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Insights and Challenges of Flight Simulation Systems in Air Transportation

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0. Abstract

Simulation is present during design, development and validation of aeronautical vehicles or systems in order to lower the costs and prevent problems during the construction phase. Flight Simulation software like X-Plane, Microsoft Flight Simulator (MSFS)/Lockheed Martin Prepar3D® and Flight Gear are the most used software when it comes to simulation of aeronautical systems in a virtual World. The X-Plane uses Computational Fluid Dynamics (CFD) and MSFS/Lockheed Martin Prepar3D® and Flight Gear use the Newtonian model for the simulation of the flight dynamics. The MATrix LABoraty (MATLAB)/Simulink enables the simulation of dynamic systems and the evaluation of the system performance. The main objective of this paper is to survey the tools and methods needed for the creation of a virtual simulation tool for a Rigid Hybrid Airship. This will allow the further testing of systems like avionics and flight controls of the vehicle.

Keywords: Flight Simulation, PCATD, X-Plane, FlightGear, Prepar3D®, MSFS, Airship.

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Insights and Challenges of Flight Simulation Systems in Air Transportation

1. Introduction

When building a new product or finding a solution to a problem, the resolution is supported by a set of elements grouped together in a particular order for a particular reason to achieve a certain objective. For that reason, it is correct to refer it as a system, comprised by its elements and its interconnections, limited by a boundary [1]. Normally the system is considered as the product but in reality it comprises a number of products for testing and training before the implementation of the final product.
Simulation was first applied in the Industrial field through mathematical models to verify and improve either their products or their method of production [2]. During the World War II, with the appearance of the first computers it was particularly used to design and develop the hydrogen bomb. Since then, simulation has been evolving as fast as technology, being a very important tool of management, design, engineering and training in different kind of fields [2].

2. Why do we simulate systems?

The best way to verify if the purpose of the system will be achieved is to test it before its production. This test has to be made to the system in development process considering its environment, which will not only suppress any major unplanned circumstances but it can also improve the efficiency of the system [2]. In order to realise this test, a model is made representing the system in study which will be applied through simulation to show how this specific system will behave. This model can be a physical, mathematical or logical representation of the system, which will also define what type of simulation will be necessary, being the most important part of simulation process [3].

There are several types of simulation:

- Virtual Simulation, representing physical and electronic (logical) systems;
- Constructive Simulation, which main focus consists in representing a system and its employment – commonly used in engineering due to its mathematical and logical models simulated with Computer Aided Design (CAD), Computer Aided Engineering (CAE) and Computer Aided Manufacturing (CAM);
- Live Simulations, where simulated operations co-exist with real operators and equipment, like in a fire drill [4].

In this particular case, we will focus on virtual simulation where the human operator interacts with a mock-up of the real World scenario, reproducing the physical movements needed, along with a computer generated reproduction of the system. Since it is applied on a graphic environment, it provides a better understanding of how the system will work by behaving and transmitting the sensation of how the real event would be. The actions made by the operator and the ones made by computer based are thus comparable to what happens in a real World, being immersive. It also makes it possible to change and add new variables to the simulated system [4]. This allows a better understanding of the system reaction to changes within its cycle or/and its environment. This is why it is mainly used on military training, emergency & rescue procedures and transportation, especially flight training, later described in this paper.

3. Simulation as a method of verification, validation, accreditation and training

Once simulation is used, it is important to establish confidence that it is a reliable source of information, given through virtual or physical interaction. The verification assures that after the simulation results analysis, the implementation of the model represents accurately the requirements and objectives of the system designed. After this verification, the level of confidence in the simulation must be determined by defining its accuracy in the represented system when compared to the real World situation. The validation has to consider that the system is a valid representation or not from the operators perspective. The *accreditation* happens when a formal certification is given to the model or simulation validated. The organization more related to that subject decides where the simulation will be applied and reaffirms the statement that the simulation and the system represented is indeed viable [4].

