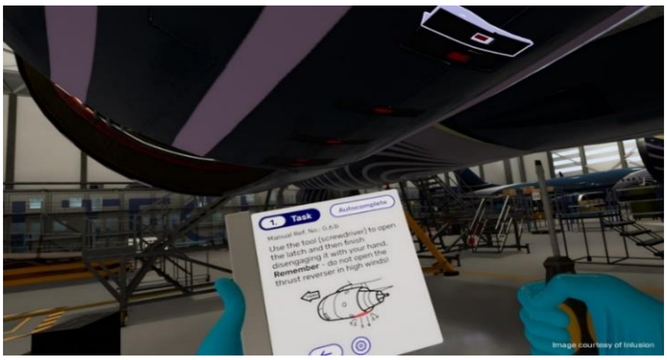


Figure 23 Thrust reverser opening procedures (Inlusion, 2020).

3.3.4 Cabin crew training[18]

“Cabin crew are essential to ensure the safety and comfort of passengers. As airlines continue to refine business models and personalize offerings to specific market segments, additional demand for cabin crew will result from aircraft up-gauging[20], denser seat configurations, and multiple cabin configurations. Regulatory requirements and customer preferences will continue to drive demand across the industry” (Boeing, 2020).

“Training continues to focus on providing superior customer service and ensuring cabin crew have the skills to recognize and mitigate safety risks. Advances in scenario-based training and mobile learning technologies support continuous learning and prepare cabin crew for situations that may occur in the cabin” (Boeing, 2020). The forecasted need for new cabin crew professionals is shown in Figure 20.

Avietra, a start-up company of the Human-Computer Interaction Laboratory of the University of Udine, created a VR based training programme for cabin crew professionals, offering multiple training scenarios, like pre-flight preparations, pre-boarding checks, boarding process, aeroplane door training, evacuation training, among others, as shown on Figure 24.

Figure 24 Aeroplane slide operation (Avietra, 2020).

In summary, this chapter started by providing an overview on how current AMTs are trained and certified and the role part-147 organizations have on said development by exposing used training methods. Then the VR development through history and currently available hardware along with the unwanted adverse health effects originating from the use of the equipment is given. Lastly, already developed VR training solutions currently on an operational environment through diverse professional areas of the aviation industry are described. The next chapter presents aeroplane system and servicing procedures relevant to the sake of this dissertation.

[20] Replacement or modification of an aeroplane to increase passenger capacity.

Chapter 4 - A-29B Super Tucano servicing procedures

The A-29B is a turboprop single-engine, low-wing, all-metal, pressurized aircraft designed in the two-seater version to perform training and operational missions. The aircraft is powered by a Pratt & Whitney PT6A68C engine with a Hartzell propeller (Embraer, 2010).

The primary flight controls are of the conventional type, mechanically actuated, and assisted by electrically controlled and mechanically actuated trim tabs. The fuselage is a semi-monocoque single unit built primarily of aluminium alloy (Embraer, 2010).

The average estimated aircraft empty weight with engine oil, hydraulic fluid, and unusable fuel and without pylons and machine guns is 3210 kg (Embraer, 2010).

The aircraft dimensions are (Embraer, 2010):

- Length: 11.3m;
- Wingspan: 11.1m;
- Tail span: 4.6m;
- Vertical stabilizer height: 3.9m.

4.1 Fuel system

The aircraft is fitted with wing internal tanks and the total fuel can be increased by up to three external tanks on the inboard and ventral pylons. The internal tanks are refuelled through a single-point refuelling receptacle for pressure refuelling procedures or through individual gravity refuelling points for gravity Refuelling/Defueling procedures, and each external tank can be refuelled through a gravity refuelling point. (Embraer, 2010).

The internal tanks are installed with a main pump and an auxiliary pump. The auxiliary pumps are powered with a 28 V DC from the EMERGENCY DC BUS and the main pumps are powered with 28 V DC from the MAIN DC BUS. (Embraer, 2010). These pumps are responsible for the supply of fuel for the propulsion systems and the transfer of fuel between tanks in the event of an unexpected failure.

4.1.1 Fuel storage

Storage is a subsystem responsible to provide a constant flow of fuel to the aircraft engine in a sealed distribution and must be able to withstand, without critical failure, the structural loads to which it may be placed under a flight operation.

The storage includes these subsystems (Embraer, 2010):

- Wing fuel tanks;
- Wing fuel tank vent;
- External fuel tanks;
- External fuel tank vent.

The fuel is stored in two integral tank assemblies, one on each wing. Each tank assembly is composed of an inboard cell, which incorporates a collector box and an outboard cell. These cells are interconnected with each other to work as a single tank (Embraer, 2010), see Figure 25.

The total fuel capacity for the two integral tank assemblies is 648L, including 18L which are unused (Embraer, 2010). As previously stated, the aircraft can be fitted, if needed, with three extra external fuel tanks, two assembled under each wing at the inboard pylons and the third on the ventral pylon, totalling the maximum fuel capacity to 1576L.

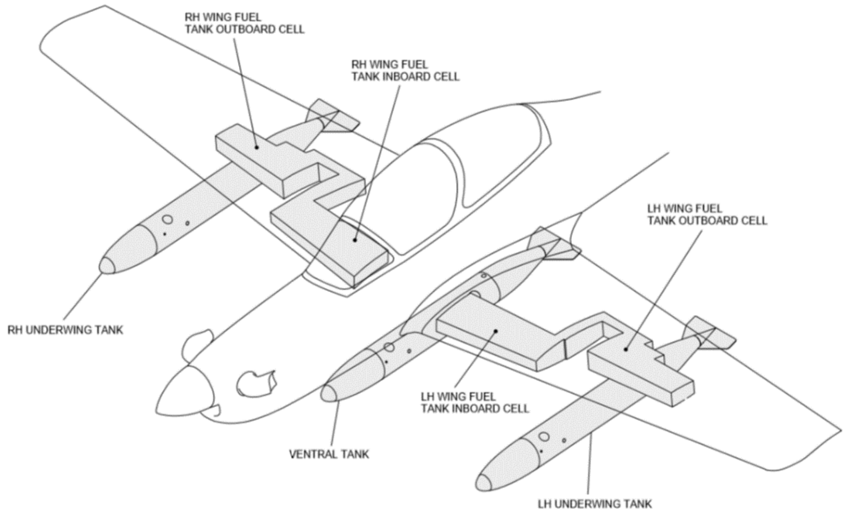


Figure 25 Fuel storage (Embraer, 2019).

4.1.2 Wing fuel tank

The fuel tank is an integral-type tank assembly. The assembly is composed of two cells, one inboard and the other outboard. The cells are interconnected through a port located at the wing rear portion and through a tube located at the machine-gun region to work as a single tank (Embraer, 2010).

The wing fuel tanks main components are as follows (Figure 26):

- Dump valve;
- Drain valves;
- Access panel;
- Gravity filler cap;
- Pressure refuelling/defuelling adapter;
- Check valve (Flapper-Type);
- Collector Box.

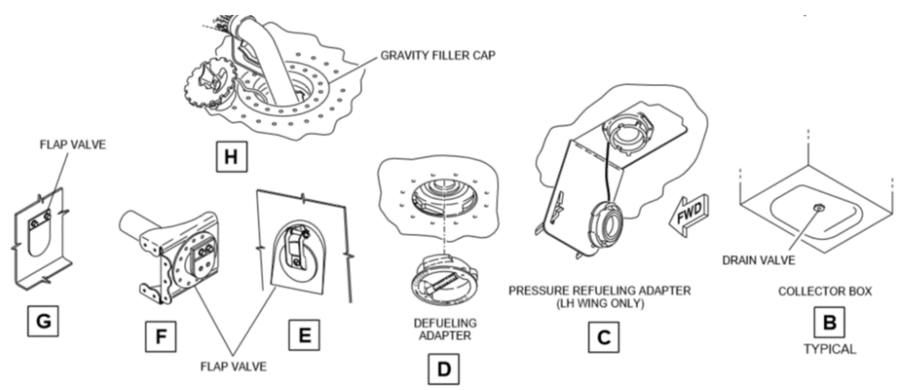


Figure 26 Wing tank main components (Embraer, 2019).

4.1.3 Fuel distribution system

The aircraft fuel distribution system permits the crew to do some operations such as: engine fuel supply and fuel transfer. The pressure refuelling, pressure defuelling, and fuel transfer operations on the ground are performed by the maintenance personnel (Embraer, 2010).

The distribution system includes these subsystems (Embraer, 2010):

- Engine feed system;
- Pressure refuelling/defuelling system;
- Fuel transfer system;
- Maintenance panel;

The distribution subsystem includes these fuel lines: engine feed line, pressure refuelling/defuelling line, transfer line, flow return line and motive flow line. The motive flow line comes from a high-pressure source and receives the fuel flow to permit the ejector pump operation in the wing tanks (Embraer, 2010), as shown in Figure 27.

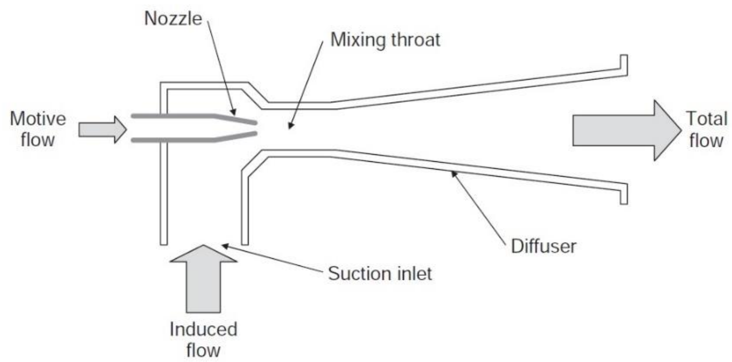


Figure 27 Principle of the ejector pumps (Langton, 2009).

There are two lines connected to the pressure refuelling adapter. One line connects the adapter to the tank interior, passing through the pressure refuelling shutoff valve. The other line connects the adapter to the two vents valves of the wing fuel tanks (Embraer, 2010).

4.1.4 Pressure refuelling/defuelling system

The pressure refuelling and defueling are made through one single adapter, installed on the LH (left-hand) underwing next to the wing root. The pressure refuelling and defuelling are available only to the wing fuel tanks. The external tanks cannot be pressure refuelled and/or pressure defuelled (Embraer, 2010) The full schematic of the referred system can be seen in Figure 28.