Although in simulation the main objective is to achieve a high level of accuracy with respect to the real World, this can be a serious issue, not only due the technologic development required but also due to its cost. It is necessary to evaluate the level of reliability that is required and to achieve the correct balance between fidelity and cost before the implementation of the simulation [4]. But it is also the opportunity to achieve high levels of fidelity that give simulation a major importance in testing models and training. The test of models assures the concept, configuration and design of full system without manufacturing any test component, allowing a better management of resources. This can predict either its performance as final product, as well as its integrity [4].
Due to its reliability, simulation also appears as a training method. Nowadays, simulators are considered a main tool when it comes to training due to their realness. From normal operation to adverse situations (that would not be safe or easily achievable) it is possible to train them in simulation [5]. Once experienced in real life, this training allows a better reaction and better understanding of the situation. That is why simulation is not only a good training method but also a good evaluation of human performance and behaviour regarding a particular system or final product [5]. The experience gained during the simulation training provides the knowledge necessary to work effectively in the real World system.

4. Flight Simulation
4.1. Introduction

Simulation has made a major contribution to the aeronautical sector. From being applied to engineering or flight training, Flight Simulation is today one discipline of aviation [6]. Aeronautical engineering uses simulation mainly to design and evaluate aircraft systems, allowing a full reproduction of the designed aircraft on flight simulation software. This will not only make evident any design problem but it will also allow manoeuvring studies to verify the flying capabilities. Flight simulation software together with a physical reproduction of the designed cockpit – Flight Simulator – can be used for flight training [7].

Flight simulators or flight training devices (FTDs) have been used in pilot training for multiple purposes, teaching them the basics of flying and communications or teaching how to fly certain aircrafts, like Type Rating; *«…to enable pilots to become proficient in instrument flying and multicrew cooperation (MCC)…»* by Crew Resource Management (CRM); [8:10-10] or how to act in certain abnormal flight situations [7]. Since the expenses regarding simulating a certain aircraft are lower than a real flight and some situations are impractical for real training, flight simulation is widely used in civil and military aviation, enhancing the safety level of Aviation [7].

Like every activity in the aeronautical sector, flight training is strictly regulated, especially when it comes to FTDs. The National Aviation Authorities (NAA), in Portugal – Autoridade Nacional de Aviação Civil (ANAC) ensures that all FTDs meet certain standards, although the differences between each country have been translated to different regulation. This process started in 1992 [9], however only in 1995 the first document from International Civil Aviation Organization (ICAO) with the work from Royal Aeronautical Society (RAeS), International Committee on FSTD Qualification (ICFQ), Civil Aviation Safety Authority (CASA) and the Civil Aviation Authority (CAA) was issued. This first effort resulted in the Joint Aviation Requirements (JAR) Standard Training Device (STD) 1A or JAR-STD-1A published in 1995 [10]. Although there

were several updates and reviews to the regulation made, it did not result as expected and the US Federal Aviation Administration (FAA) and the European Joint Aviation Authorities (JAA) ended using different terms for similar FTDs.
In March 2006 the Royal Aeronautical Simulation Flight Simulation Group (RAeS FSG) established an International Working Group (IWG) with the goal to harmonize flight simulation regulation [11]. The results of the IWG meetings are the development of a matrix with 150 Training Tasks with each of the 14 Training Types [10]. The ICFQ developed a new qualification criteria for the complete suite of Flight Simulation Training Devices (FSTD) [12]. This new classification covers the 26 types of Training Devices to 7 types of devices as shown in Figure 1. The highest type is Level VII, similar to the current Level D Full Flight Simulator (FFS) used by FAA, but it includes enhancements like the fidelity of visual systems and the simulation of communications and air traffic control [12].

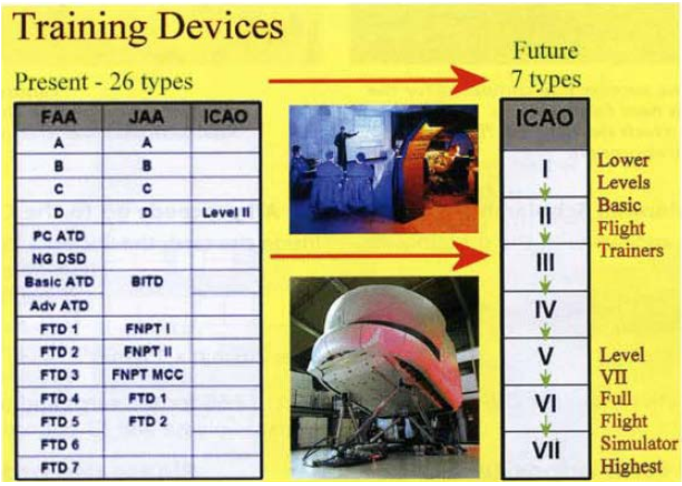

Figure 1 – Training Devices, Present to Future [11:1]