The pressure refuelling system is designed to supply fuel flow to the wing fuel tanks to a maximum pressure of 50 psi, applied to the refuelling single adapter. The refuelling operation is performed through the adapter and controlled through the refuelling panel, installed in compartments with access doors. The panel is equipped with switches and indicator lights to control the pressure refuelling (Embraer, 2010).

A shutoff valve automatically stops the refuelling process when the fuel maximum quantity in each wing tank is reached. It is done through a high-level sensor, installed at the upper portion of each wing fuel tank, which sends a signal when the fuel quantity reaches a high level (Embraer, 2010).

The refuelling system is started when the fuelling switch, located on the refuelling panel, is set to the “ON” position. There are restrictors installed in the refuelling lines and in the main fuel line to do the balance of the flow and permit the fuel maximum flow in the wing tanks (Embraer, 2010).

The pressure defueling is performed through an electric pump of the tank to be defuelled. The pressure defueling is performed by the pump or by suction using defuelling equipment. A pressure defueling valve, electrically activated through the maintenance panel, is installed to permit communication, when open, between the pressure refuelling line and the engine feed line (Embraer, 2010).

The pressure defueling valve is controlled through the three-position (XFER/ON/OFF) defueling switch of the maintenance panel, located in the aircraft LH electronic compartment. The defueling switch has a safety guard for preventing inadvertent operation of the defueling valve (Embraer, 2010).

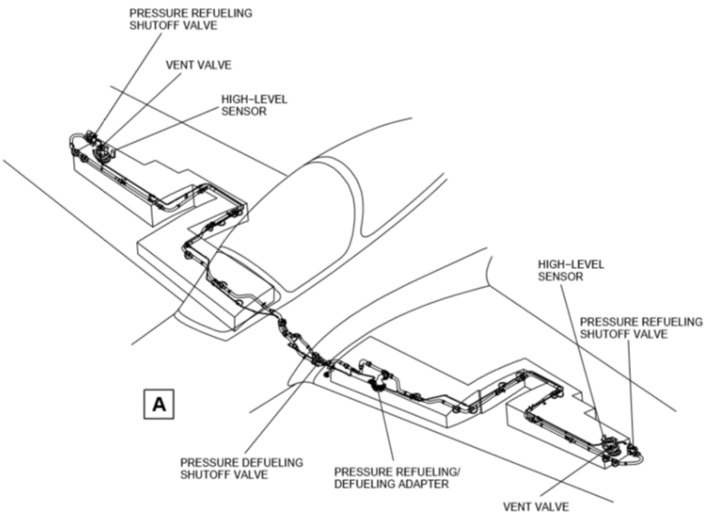


Figure 28 Pressure refueling/defueling system (Embraer, 2010).

4.1.5 Fuel transfer system

The aircraft is equipped with a fuel transfer system used to transport fuel from each external tank to the wing tanks. During the fuel transfer, the air flow is driven from the wing tanks to the atmosphere by the pressure relief valve to keep the pressure in the tanks within proper limits (Embraer, 2010).

The external tank selection for the fuel tank transfer is made through the three-position “OFF”, “VNTRL/AUTO”,” U/WING” fuel transfer switch, located on the fuel panel (Embraer, 2010).

With the three external tanks installed, the transfer sequence in the automatic mode is initiated in the ventral tank. When the fuel in the ventral tank runs out, the fuel from the underwing tank starts to be transferred to the wings (Embraer, 2010). The operation is automatically stopped when a high level is reached on the wing tanks or when the fuel on the ventral and underwing tanks runs out of fuel.

The transfer in the manual mode is performed by selecting the desired tank on the XFR selector switch and commanding the transfer through the pump manual activation button (OVRD), combined with the indicator lights installed on the fuel panel (Embraer, 2010).

The fuel transfer system has the following components (Embraer, 2010):

- **Fuel pump**: centrifugal-type electric pump is installed in the rear portion of each external tank, responsible for pumping the fuel from the external tanks to the wing’s tanks (Embraer, 2010).

- **Fuel pressure switch**: installed at the transfer line of each external tank. Supplies a signal to activate the transfer light, on the fuel panel (Embraer, 2010).
- **Check valve**: five check valves installed at the lines that transfer fuel from the external tanks to the wing tanks. The purpose of these valves is to prevent the return of the fuel flow (Embraer, 2010).
- **High-level sensor**: installed at the wing tank, this system is used to interrupt the transfer of fuel from the external tanks to the wing tanks (Embraer, 2010).

4.1.6 Controls and indicators

The fuel system control panel, located in the front cockpit main instrument panel, comprises two knobs, one toggle switch, one push-button and associated indicator lights. The main fuel pumps are controlled through the main pumps knob, whereas the auxiliary pumps are controlled through the aux pumps knob (Embraer, 2010), see Figure 29.

The XFR (transfer) toggle switch controls the transfer fuel pump from the external tanks. If the automatic mode fails, an OVRD pushbutton allows the pilot to control the external tank fuel transfer manually (Embraer, 2010) If the indicator light is green, it represents the fuel pumps are operating as expected, see Figure 29.

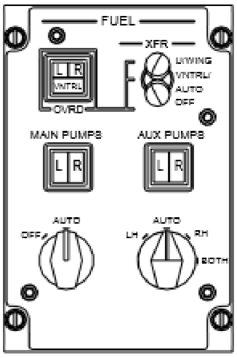


Figure 29 A29B Fuel controls (Embraer, 2010).

Two float-type quantity sensors, connected in series, are installed in each wing fuel tank. These sensors send a signal informing the fuel quantity. The fuel quantity indication is displayed on the EICAS format on the digital L (left-wing) and R (right-wing) indicators and their sum is represented by the inner analogue arc and the digital field in the centre of the arc (Embraer, 2010), see Figure 30.

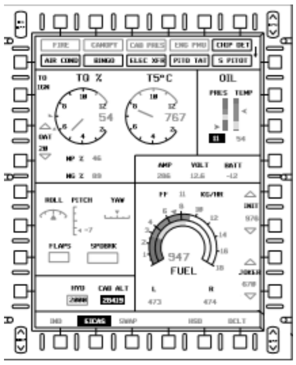


Figure 30 A29B CFMD for fuel levels (Embraer, 2010).

The mechanical indicating system allows the operator to verify, on the ground, the fuel quantity in the wing fuel tanks in case of fuel-quantity electrical indicating system failure. The fuel-quantity mechanical indicator consists of a graduated scale used in the measurement point located at each underwing (Embraer, 2010).

4.2 ISPEC 2200 ATA Standard Numbering System - classification and servicing

ATA Chapters, also known as the ATA 100 System Codes, are part of the standard ISPEC 2200 (published by Airlines for America formerly known as Air Transport Association) that succeeded the ATA 100 standard that ceased in 2000),[21] refers to the categorization of systems of an aircraft.

This type of system numbering can be found in any Component Maintenance Manual for any civilian aircraft (for military aircraft the similar approach is provided by MIL-STD-1808C from the Department of Defence of the Unites States of America) (Aerospace, 2020).

Embraer uses on its maintenance manuals, a numbering standard like the ISPEC 2200 standards with the ex-ATA 100 as the foundation. As such, the numbering system as it comes on the Embraer maintenance manual will be adopted as the numbering standard throughout the dissertation and will be designated hereinafter as Embraer chapter XX-XX. For this dissertation, Embraer chapter 12-12 regarding fuel servicing applies.

4.2.1 Embraer chapter 20 - Standard practices

Before any servicing action takes place on the aeroplane, procedures described under the Embraer chapter 20 must be followed to prevent accidents during aeroplane maintenance, such as confirming that there is no armament installed on the aeroplane or the area around the aeroplane is free from residues, grease, oil, and fuel (Embraer, 2010).

After the aeroplane is considered safe for maintenance, grounding procedures must be performed to prevent any fire that can originate from a spark, thus ensuring a safe refuelling procedure.

Safe refuelling operations require strict adherence to procedures and careful application of the safety precautions, not only by the refuelling operators but also flight crew, the cabin crew, and the other ground operators. In addition to the availability of the firefighting equipment and use of personal protection by the fuelling operator, bonding to earth the aircraft and respecting the fuelling safety zone is essential (Airbus, 2020).

Bonding ensures electrical continuity between the aircraft and the refuelling vehicle, preventing any spark to appear when the ground operator connects the refuelling hose to the aircraft coupling. It is mandatory to bond the aircraft to the refuelling vehicle/device before connecting the refuelling hose (Airbus, 2020)

4.2.2 Embraer chapter 24 - Electrical system

As previously discussed, the Super Tucano can be pressurized refuelled/defuelled while resorting to an external power source, as such a list of procedures must be followed to correctly power the aeroplane. Embraer chapter 24 describes the procedures to be followed.

4.2.3 Embraer chapter 12-14 - Landing gear

The landing gear is one of the critical systems of an aeroplane. They are designed to support their weight during ground operations and withstand the structural loads the aeroplane is placed under in landings and take-off operations. As such scheduled inspections, servicing and maintenance are performed to ensure compliance with the regulations and thus airworthiness of the aircraft (and/or system) will be ensured.

The Embraer chapter 12-14 identifies the tasks that are part of the servicing to be performed (in general terms) on a landing gear. Lubrication is critical as the landing gear is composed of multiple moving parts under constant

[21] For the sake of simplicity, the aircraft systems numbering is called hereinafter as ATA XXX instead of ISPEC 2200 ATA XX.

friction, so a proper lubrication action can extend a landing gear life cycle and prevent irreversible damages (Embraer, 2010).

Another component of the landing gear that must be serviced is the landing gear shock absorber, responsible to dampen the loads the landing gear and aeroplane are placed under during landing operations. The Embraer chapter 12-14 lists the procedures to be complied with to perform the servicing on a landing gear shock absorber.

Lastly, under the Embraer chapter 12-14, a tire pressure check must be performed to check if the tire inflation is under the specified setting. As shown in Figure 31.

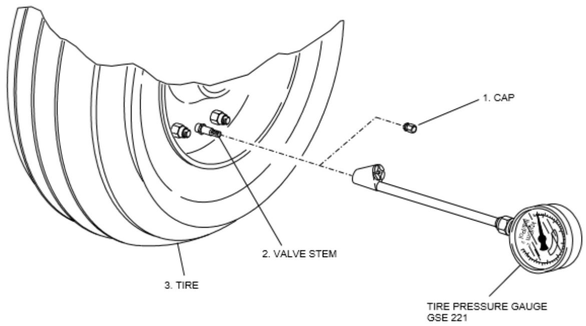


Figure 31 Tire inflation check (Embraer, 2010).

4.2.4 Embraer chapter 12-15 - Oxygen

Oxygen, the life-sustaining gas we need to survive. It makes up around 21% of the air in the atmosphere. Although this amount is sufficient at or near sea level, at higher altitudes we require supplemental oxygen due to the decreased density of air. At 3000 m or higher, above sea level, in a non-pressurized aeroplane, pilots require it to avoid hypoxia (Escobar, 2001), a situation that will cause pilots to lose conscience. With the increase of the cruising altitude and factors like whether a normal ascent or rapid decompression occurred, the pilot Time of Useful Consciousness, TUC, diminishes.

The aircraft is equipped with an emergency oxygen system composed of a high-pressure cylinder installed on the ejection seat, which can be used in case of an ejection, OBOGS (On-Board Oxygen Generating System) failure, or in an emergency that requires its use (Embraer, 2010).

When the emergency oxygen system gets used or depleted, a system recharge must be performed. The Embraer chapter 12-15 specifies the rules to be followed to perform an emergency oxygen system recharge.

4.2.5 Embraer chapter 12-16 - engine oil

Engine oil operates within an engine, where main goals include reducing friction, cooling, sealing, cleaning, and serving as protection for moving parts (Zuehlke, 2004). Oil must be changed as it starts to get contaminated by combustion produced chemicals such as Dihydrogen monoxide, which is a highly corrosive chemical capable of damaging engine components. Some aircraft have on their engine a Sight Glass, like the Super Tucano, to be used as a tool to check if oil servicing is needed - see Figure 32.

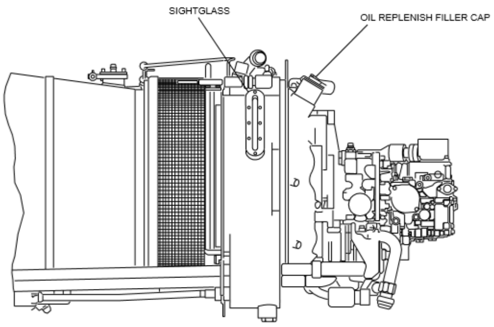


Figure 32 Engine oil – replenishment (Embraer, 2010).

4.2.6 Embraer chapter 12-21 - Flap flexible driveshaft

The amount of lift generated by a wing depends on the shape of the air foil, the wing area, and the aircraft velocity. During take-off and landing, the aeroplane's velocity is low when in comparison with cruise speeds. To keep the lift high, aeroplane designers increase the wing area and change the air foil shape by putting some moving parts on the wings leading and trailing edges (NASA, 2018) These moving parts are called flaps and slats.

The main purpose of the flexible driveshaft is to drive the flap linear actuators that enable flap and slats retraction or extension. Since it is a moving aircraft component under friction, the flap flexible driveshaft must be lubricated (Embraer, 2010) – see Figure 33.

Lastly, if damage is detected on the flap linear actuator, Embraer chapter 12-21 must be followed to proceed to the flap linear actuator restoration.

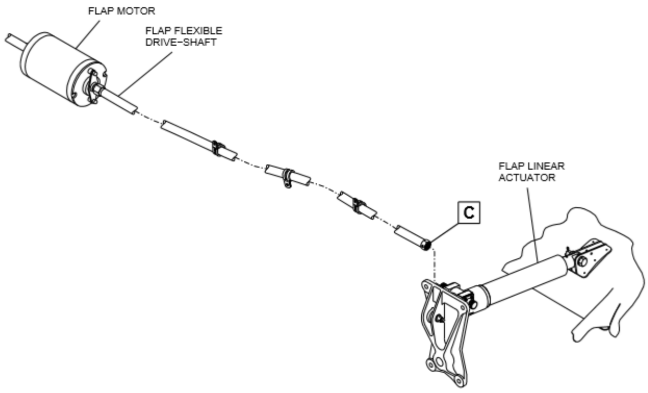


Figure 33 Flap extension/retraction system (Embraer, 2010).

4.2.7 Embraer chapter 12-22 - Aircraft cleaning

During every flight, an aircraft accumulates dust and grime on its external surface. In addition to making the aircraft look dirty and less appealing, the dirt that accumulates on the aircraft surface impacts the fuel it consumes by making it less aerodynamic (Blaukaiser, 2021).

In recent years, several chemical companies have been developing an effective alternative to wet washing, and so the term dry washing/cleaning was born. The product is made up of safe surfactants that ensure the aircraft surface is sufficiently wet and that the cleaner is not repelled into small droplets on surfaces to be cleaned (Wright, 2005).

4.2.8 Embraer chapter 12-12 - Fuel servicing

As previously stated, the internal fuel tanks can be refuelled either under pressure or by gravity, whereas the external fuel tanks can be refuelled only by gravity. The pressure refuelling system is powered by 28 V DC from the HOT DC BUS or an external power source and requires refuelling pressure between 35 and 50 psi (Embraer, 2010) For every fuel servicing action, the aircraft must be in a safe condition for maintenance, under the Embraer chapter 20 procedures.

Under Embraer chapter 12-12 instructions, the fuel servicing actions that can be performed are:

1. Aircraft pressure refuelling;
2. Aircraft pressure defueling;
3. Aircraft gravity refuelling;
4. Aircraft gravity defueling;
5. Fuel tank drainage.

If a failure is detected on the fuel-quantity electrical indicating system, a mechanical fuel quantity must be performed, using the mechanical indicator (Dip Stick). The instructions to be followed for this operation are described under Embraer chapter 12-12-02.

4.2.9 Embraer chapter 12-13 - Hydraulics servicing

"Hydraulic systems are used on aircraft to move and actuate landing gear, flaps, and brakes. Larger aircraft use these systems also on flight controls, spoilers and thrust reversers, among others. The reason to use hydraulics is that they can transmit a very high pressure or force with a small volume of fluid" (EAI, 2020) The hydraulic fluid used usually have high flash points, adequate viscosity, lubricant properties, and thermal capacity/conductivity.

Scheduled inspections and testing show that trouble in a hydraulic system is inevitable whenever the liquid can become contaminated. The nature of the trouble, whether a simple malfunction or the destruction of a component, depends to some extent on the type of contaminant. Two general contaminants are (FAA, 2018):

- Abrasives, including particles as core sand, weld spatter, machining chips, rust and particles resulting from the degradation of moving components under constant friction;
- Nonabrasive, including those resulting from oil oxidation and soft particles worn or shredded from seals and other organic components.

The Engine Indicating and Crew Alerting System (EICAS), a display located on the front cockpit, allows the pilots and maintenance mechanics to monitor the hydraulic system for malfunctions (Embraer, 2010).

Hydraulics system reservoir must be regularly inspected/checked, to prevent system contamination and damage to components. The servicing actions to be performed are under Embraer chapter 12-13-01.

In case of a hydraulic system main circuit or emergency DC bus power failure, the landing gear can be extended through an accumulator controlled by the emergency extension control lever. Moving this lever from NORM to EMER DOWN position disables the normal operation of the landing gear and supplies fluid under pressure from the accumulator to the extension line of all landing gear manoeuvre actuators and the nose landing gear aft door actuator (Embraer, 2010).

When one or two of the emergency brake accumulators actuates, the subsequent servicing action must be performed, the instructions required to be followed are specified under the Embraer chapter 12-13-02.

For the VR application, it is expected that all the equipment's necessary to complete the procedures under the Embraer chapter 20, Standard practices, with relevance for the fuel servicing actions, like grounding procedures and aeroplane immobilization equipment are integrated into the solution.

All equipment, panels and controls described in the Embraer chapter 12-12 must also be integrated into the VR application and lastly, the equipment necessary to power the aeroplane while resorting to an external DC power source must also be integrated. A more in-depth overview of the equipment to be integrated will be given in this dissertation chapter 6 and 7.

In summary, this chapter provided an insight into the Embraer aeroplane systems and procedures relevant to the solution. The next chapter addresses the software used during the development of the solution by providing an insight into the software interface and functionalities.

Chapter 5 – On the Unity

As established by the high-level requirements, Unity is the used software in the development of the solution that was defined by ETI to be used in this work. As such, this chapter intends to provide an insight into the software capabilities and its structure.

Unity is a game development framework that supports and brings together several important areas of software development. Developers can import 2D and 3D graphics and resources from other software, mount them in scenes and environments and add lighting, audio, special effects, physics, animation, interactivity, and game logic (Unity, 2020). Only the most important functionalities within Unity will be approached.

5.1 Unity editor Interface

As with any game engine, an editor is needed to develop our desired system, as such, this section pretends to illustrate how the Unity editor is divided and its respective functions – see Figure 34.

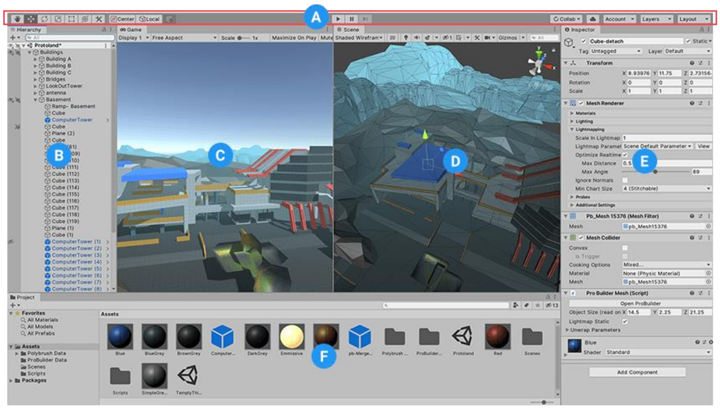


Figure 34 Unity Editor Interface (Unity, 2014).