The classification mentioned above was published in *ICAO Doc 9625 Manual of Criteria for the Qualification of Flight Simulation Training Devices Volume 1 – Aeroplanes*, *Third Edition* published in July 2009 [12] but until now, only 2 NAAs, Singapore and Russia, have adopted this qualification [12]. In the meantime, the FAA adopted the JAR-FSTD A in 2008 [13] and in 2010 the European Aviation Safety Agency (EASA) adopted the Certification Specifications (CS) FSTD(A) with the same applicability that JAR-FSTD A [14]. By 2016 a review by EASA is expected to assure the alignment with the new ICAO doc. 9625, 3rd edition [15].

4.2. Flight Simulators classification according to JAR-FSTD A and CS-FSTD(A) Regulation

According to JAR-FSTD A and the CS-FSTD(A), the FSTD are divided by level of fidelity as following:
«Full Flight Simulator (FFS): *A full size replica of a specific type or make, model and series aeroplane flight deck, including the assemblage of all equipment and computer programs necessary to represent the aeroplane in ground and flight operations, a visual system providing an out of the flight deck view, and a force cueing motion system. It is in compliance with the minimum standards for FFS Qualification.»* [13:1-B-1]. This type of simulator is used to qualify pilots in Type-Rating of a specific aircraft like Airbus A320 or Boeing 737. In this type of Flight Simulator it is possible for a pilot to fly a new type of aircraft without having flied that aircraft in real World. This is called the Zero Flight Time Training (ZFTT) [16]. It has the capability to act as a Fixed Based Simulator (FBS) without motion, making the operation of Simulator less expensive [16]. It has four levels of fidelity A, B, C and D, where A has the lowest capabilities and the D has the highest level of fidelity which include a motion system with six degrees of freedom, providing effects like turbulence, windshear, engine failure and other abnormal

situations. In Figure 2 we have in the left side the exterior of Airbus A320 FFS and in the right side we have the inside of the simulator. The classification applied by FAA is the same in the EASA.

Figure 2 – Full Flight Simulator (FFS), outside in the left, inside in the right [17:1]

«Flight Training Device (FTD): *A full size replica of a specific aeroplane type's instruments, equipment, panels and controls in an open flight deck area or an enclosed aeroplane flight deck, including the assemblage of equipment and computer software necessary to represent the aeroplane in ground and flight conditions to the extent of the systems installed in the device. It does not require a force cueing motion or visual system. It is in compliance with the minimum standards for a specific FTD Level of Qualification.»* [13:1-B-1]. The FAA has seven categories for this type of device but JAA has only three levels, both including a level for helicopters (level 7 and 3, respectively) [18]. The FAA Level 1, 2 and 3 are no more in production [19]. Level 4 has touch screens that help the trainee to learn procedures for instruments, Flight Management Systems (FMS), Master Control Display Unit (MCDU), Primary Flight Display (PFD), Navigation Display (ND), Electronic Centralized Aircraft Monitoring (ECAM) and other type of systems. In this type of device the control yoke doesn´t exist [19]. Level 5 represents a "class" of aircraft (like single-engine, multi-engine, gas turbine propulsion or piston propulsion), that also requires a qualification. Level 5 represents a device that looks like the aircraft the operator is going to fly [19]. At this stage a yoke or a sidestick is used. Level 6 makes use of a dynamic model with all the aerodynamic data [19]. It´s the most realistic way to simulate the flight [18].

«Flight and Navigation Procedures Trainer (FNPT): *A training device which represents the flight deck or cockpit environment including the assemblage of equipment and computer programs necessary to represent an aircraft or its class in flight operations to the extent that the systems appear to function as in the aircraft. It is in compliance with the minimum standards for a specific FNPT Level of Qualification.»* [13:1-B-1]. There are three categories, each one with its traits. For instance, between FNPT I and II, their big difference is the visual system that can be generated by 5 channels in FNPT II [20],[21]. The FNPT III is only used for helicopters [19] and the MCC qualification is only possible in FNPT II and FNPT III [13]. For MCC qualification the FNPT II has to accomplish certain minimums of technical requirements, like dual controls [13].