(A) **"The toolbar** provides access to the essential working features. On the left, it contains the basic tools for manipulating the scene view and the game objects within it. In the centre of the play, pause and step controls are available. The buttons to the right give access to Unity collaborate, Unity cloud services and Unity account, followed by a layer visibility menu, and finally the editor layout menu" (Unity, 2020);

(B) **"The hierarchy window** is a hierarchical text representation of every game object in the scene. Each item in the scene has an entry in the hierarchy, so the two windows are inherently linked. The hierarchy reveals the structure of how game objects are attached to each other" (Unity, 2020);

(C) **The game view** simulates how the final rendered game will look through the scene cameras. When the user clicks on the play button, the simulation begins (Unity, 2020);

(D) **The scene view** allows the user to visually navigate and edit the scene. The scene view shows a 3D or 2D perspective (Unity, 2020);

(E) **"The inspector window** allows the user to view and edit all properties of the currently selected game object. Because different types of game objects have sets of properties, the layout and contents of the inspector window change each time a different game object is selected" (Unity, 2020);

(F) The project window displays to the user the library of assets that are available to use in the project (Unity, 2020).

5.2 Functionalities

5.2.1 Graphics

Modern game engines allow the developer to generate graphics and help simplify the production and import of resources from various platforms. For most games, game engines provide an architecture with high-performance rendering and quick access to the graphics API[22], so the developer gets the best possible visual fidelity (Unity, 2020) - see Figure 35.

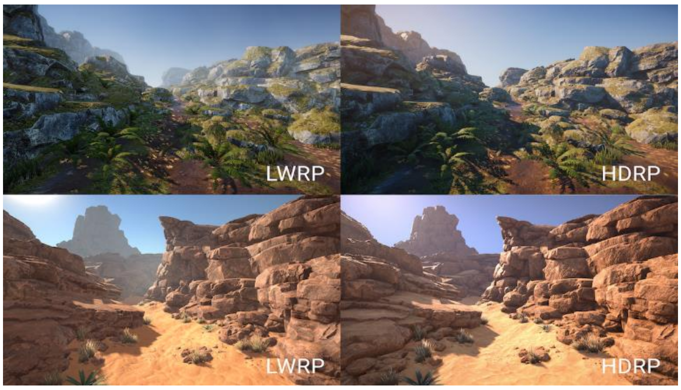
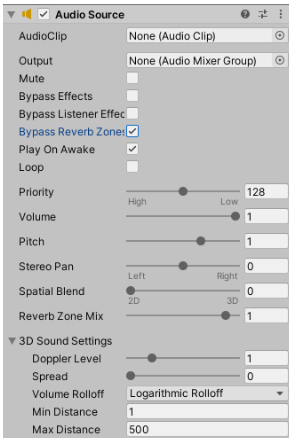


Figure 35 Graphical capabilities of Unity (Unity, 2020).

5.2.2 Audio

Unity allows the user to choose his sound from scratch, starting with musical composition, sound effects, dubbing and ending with post-production or the user can purchase sound effects from resource platforms, such as the Unity asset store, which can be combined and mixed in several ways (Unity, 2020).

Unity helps to integrate these sounds natively or through third-party applications, so a focus on the creative composition and positioning of sounds in the game scenes can be given, as well as assigning sounds to events (Unity, 2020). Figure 36 demonstrates the component to be attached to a game object to provide the desired sound effect, allowing the developer to control what audio clip will be played, how it is going to be played, when it is played and how we want the sounds effects to dissipate through a 3D space.



[22] Application Programming Interface.

Figure 36 Unity Audio Source component.

5.2.3 Physics

The physics system in a game engine provides all the physics of the game objects. The developer does not need to do all the coding on his own, nor must code all movements created in the scene by the elements of the game, or the collision between the components of the game. Unity allows the developer to edit game objects physical properties, as shown in Figure 37 (Unity, 2020).

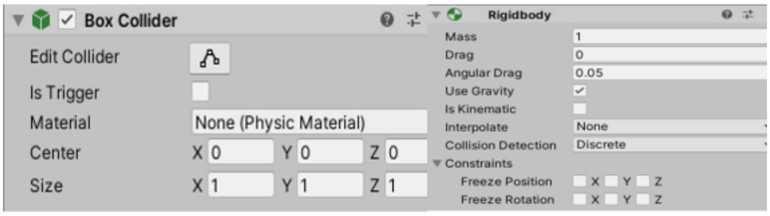


Figure 37 Box Collider and Rigid body components.

5.2.4 Graphical User Interfaces (GUI)

The GUI is a UI toolkit for developing user interfaces for games and applications. It is a game object-based UI system that uses components and the game view to arrange, position and style user interfaces (Unity, 2020) - see Figure 38.

The developer has the option to select from 3 rendering modes for the UI:

- **"Screen Space – Overlay**. This render mode places UI elements on the screen rendered on top of the scene. If the screen is resized or changes resolution, the canvas will automatically change the size to match the screen size" (Unity, 2020);
- **Screen Space – Camera**. This render mode is like the previously discussed, but in this render mode the UI is placed at a given distance in front of a specified camera (Unity, 2020);
- **World Space**. In this render mode, the UI will behave as any object in the scene (Unity, 2020).

Figure 38 Example of a User Interface (Unity, 2014).

5.2.5 Scripts

"Scripting is an essential component in all applications made in Unity. Most applications need scripts to respond to the input given by the player and to arrange for events in the gameplay to happen when they should. Beyond that, scripts are used to create graphical effects, control the physical behaviour of objects or even implement a custom Artificial Intelligence (AI) system for characters in the game” (Unity, 2020).

Since Unity is not a programming language, external software must be used to create the scripts for the applications. Unity supports both C# and JavaScript languages. For the sake of this dissertation, the compiler Visual Studio and C# language were used - see Figure 39.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;


public class CanopyOpen : MonoBehaviour
{
    public bool isClosed = true;
    public GameObject Canopy;
    public Toggle toggle;
    void Start()
    {
        toggle.isOn = false;
    }
    void OnMouseDown()
    {
        if (Input.GetMouseButtonDown(0) && isClosed == true)
        {
            isClosed = false;
            Canopy.GetComponent<Animator>().Play("OpenCanopy");
            toggle.isOn = true;

        }
        else if (Input.GetMouseButtonDown(0) && isClosed == false)
        {
            isClosed = true;
            Canopy.GetComponent<Animator>().Play("CloseCanopy");
            toggle.isOn = false;
        }

    }
}
```

Figure 39 Script for Super Tucano canopy opening procedure.

5.2.6 Virtual Reality

Unity supports VR applications, as shown in Figure 40 and lets the developer target virtual reality devices directly from Unity, without using any external plug-in in the projects. It provides a base API and feature set with compatibility for multiple devices. It provides forward compatibility for future devices and software (Unity, 2018).

By using native VR support in Unity, the developer gains (Unity, 2018):

- Stable versions for each VR device;
- A single API interface to interact with different VR devices;
- A clean project folder with no external plug-in for each device;
- The ability to include and switch between multiple devices during runtime;
- Better performance.

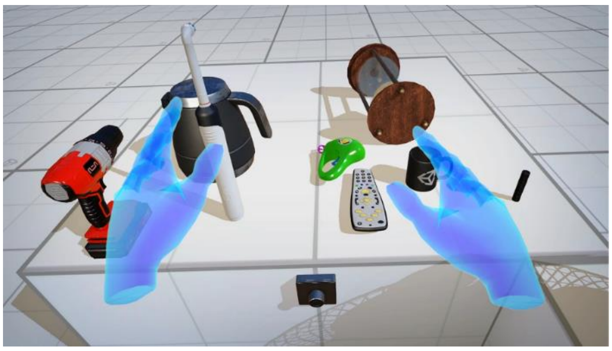


Figure 40 Unity VR application with hand-tracking functionalities (Unity, 2020).

Chapter 6 - Aircraft maintenance training requirements

This chapter specifies the system design processes to be applied and followed on the feasibility to develop a VT (Virtual Trainer) for fuel servicing actions on the Embraer A-29B Super Tucano aeroplane, providing a broad vision of the system structure, identifying client needs, users and other parts involved and their responsibilities on the development of a Virtual Trainer.

The VT tries to provide greater accessibility for new trainees to develop or acquire the necessary technical expertise to perform servicing actions on the aeroplane, without the possibility of damaging the aeroplane at any given time. Since no real aeroplane is needed for this approach of training, multiple scenarios a professional may face during his/her career can be addressed and practised.

6.1 System design processes

System design processes are interdependent, iterative, and recursive processes leading to a validated set of requirements and a solution that satisfies a set of stakeholder expectations. The used framework on the development of the solution was the waterfall methodology[23], where five system processes are to be taken into account, as depicted by Figure 41:

- Requirements;
- Design;
- Implementation;
- Verification;
- Maintenance.

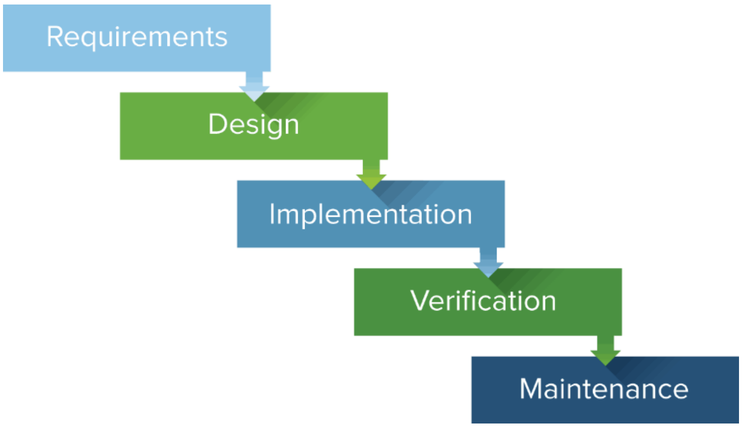


Figure 41 Stages of the waterfall methodology (Smartsheet, 2021).

The first stage of any project development resorting to this methodology starts with the definition of the system requirements, meaning that a meeting held between the stakeholders' results in a set of conditions and functionalities the solution must abide by. When the defined requirements are agreed upon, the next phase can begin.

The design phase consists of the logical design of the solution, where all the connections and relations between the software and hardware elements to be used on the final solution must be theorized and documented and so be used as a blueprint for the implementation phase.

[23] ETI standard system development methodology.

In the implementation stage both the previous phases come together, and the first iteration of the solution comes to fruition. After that the solution must enter the verification stage and is reviewed by the stakeholders, scrutinizing whether the iteration complies with the documentation produced by the first two stages. If the solution is between acceptable levels of compliance, its use in a real operational environment is enabled. On the flipside, if it falls outside of said levels, new iterations must be performed until it reaches so.

In the last phase, the product must be maintained and supported, whenever the repeated use of the solution on a real-life operation uncovers bugs and errors. The corrections must be performed until all requirements have been met, meaning the customer is pleased.

6.2 System operation and purpose

VT will provide a Graphical User Interface (GUI), with all the system functionalities and assistance on the learning material navigation, allowing the student or instructor freedom to determine the desired fuel servicing actions to be practised.

The GUI uses modern art-based technology on a 3D interface, content navigation command buttons, audio volume control, content hierarchical navigation menu interface, content completion status (not attempted, completed, not completed), full-screen feature, multiple screens, easy-to-customize screen layouts, as such, VT will have different combinations of information on the screens.

VT will provide the user with the option to perform the servicing procedures training using guides under the form of a checklist. The checklist will also serve as an alert tool, alerting the user if a wrong action was performed or if any action is missing.

The user will have at his/her disposal full access and interactivity with all the cockpit panels and exterior panels required to perform the selected training. Ground Support Equipment (GSE) and complementary tools will be also available for use, enabling servicing actions to be performed.

The checklist procedures that will be used as a user guide, will be compiled from the Embraer Maintenance Manual for the A29-B Super Tucano aeroplane.

6.3 Dependencies

The development phase of the project is dependent on the 3D models to be supplied from the design team, ranging from the 3D model of the aeroplane and its respective components and interfaces to the complementary tools and GSE models. All the supplied 3D models are intended to provide the user with an immersive experience and an as close as possible representation of a real-life operational environment.

Embraer A29-B Super Tucano Flight Manuals and Aircraft Maintenance Manuals must be supplied. For the sake of this project, Embraer chapter 12-12 documentation was the mainly used tool to create the VT. Sounds samples of audio expected to be encountered during servicing actions must be also supplied.

As the time available was a constraint, a table specifying the 3D models and their corresponding priority for the project was created to be used by the design team as a guide.

6.4 Operational environment

The system to be developed is intended to be used on maintenance technicians training. However, it is expected the users already possess previous knowledge of the following aeroplane systems:

- Airframe;
- Powerplant;
- Avionics;
- Structures.

For the development of the system, the software used was a game engine called Unity. As such, a computer with the following minimum requirements was required:

Minimum requirements	OS Windows
Operating system version	Windows 7 (SP1+) and Windows 10, 64-bit versions only.
CPU	X64 architecture with SSE2 instruction set support
Graphics API	DX10, DX11, and DX12-capable GPUs
Additional requirements	Hardware vendor officially supported drivers

Table 2 System minimum requirements for Unity use.

The computer must allow up to 4 monitors to be installed, allowing multiple layout configurations, a mouse and keyboard must be provided, as they are responsible for providing the inputs for the created environment. The use of a headset to block outside noise is advised.

Posteriorly VR devices shall be incorporated, like HMDs and devices capable of Gesture Tracking. With the use of VR devices, their respective software driver must be installed.

The system must be composed of various interconnected systems. The main systems worth noting are:

- Cockpit system, responsible for providing access and interactivity with its panels;
- Audio system, responsible for reproducing audio, when expected;
- Aircraft system, responsible for allowing the external view of the aeroplane and access to the required external panels;
- Ground crew tools system, responsible for providing all the necessary tools for the desired procedure;
- User system, responsible for providing the functionalities for the user.

6.5 Requirements identification

To a better understanding of the scope of the requirements, as well as an easier tracking of the requirements, each requirement was identified with a reference that was defined as SR-XXX-###, where XXX is an alphabetic acronym and ### a sequential number.

Acronym	Description
AUD	Audio Requirements
ACT	Aircraft Requirements
GCT	Ground Crew Tools requirements
USR	User Requirements
CKP	Cockpit Requirements

Table 3 List of acronyms for the requirements

The priority[24] levels are divided into the following levels:

- **High** - applicable to requirements that are critical to the system and must be implemented;
- **Medium** - applicable to requirements that are not as critical to the system as the "High", but its implementation is recommended;
- **Low** - applicable to requirements that are not critical but can positively contribute to the system performance.

6.6 Validation methodology

For each requirement, a validation[24] testing methodology will be defined. The following methods of validation shall be considered:

- **Inspection,** "observation using one or more of the five senses, simple physical manipulation, and mechanical and electrical gauging and measurement to verify that the item complies with its specified requirements" (United States Department of Transportation, 2010);
- **Demonstration**, "the actual operation of an item to provide evidence that it accomplishes the required functions under specific scenarios" (United States Department of Transportation, 2010);
- **Test**, "application of scientific principles and procedures to determine the proprieties or functional capabilities of items. The test is similar to demonstration, but is more precise, generally requiring specialized test equipment, configuration, data, and procedures to verify that the item satisfies the requirement" (ASEAN, 2012);
- **Analysis,** "use of established technical or mathematical models or simulations, algorithms, or other scientific principles and procedures to provide evidence that the item meets its stated requirements" (ASEAN, 2012).

This validation process was conducted by ETI head of business development, and the intern assigned to the project. Feedback given from Part-147 instructor was also taken into consideration.

6.7 Functional requirements

In software engineering and systems engineering, the main goal of the designer is to create a product that complies with the defined requirements, as such, functional requirements defined throughout the design phase must be followed to reach the final product to be subsequently used on an operational environment. The designer lists all the functionalities the software shall provide for the customer and users. As such, for the development of the solution the functional requirements were divided into the following groups:

- Audio requirements;
- Cockpit requirements;

[24] Parameters used during the definition of the functional requirements.

- Aircraft requirements;
- Ground crew tools requirements;
- User requirements.

6.7.1 Audio requirements

ID	Description	Priority[24]	Validation[24]
SR-AUD-001	The fuel truck must reproduce audio when operating	Low	Inspection
SR-AUD-002	The GPU must reproduce audio when operating	Low	Inspection
SR-AUD-003	The aeroplane must reproduce audio when operating	Low	Inspection
SR-AUD-004	The panels switches must reproduce audio when interacted	Low	Inspection
SR-AUD-005	The light panels must reproduce audio when actuated	Low	Inspection
SR-AUD-006	The Canopy opening/closing motion must reproduce audio	Low	Inspection
SR-AUD-007	The checklist must reproduce audio for alerts	Low	Inspection
SR-AUD-008	EICAS must reproduce audio when expected	Low	Inspection
SR-AUD-009	Audio from the surroundings must be reproduced	Low	Inspection

Table 4 Audio Requirements

6.7.2 Cockpit Requirements

ID	Description	Priority	Validation