«Basic Instrument Training Device (BITD): *A ground based training device which represents the student pilot's station of a class of airplanes. It may use screen based instrument panels and spring-loaded flight controls, providing a training platform for at least the procedural aspects of instrument flight.»* [13:1-B-1]. This type of classification is primary used by EASA. In FAA this type of device can be classified as Basic ATD or Advanced ATD.

4.3. Flight Simulators classification according to ICAO Qualification Levels

The qualifications referred in the ICAO Doc. 9625 *"Manual of Criteria for the Qualification of Flight Simulation Training Devices" Volume I, Aeroplanes and Volume II Helicopters* divide the FSTD in seven categories [22], like in Table 1 [23]. This was based on 200 Training tasks, 15 Training types, 13 FSTD features and the existing NAA FSTD requirements and standards. This subdivided the FSTD in two designations, for Training (T) or Training to proficiency (TP), with the fidelity level of each feature defining its type [22].

Level of feature fidelity [22:I-1-2] :

- *«**None or Not Applicable (N):** Feature not required for FSTD;*
- ***Generic (G):** The lowest level of required fidelity for a given FSTD feature;*
- ***Representative (R):** The intermediate level of required fidelity for a given FSTD feature;*
- ***Specific (S):** The highest level of required fidelity for a given FSTD feature.»*

Table 1 – Qualification levels of Flight Simulation Training Devices (FSTDs) according to ICAO 9625 [23:82]

Type of FSTD	***Characteristics of requirements***
I	*The first level would contain an enclosed or perceived cockpit/flight deck, excluding distraction, which will represent that of the aeroplane derived from, and appropriate to class, to support the approved use; lighting environment for panels and instruments should be sufficient for the operation being conducted; modelling of aerodynamics and engines (thrust, temperature, mass); aircraft systems; sound system; visual system. The ATC environment simulation is not required.*
II	*Meets the same requirements as 1st level, but also to include the simulation of ATC environment as messages, visual environment, airport movements, weather reports and others.*
III	*Meets the previous requirements, but also uses for example the simulation of runway condition, including information on pavement condition (wet, dry). The ATC environment simulation is not required.*
IV	*This level meets the same requirements as previous levels. It is added for example on ATC environment simulation; sounds of outside environment (weather, meteoric water); voice control.*
V	*This level meets the same requirements as level IV, but is added for example on runway conditions simulation (dry, wet, icings, water holes); aircraft systems simulation (communication, navigation, warning device); dynamic feeling of control; failure of brakes dynamics and tires; degradation of brakes efficiency.*
VI	*This level meets the same requirements as level V , but is added for example on ATC extended environment simulation; the motion system includes the acceleration feeling, Buffet in the air due to flap and spoiler/speed brake extension; Buffet due to atmospheric disturbances, e.g. turbulence in three linear axes (isotropic), In-flight vibrations A motion system (force cueing) should produce cues at least equivalent to those of a 6 DOF platform motion system (i.e., pitch, roll, yaw, heave, sway, and surge). Weather environment contains e.g. simulation of turbulence.*
VII	*The highest approved level. It has to meet all previous requirements with their details and authentic realization as in the real aircraft.*

4.4. Personal Computer-based Aviation Training Device (PCATD)

PCATD acronym is only used by FAA and this device consists in three main parts, the PCATD software, the approved flight controls configuration, and a Personal Computer (PCATD Hardware) like in Figure 3 [24]. ELITE company was the first company to have a PCATD device certified in 2003. It is important to refer that for that certification, the FAA has to certify all the 3 parts [11].