SR-CKP-001	The fuel panel must have a layout equal to the one on the Super Tucano	High	Inspection
SR-CKP-002	The XFR switch must be simulated	High	Demonstration
SR-CKP-003	The main pumps switch must be simulated	High	Demonstration
SR-CKP-004	The auxiliary pumps must be simulated	High	Demonstration
SR-CKP-005	The TRIMS/FUEL/HYDR panel must have a layout equal to the one on the Super Tucano	High	Inspection
SR-CKP-006	The FUEL/HYDR/BLEED SHUTOFF switch must be simulated	High	Demonstration
SR-CKP-007	The EICAS must have a layout equal to the one on the Super Tucano	High	Inspection
SR-CKP-008	EICAS must simulate fuel quantity in the aeroplane	High	Demonstration
SR-CKP-009	The electrical panel must be simulated	Medium	Demonstration
SR-CKP-010	The EXT PWR switch must be simulated	Medium	Demonstration
SR-CKP-011	The circuit breakers must be simulated	Medium	Demonstration
SR-CKP-012	The front cockpit MDP1/MDP2/AVIONICS MASTER panel must be simulated	Medium	Demonstration

Table 5 Cockpit Requirements

6.7.3 Aircraft requirements

ID	Description	Priority	Validation
SR-ACT-001	The refuelling panel must have a layout equal to the one on the Super Tucano	High	Inspection
SR-ACT-002	The refuelling switch must be simulated	High	Demonstration
SR-ACT-003	The LH and RH valve switch must be simulated	High	Demonstration
SR-ACT-004	The LH and RH valve lights must be simulated	High	Demonstration
SR-ACT-005	The aircraft two grounding points must be simulated	High	Demonstration
SR-ACT-006	The access door 166BR must be simulated	Medium	Demonstration
SR-ACT-007	The external power receptacle must be simulated	Medium	Demonstration
SR-ACT-008	The external power indicator must be simulated	Medium	Demonstration
SR-ACT-009	The access door 521BB must be simulated	High	Demonstration
SR-ACT-010	The pressure refuelling port must be simulated	High	Demonstration
SR-ACT-011	The access door 415AL must be simulated	High	Demonstration
SR-ACT-012	The maintenance panel must have a layout equal to the one on the Super Tucano	High	Inspection
SR-ACT-013	The defueling switch must be simulated	High	Demonstration
SR-ACT-014	The drain valves on the aircraft wings must be simulated	High	Demonstration
SR-ACT-015	The LH and RH gravity filler cap must be simulated	High	Demonstration
SR-ACT-016	The gravity filler cap on the external tanks must be simulated	High	Demonstration
SR-ACT-017	The defueling port must be simulated	High	Demonstration

Table 6 Aircraft Requirements

6.7.4 Ground Crew Tools Requirements

ID	Description	Priority	Validation
SR-GCT-001	Grounding cables must be simulated	High	Demonstration
SR-GCT-002	The GPU must be simulated	High	Demonstration
SR-GCT-003	The fuel truck must be simulated	High	Demonstration
SR-GCT-004	The fuel hose must be simulated	High	Demonstration
SR-GCT-005	The defueling cart must be simulated	High	Demonstration

Table 7 Ground Crew Tools Requirements

6.7.5 User requirements

ID	Description	Priority	Validation
SR-USR-001	The user must be able to move in any direction	High	Demonstration
SR-USR-002	The user must have a vision system with 3 degrees of freedom	High	Demonstration
SR-USR-003	The user must be able to grab and move objects	High	Demonstration
SR-USR-004	The user must be able to interact with all the components relevant for the fuel servicing tasks	High	Demonstration
SR-USR-005	The user must have a checklist to serve as a guide	High	Demonstration
SR-USR-006	The user must be able to perform basic movement functions like crouching and walking	High	Demonstration
SR-USR-007	The user must have a zoom-in/out functionality	High	Demonstration
SR-USR-008	The user must be alerted if the checklist is not followed	High	Demonstration
SR-USR-009	The user must be able to alternate between the exterior and the cockpit	High	Demonstration
SR-USR-010	The user must have a selection menu of the fuel servicing tasks to approach	High	Demonstration
SR-USR-011	The user must have a grading system	Low	Demonstration
SR-USR-012	The user must be able to end the current servicing tasks at any given time	High	Demonstration
SR-USR-013	The user must be able to alternate between the chosen servicing tasks	High	Demonstration
SR-USR-014	The user must be able to remove or set inactive any aircraft component	Low	Demonstration

Table 8 User Requirements

6.8 System architecture

The purpose of the system architecture is to develop a credible structure with the objective of meeting project expectations, requirements and constraints. This task consists of system components and sub-systems, which will work together to implement the final version of the project. To describe system architectures, formalization of languages must be performed. Collectively these are designated as architecture description languages (ADLs).

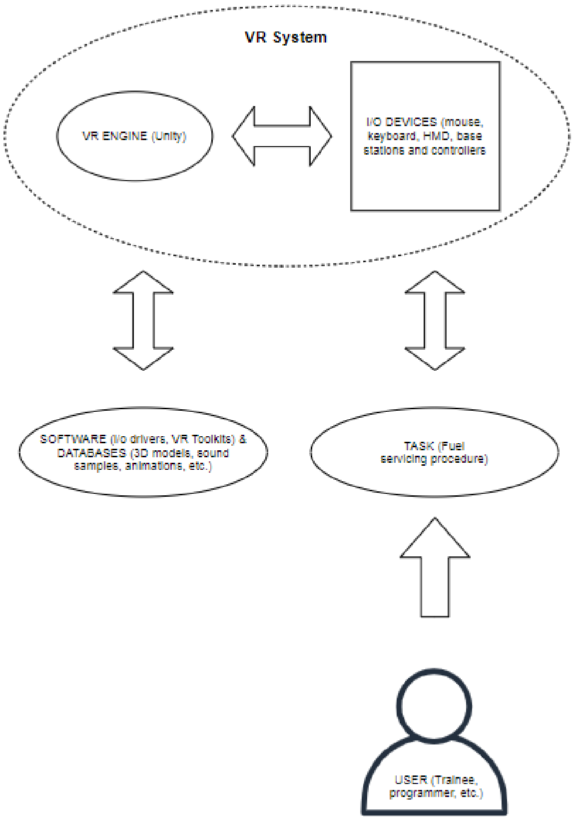


Figure 42: VR system architecture of the project using ADLs.

As described in *Figure 42*, the desired solution to be developed is divided into 5 main groups:

- **Task** - Procedures to be performed by the trainee;
- **User** - Responsible for completing the task while resorting to a VR system;
- **I/O[25] devices** - Responsible to provide all the inputs and outputs between the user and the VR system;
- **VR game engine** - Responsible for running the application;
- **Software & databases** - Responsible for providing all the I/O drivers, VR toolkits, 3D models, sound samples, etc. to be incorporated into the virtual world.

[25] Input/output devices.

6.8 Execution flow

The execution flow, as shown by Figure 43, is a flowchart used to provide an overview of how the solution must perform.

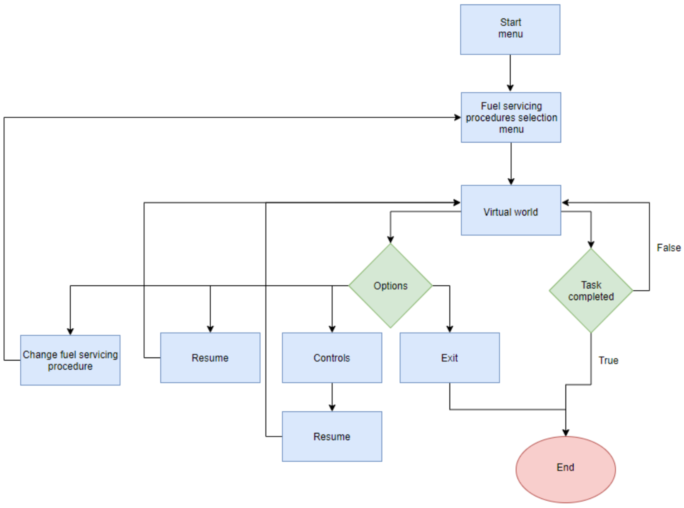


Figure 43 Execution flow.

When the user runs the application a start-up menu interface is presented, where an interactable "Start" button must be clicked on to open the next interface.

The following menu is a fuel servicing procedure selection interface, where the same principles of the previous menu are used, as the desired procedure to be trained must be selected. The user will have at his disposal the following options:

- Pressure refuelling with an external power source (Guided/Unguided/VR);
- Pressure refuelling without an external power source (Guided/Unguided/VR);
- Pressure defueling with an external power source (Guided/Unguided/VR);
- Gravity refuelling (Guided/Unguided/VR);
- Gravity defueling (Guided/Unguided/VR);
- Fuel tank drainage (Guided/Unguided/VR.

After a fuel servicing procedure is selected, the user is inserted in the game scene, where the selected training procedure must be performed. All the equipment, panels, switches, and ports necessary for the procedure are provided. The user is enabled to perform the following tasks, as specified by the high-level requirements:

- Fuelling procedures on the aeroplane;
- Access to refuelling ports of the aeroplane;
- Safety procedures on the aeroplanes;
- Grounding procedures on the aeroplane;
- External powering of the aeroplane procedures;
- Operation of the external fuel panels;
- Operation of the internal fuel panels;
- Operation of the fuel hose.

The user is not surrounded by a virtual world of only the aeroplane and the user. As such, all the 3D models expected to be encountered in a real-world operation must be incorporated. After spawning, the user will have at his/her disposal, on the left hand, the Embraer maintenance manual for the procedure selected, to be used as a checklist. A controls interface is set to active whenever the user presses a predetermined button.

The manual has at every task of the procedure a checkbox that will be set to the "check" position, whenever the correct action is taken. If a wrong action is performed or missing, an alert is given. The user can also close/open the manual and scroll through the pages.

Interaction with the access ports necessary for the fuelling, grounding and external powering procedures will be possible. The user will also have at his disposal a motion system for both VR and non-VR applications where a camera will track all the movement taken, working as the eyes of the player.

CAD models that must be connected to others during operation, namely the fuel nozzle with the pressure refuelling port, among others, will have a collider that will create a joint whenever a collision between the two is detected. The same joint is *destroyed* whenever a pre-determined force is applied.

To keep the virtual world easy to navigate, the only 3D models that will be available on awake, besides the aeroplane the user and the surroundings, will be the EPU[26] and the fuel truck. A bench with an instantiate interface will be available for the user to select the 3D model desired to spawn when the fuelling procedure currently under training demands the use of equipment currently not available in the virtual world.

The user can open/close the canopy when a correct input is provided. When the canopy is open, the cockpit can be entered. Inside, all the switches and knobs relevant to the task will be interactable and the lights of the used panels must trigger in response to the interacted switch or knob, as expected when replicating a real-life operation. EICAS will provide an alert whenever the fuel tanks are full or empty depending on the chosen procedure.

If the user completes the selected task, the application will end, providing the elapsed time during the procedure. However, during runtime, the procedure can be paused by a predetermined button. As soon as the button is pressed all interactions in the training environment are disabled and an interface will be set to active, providing the following options:

- **Exit** – The application ends;
- **Options** – Allows customization of the mouse and keyboard sensitivity;
- **Resume** – The training is resumed;
- **Change fuel servicing procedures** – The application will open the servicing procedures task selection interface.

In summary, this chapter addresses the system design process to be taken to further advance the development of the project, as a way of reaching the final iteration of the project. The following chapter will focus on the lastly iterated design solution and a more focused description of the VR hardware used.

[26] External Power Unit.

Chapter 7 - Aircraft maintenance training solution

This chapter addresses the development phase of the solution with the requirements set forth by ETI to be followed with the intent of reaching a final solution. Due to time constraints and with the available CAD models supplied only 1 fuel servicing procedure was developed, the pressure refuelling without an external power source, where 3 versions of the said task are available to be chosen.

The 3 versions have the same end goal of completing the chosen training procedure, however, each task has specific functionalities inherent to each version, and as such, said functionalities will be addressed. A more in-depth overview of the VR hardware established on the requirements will also be given. Lastly, a copy of the Embraer maintenance manual is provided In Annex A.

7.1 Headset HTC VIVE pro - presentation

The headset has two cameras equipped on the front side of the headset to be used for 3D tracking stereoscopic vision. The Vive Pro is also equipped with built-in on-ear headphones, where a volume adjuster and a mute button are available (Vive, 2020).

The horizontal part of the headband is supported by a plastic structure and is also padded for extra comfort. A dial button is equipped on the backside of the headset to provide the ability to tighten the equipment. Lastly, an adjustable vertical strap coming from the top of the visor to the back end of the headset can be used to hold the equipment in a fixed position when worn (Vive, 2020).

The Vive Pro has dual 3.5 inches 1,440-by-1600 AMOLED screens responsible for the display system with a refresh rate of 90 Hz and a field of vision of 110 degrees. This display enables images of a density of 615 pixels per inch. The increase of the referred image density leads to a reduction of the Screen-Door-Effect (Vive, 2020).

This equipment requires a Link Box that serves as the connection hub between the hardware and the computer. The link box has 4 cable entrances, the headset cable port, the power port, the display port, and the 3.0 USB port, and has one power button, responsible for turning on/off the headset (Vive, 2020).

This equipment must also have two base stations installed on each side of the working area while facing the centre. The base stations are responsible for the tracking of the headset and controller’s exact position.

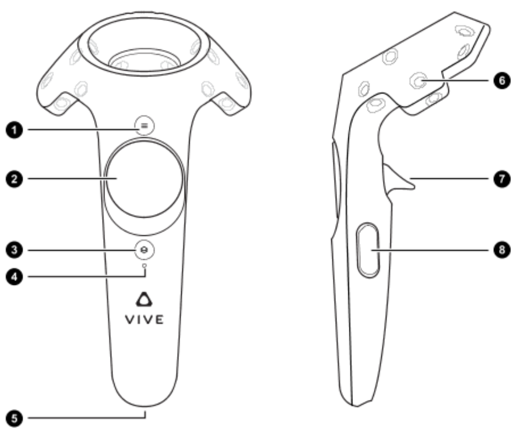


Figure 44 Vive controllers (Vive, 2020).

Lastly, the Vive controllers are comprised of the following components, as shown by Figure 44 (Vive, 2020):

1. Menu button;
2. Trackpad;
3. System button;
4. Status light;
5. Micro-USB port;
6. Tracking sensor;
7. Trigger;
8. Grip.

7.2 Pressure refuelling without an external DC power supply

In the guided version of the procedure, no deviation from the Embraer maintenance manual regarding the selected training is allowed, to this end, a copy of the said manual is provided to the user, to be used as a guide. After each procedure of the task is completed, a green mark is given, as depicted by Figure 45.

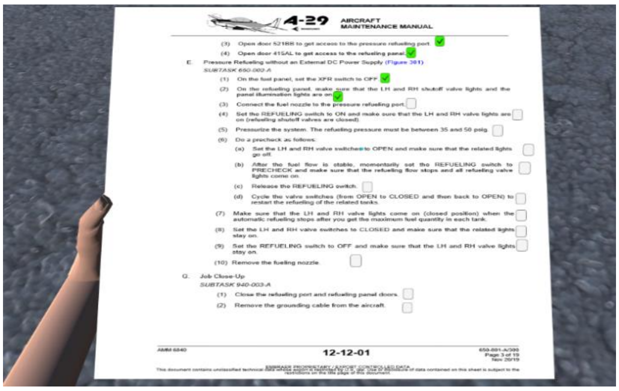


Figure 45 Embraer maintenance manual.

As with any fuelling procedure, before any servicing action can be taken, instructions set forth on the Embraer maintenance manual chapter 20 of the given aeroplane must be followed to guarantee the aeroplane is in a safe condition for maintenance. Due to the time constraints, all the fuelling procedures addressed hereinafter will consider that the A-29B Super Tucano is in a safe condition for maintenance, as established by Embraer chapter 20, as the necessary CAD models to approach this condition were not supplied. To this end, at the start of any version of the training task chosen, the user is informed of this condition and is led to proceed to the next task.

In the following task, the aeroplane must be grounded as it prevents any static discharge from igniting a fire. To do so, the aeroplane must be parked adjacently to an approved grounding point. The grounding cables must be first connected to the grounding point on the hangar and then to the aeroplane grounding points located on the underside of each wing leading edge, as depicted in Figure 46.

Figure 46 Grounding Procedure.

After the grounding operation of the aeroplane is completed, door 521BB, located under the LH[27] wing leading edge must be opened to provide access to the pressure refuelling port. To open the referred door, two latches must be opened. Following the opening procedure, a cap must be unplugged from the refuelling port and the task is considered complete, as depicted in Figure 47.

Figure 47 Door 521BB.

After completion, door 415Al must be opened to provide access to the refuelling panel, where the refuelling switch and the LH and RH[28] valve switches, responsible for controlling the LH and RH internal fuel tanks shutoff valves, and their respective lights, indicating their position (open or closed) are located. As depicted in Figure 48.

Figure 48 Door 415AL.

Afterwards, the user must enter the front cockpit and on the fuel panel, the XFR switch must be set to off, as fuel transfer from the external tanks to the internal tanks is not intended during fuelling procedures.

For the next task, the fuel nozzle cap must be removed, so the nozzle can be connected to the pressure refuelling port. When connected, the nozzle must be rotated and the red handle, as depicted in Figure 49, must be closed to lock the nozzle position. After completion, the refuelling switch can be set to on and if the operation is proceeding as expected, the LH and RH valve lights should be on, signalling that the respective fuel tank shutoff valves are closed and no fuel is entering the tanks.

[27] Left-Hand.
[28] Right Hand.

Figure 49 Fuel nozzle.

Before the refuelling shutoff valves can be opened to start the filling procedure of each internal tank, the system aeroplane fuel must be pressurized to a pressure between 35 and 50 psig. These pressures must be checked on the instruments available on the fuel truck, more specifically on the pressure gauge. After this, the LH and RH valve switches located at door 415AL, are set to the open position and the related lights are expected to go off, as it indicates that the LH and RH tanks shutoff valves are opened and the fuelling of the internal tanks is occurring.

After the fuel flow is stable, with a pressure between 35 and 50 psig, a pre-check must be performed, where the refuelling switch must be set to the precheck position and all the refuelling flow should stop, and the refuelling valves lights should come on. If both conditions occur, the operation is proceeding as expected and the refuelling switch can be released. When the switch is released, the fuelling does not resume, as the valve switches must be cycled from open to close and then back to open to restart the refuelling of the related tanks.

When the maximum fuel quantity in each tank is obtained, the refuelling procedure automatically stops, and the LH and RH valve lights come on. After this, the LH and RH valve switches must be set to close, and the related lights must stay on. Subsequently, the refuelling switch must be set off, and the LH and RH valve lights are still activated, meaning the procedure was performed as stipulated on the Embraer maintenance manual.

To complete the procedure, the fuelling nozzle must be removed, and the pressure refuelling port and refuelling panel must be closed. Lastly, the grounding cables must be disconnected from the aeroplane. After the last task is completed, a message is given reporting to the user that the training was completed with success, and a timer of the elapsed time is also shown.

In the unguided version of the procedure, deviation from the Embraer maintenance manual regarding the selected training is allowed. However, differently from the guided version, no checkmark of the completed tasks is shown to the user during the procedure. Whenever a user considers that the procedure was completed successfully, a grade of his/her performance is given, where the green checkmark represents the completed tasks and the red checkmarks the unfinished tasks of the procedure, as depicted in Figure 50.

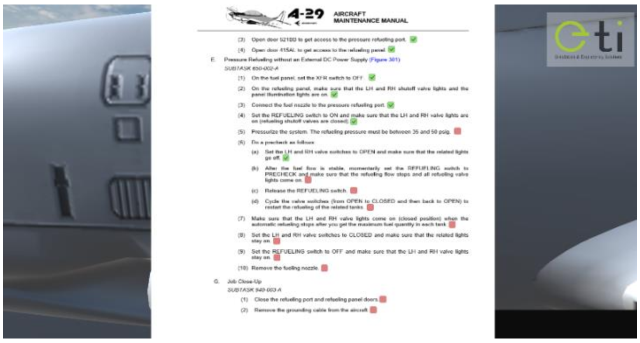


Figure 50 Unguided version grading system.

The VR version follows the same principles as the guided version, where the tasks must be completed in the order as they are shown by the Embraer maintenance manual. However, instead of resorting to the use of a keyboard and mouse to provide input and a monitor to receive the output, said equipment is replaced by hand-held controllers and an HMD.

Inside the training environment, both controllers have a CAD model resembling gloves, representing the user's hands, however, the left hand-held controller is also holding a copy of the Embraer maintenance manual that maintains its relative position in relation to the left-hand controller whenever a movement is performed by the said controller. Each page of the manual has an interactable button that allows the user to change pages, using the right-hand controller trigger. The setup is depicted in Figure 51.

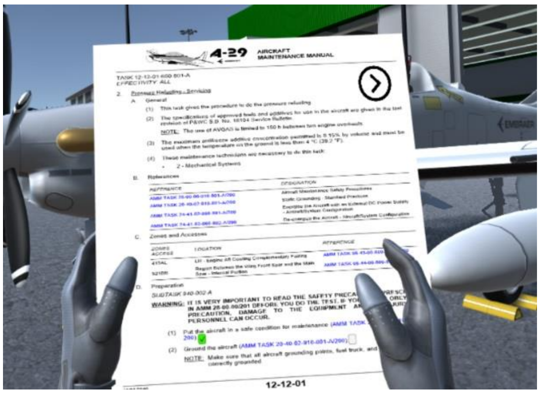


Figure 51 VR Setup.

As shown in the previous subchapter regarding the used hardware, the HTC VIVE Pro, the hand-held controller comprises of diverse components that can be used when the developer sees fit. As such, the following components were used on the solution:

1. Left-hand controller trackpad, responsible for the locomotion system of the user;
2. Left-hand controller trigger button, allowing the user to crouch and stand up, when the task so it demands;
3. Right-hand controller grip button, responsible for the action of grabbing objects;
4. Right-hand controller trigger button, to be used when a component of the training environment must be interacted.

As previously discussed in chapter 3, low framerates contribute to the surge of unwanted health effects, to this end, changes in how the training environment lights are rendered must be adjusted for the VR version, as it demands more processing power. If the developer intends to maximize the graphical capabilities of the solution, without taking into account computer performance, dynamic lighting of the training environment is advised.

Dynamic lighting is used when objects get moved during training, as such the shadows and the angle of light incidence on the moving object must be recalculated during runtime. However, if an object is not moving the same principle applies, so it allocates some of the processing power without the need to do so.

To improve performance, lights can be baked, meaning every calculation regarding light incidence and shadows on objects is pre-calculated in the unity editor as data and saved to the computer disk as a light map. When this setting is used and the object has moved no changes in the lighting of the object will occur.

Lastly, to the same end, dynamic occlusion is performed as the camera the user uses only renders the scenarios that are on his/her line of sight, reducing therefore the processing power used.

In summary, this chapter presented the final iteration of the solution while providing a roadmap and functionalities of the procedures and performance-enhancing changes made. The next chapter addresses the final considerations that arose from the development of the project as well as recommendations for future work.

Chapter 8 – Conclusions

The aviation industry is on a never-ending path of self-improvement in search of minimizing human errors resulting from non-compliance with aviation authorities' regulations. As stated by EASA previous yearly reports of accidents and incidents on state members, there are still reports occurring from wrongly performed fuel servicing procedures. As such new solutions must be developed to tackle this condition and mitigate undesirable occurrences.

ETI, a company specialized in the development of training solutions for the defence and aviation industry, intends to create a solution that can be used on the training of fuel servicing procedures through the use of the VR technology currently available. The solution was developed on a game development framework named UNITY, which allows VR applications to be created and the hardware used for that end was the HTC VIVE Pro HMD and its controllers.

The developed project supplied a demonstrator in the context of EASA part-147 organizations with an accessible tool using VR technology that can be used on the training without the need for real aeroplanes and components to be available while eliminating the risk of damaging aeroplane components and reducing the logistical difficulties regarding training session scheduling.

In brief, the training based on VR solution for a given maintenance scenario allows for multiple times until the procedure can be executed on an error-free procedure.

The project at the early stages aimed to approach all 6 servicing procedures regarding fuel procedures on the aeroplane. However, due to time constraints, the document sent to the designing team specifying the necessary CAD models as well as the priority levels were not fully fulfilled hindering the possibility of developing all the proposed fuel servicing procedures.

Due to said limitations, only the procedure of pressure refuelling without EPU is addressed, as well as its 3 possible versions: guided, where the user must complete the selected procedure and is not allowed to perform deviations from the maintenance manual; unguided, the user is allowed to perform deviations from the manual but his/her grades are affected negatively if a deviation from the manual occurs and VR, the user proceeds to a guided training procedure equal to the guided version, however, VR peripherals are used instead.

The project started by defining the requirements that the solution must abide by. The requirements were divided into 5 subgroups: audio requirements that consist of all functionalities relative to sounds expected to be encountered on a real-life operation; cockpit requirements that describe all the components and subsequent functionalities and layouts inside the cockpit of the aeroplane the solution model must possess; aircraft requirements that describe all the components and subsequent functionalities and layout of the exterior structure of the aeroplane the solution model must possess; ground crew requirements that describe all the components external to the aeroplane system that the solution must possess and user requirements that describe all the functionalities the solution must provide the user with to allow training completion.

Upon reaching the final iteration of the solution, the application was validated by the intern and ETI Head of Business Development, where the document created during the requirements identification phase was inspected to confirm if the solution complies with all said requirements.

Due to time constraints, as previously stated, the solution does not comply with all said requirements because only 1 procedure of the initial 6 intended is developed. However, requirements relative to the procedure of pressure refuelling without EPU were fulfilled and therefore the solution was validated.

Since training stations are only limited by the number of available VR hardware, multiple trainees, placed in different virtual worlds, can be trained at the same time on the same task of a given procedure, the solution that is impossible on a real-life procedure training, where the training is typically restricted to 1 instructor and 1 student. As such, the developed VR demonstrator proved to be a viable and recommended technology to be implemented.

Due to the versatility this technology possesses, trainees are placed under multiple scenarios and conditions that would otherwise be unwise to recreate on a real-life training procedure, for example, ignition of a system during refuelling procedure. As such, if any unwanted condition ever occurs, the trainee/professional has previous experience of how he/she should react.

When the HMD and controllers are used during training, the user field of view is restricted to the virtual training ground, subsequently creating an immersive experience that promotes trainee engagement in the learning process with the end goal of achieving better approval rates.

The used hardware supplied for the development of the solution is not wireless and while the HMD used allows for a 6 DOF movement system, it proved impractical to create a solution with only 6 DOF as the distances required to be taken during a training procedure are impractical, but possible, to recreate on an exact scale. This situation can be fixed by the use of a 6 DOF system with the aid of an extra locomotion system, like the one used on the solution, whenever bigger distances must be travelled or by using only a 6 DOF system on a training area capable of supporting said distances.

Furthermore, the final version of the software proved that the first use caused some unwanted health effects previously stated in chapter 3. This condition remains after first use and the severity can change from user to user.

Said conditions were reduced when performance-oriented changes were carried out, as stated in the last chapter. Tests on the solution while using a 6 DOF movement system proved to also be a minimizing factor of the adverse effects resulting from the use of VR technology.

Since a 6 DOF system proved inviable to incorporate, a system of 3 DOF system was used instead. This system does not possess a motion system natively, as such, a movement system was implemented where the user uses the left trackpad to move through the training procedure space.

Nevertheless, this type of movement proved to be a non-ideal solution due to the hardware limitations, as movement taken using the controller created discrepancies between what the eyes were sensing and the rest of the human senses, and so be another contributing factor for negative health symptoms.

8.1 future work

VR technologies have gained traction as a viable solution for at-home or distance training, allowing instructors and trainees to be inserted in the same training environment remotely. Even though the developed solution does not possess nor was required to have multiplayer functionalities, it can do so and would be an ever more needed feature to be added.

It is also recommended the creation of a database for each trainee, storing all the information of his/her previous training sessions to be used for future reviews.

Another recommendation would be the use of a wireless HMD that does not require base stations and controllers by using hand-tracking features or in the worst-case scenario, the same setup as the one used but with the wireless adapter installed.

Lastly, a broader spectrum of fuel servicing procedures or any other maintenance actions should be developed to create a diverse training experience for the user, resulting in better know-how of the maintenance procedures that must be taken on a real-life operation.

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Annex A – Embraer Chapter 12-12 Fuel Tank Servicing

EFFECTIVITY: ALL

1. General

   A. This section gives the procedures to perform the activities below:

   - Aircraft pressure defueling;
   - Fuel tank drainage;
   - Aircraft gravity defueling;
   - Aircraft pressure refueling;
   - Aircraft gravity refueling.

   B. The procedures in this section are given in the sequence below.

TASK NUMBER	*DESCRIPTION*	*EFFECTIVITY*
12-12-01-650-801-A	Pressure Refueling - Servicing	ALL
12-12-01-650-802-A	Pressure Defueling - Servicing	ALL
12-12-01-650-803-A	Gravity Refueling - Servicing	ALL
12-12-01-650-804-A	Gravity Defueling - Servicing	ALL
12-12-01-680-801-A	Fuel Tank Drainage - Servicing	ALL

   C. The abbreviations and acronyms used in this section are given in the sequence below:

ABBREVIATION	*DESCRIPTION*
°C	Degree Celsius
°F	Degree Fahrenheit
h	Hour
LH	Left-hand
psig	Pounds per Square Inch - Manometric
RH	Right-hand

TASK 12-12-01-650-801-A

EFFECTIVITY: ALL

2. Pressure Refueling - Servicing

A. General

(1) This task gives the procedure to do the pressure refueling.

(2) The specifications of approved fuels and additives for use in the aircraft are given in the last revision of P&WC S.B. No. 18104 Service Bulletin.

NOTE: The use of AVGAS is limited to 150 h between two engine overhauls.

(3) The maximum antifreeze additive concentration permitted is 0.15% by volume and must be used when the temperature on the ground is less than 4 °C (39.2 °F).

(4) These maintenance technicians are necessary to do this task:

- 2 - Mechanical Systems

B. References

REFERENCE	*DESIGNATION*
AMM TASK 20-00-00-910-801-A/200	Aircraft Maintenance Safety Procedures
AMM TASK 20-40-02-910-801-A/200	Static Grounding - Standard Practices
AMM TASK 24-41-02-860-801-A/200	Energize the Aircraft with an External DC Power Supply
AMM TASK 24-41-02-860-802-A/200	De-energize the Aircraft - Aircraft/System Configuration

C. Zones and Accesses

ZONES ACCESS	*LOCATION*	*REFERENC*
415AL	LH - Engine Aft Cowling Complementary Fairing	AMM TASK 06-43-00-800-801-A/100
521BB	Region between the Wing Front Spar and the Main Spar – Internal Portion	AMM TASK 06-44-00-800-801-A/10

D. Preparation

SUBTASK 940-002-A

WARNING: IT IS VERY IMPORTANT TO READ THE SAFETY PRECAUTIONS PRESCRIBED IN AMM 28-00-00/201 BEFORE YOU DO THE TEST. IF YOU DO NOT OBEY THIS PRECAUTION, DAMAGE TO THE EQUIPMENT AND/OR INJURY TO PERSONNEL CAN OCCUR.

(1) Put the aircraft in a safe condition for maintenance (AMM TASK 20-00-00-910-801-A/ 200).

(2) Ground the aircraft (AMM TASK 20-40-02-910-801-A/200).

NOTE: Make sure that all aircraft grounding points, fuel truck, and refueling port are correctly grounded.

(3) Open door 521BB to get access to the pressure refueling port.

(4) Open door 415AL to get access to the refueling panel.

E. Pressure Refueling without an External DC Power Supply

SUBTASK 650-002-A

(1) On the fuel panel, set the XFR switch to OFF.

(2) On the refueling panel, make sure that the LH and RH shutoff valve lights and the panel illumination lights are on.

(3) Connect the fuel nozzle to the pressure refueling port.

(4) Set the REFUELING switch to ON and make sure that the LH and RH valve lights are on (refueling shutoff valves are closed).

(5) Pressurize the system. The refueling pressure must be between 35 and 50 psig.

(6) Do a precheck as follows:

(a) Set the LH and RH valve switches to OPEN and make sure that the related lights go off.

(b) After the fuel flow is stable, momentarily set the REFUELING switch to PRECHECK and make sure that the refueling flow stops and all refueling valve lights come on.

(c) Release the REFUELING switch.

(d) Cycle the valve switches (from OPEN to CLOSED and then back to OPEN) to restart the refueling of the related tanks.

(7) Make sure that the LH and RH valve lights come on (closed position) when the automatic refueling stops after you get the maximum fuel quantity in each tank.

(8) Set the LH and RH valve switches to CLOSED and make sure that the related lights stay on.

(9) Set the REFUELING switch to OFF and make sure that the LH and RH valve lights stay on.

(10) Remove the fuelling nozzle.

F. Pressure Refueling with an External DC Power Supply

SUBTASK 650-006-A

(1) Energize the aircraft with the external DC power supply (AMM TASK

24-41-02-860-801-A/200).

(2) On the refueling panel, make sure that the LH and RH shutoff valve lights and the panel illumination lights are on.

(3) Connect the fuel nozzle to the pressure refueling port.

(4) Set the REFUELING switch to ON and make sure that the LH and RH valve lights are on (refueling shutoff valves are closed).

(5) Pressurize the system. The refueling pressure must be between 35 and 50 psig.

(6) Do a precheck as follows:

(a) Set the LH and RH valve switches to OPEN and make sure that the related lights go off.

(b) After the fuel flow is stable, momentarily set the REFUELING switch to PRECHECK and make sure that the refueling flow stops and all refueling valve lights come on.

(c) Release the REFUELING switch.

(d) Cycle the valve switches (from OPEN to CLOSED and then back to OPEN) to restart the refueling of the related tanks.

(7) Make sure that the LH and RH valve lights come on (closed position) when the automatic refueling stops after you get the maximum fuel quantity in each tank.

(8) Set the LH and RH valve switch to CLOSED and make sure that the related lights stay on.

(9) Set the REFUELING switch to OFF and make sure that the LH and RH valve lights stay on.

(10) Remove the fuel nozzle.

(11) De-energize the aircraft (AMM TASK 24-41-02-860-802-A/200).

G. Job Close-Up

SUBTASK 940-003-A

(1) Close the refueling port and refueling panel doors.

(2) Remove the grounding cable from the aircraft.