Figure 3 – PCATD certified by FAA from ELITE Company [24]

4.4.1. PCATD Software

The idea of creating the PCATD software was mainly to reduce the cost of simulation. With the improvement of computer processor capability (more memory, and more graphic possibilities) as well as high performance Personal Computer (PC) – the designers of this type of software have now more resources than ever. The software engineers have to choose between two types of flight models: the Newtonian model or the Computational Fluid Dynamics (CFD) model. The Newtonian model used by Microsoft Flight Simulator (MSFS) has the advantage of being easier to implement but less realistic with stall situation, tight turns and other abnormal situations of flying. The Newtonian Model uses steady-state derivatives [25:6]:

$$\mathrm{C_D} = C_{D_0} + C_{D_\alpha}\alpha + C_{D_{i_h}} i_h + C_{D_{\delta_e}}\delta_e + \Delta C_{D_{flap}} + \Delta C_{D_{Spoiler}} \quad (1)$$

$$\mathrm{C_L} = C_{L_0} + C_{L_\alpha}\alpha + C_{L_{i_h}} i_h + C_{L_{\delta_e}}\delta_e + \Delta C_{L_{flap}} + \Delta C_{L_{Spoiler}} \quad (2)$$

$$\mathrm{C_M} = C_{M_0} + C_{M_\alpha}\alpha + C_{M_{i_h}} i_h + C_{M_{\delta_e}}\delta_e + \Delta C_{M_{flap}} + \Delta C_{M_{Spoiler}} \quad (3)$$

$$\mathrm{C_l} = C_{l_0} + C_{l_\beta}\beta + C_{l_{a_e}}\delta_a + C_{l_{er}}\delta_r \quad (4)$$

$$\mathrm{C_Y} = C_{Y_0} + C_{Y_\beta}\beta + C_{Y_{a_e}}\delta_a + C_{Y_{er}}\delta_r \quad (5)$$

$$\mathrm{C_N} = C_{N_0} + C_{N_\beta}\beta + C_{N_{a_e}}\delta_a + C_{N_{er}}\delta_r \quad (6)$$

Where:

$C_D = Airplane\ drag\ coefficient$

$C_L = Airplane\ lift\ coefficient$

$C_M = Airplane\ pitching\ moment\ coefficient$

$C_l = Airplane\ rolling\ moment\ coefficient$

$C_Y = Airplane\ side\ force\ coefficient$

$C_N = Airplane\ yawing\ moment\ coefficient$

$\beta = Sideslip\ angle$

$$C_{D_\alpha} = \frac{\partial C_D}{\partial \alpha}$$

$$C_{D_{i_h}} = \frac{\partial C_D}{\partial i_h}$$

$$C_{L_\alpha} = \frac{\partial C_L}{\partial \alpha}$$

$$C_{M_\alpha} = \frac{\partial C_M}{\partial \alpha}$$

$$C_{M_{\delta_e}} = \frac{\partial C_M}{\partial \delta_e}$$

$$C_{l_{a_e}} = \frac{\partial C_l}{\partial a_e}$$

$$C_{Y_\beta} = \frac{\partial C_Y}{\partial \beta}$$

$$C_{Y_{er}} = \frac{\partial C_Y}{\partial er}$$

$$C_{N_{a_e}} = \frac{\partial C_N}{\partial a_e}$$

$0 = At\ zero - lift\ state$

$\alpha = Angle\ of\ attack$

$i_h = Horizontal\ tail\ incidence\ angle$

$\delta_e = Elevator\ deflection$

$flaps = Due\ to\ flaps$

$spoiler = Due\ to\ spoiler$

$\delta_a = Aileron\ deflection$

$\delta_r = Rudder\ deflection$

$$C_{D_{\delta_e}} = \frac{\partial C_D}{\partial \delta_e}$$

$$C_{L_{i_h}} = \frac{\partial C_L}{\partial i_h}$$

$$C_{L_{\delta_e}} = \frac{\partial C_L}{\partial \delta_e}$$

$$C_{M_{i_h}} = \frac{\partial C_M}{\partial i_h}$$

$$C_{l_\beta} = \frac{\partial C_l}{\partial \beta}$$

$$C_{l_{er}} = \frac{\partial C_l}{\partial er}$$

$$C_{Y_{a_e}} = \frac{\partial C_Y}{\partial a_e}$$

$$C_{N_\beta} = \frac{\partial C_N}{\partial \beta}$$

$$C_{N_{er}} = \frac{\partial C_N}{\partial er}$$

The CFD uses the blade element theory. The blade element theory implies breaking the aircraft into small elements and then calculating the forces and moments on each of these elements many times per second [26]. With this method, the simulator, like X-Plane has the possibility to compute the forces applied on the airplane more detailed [26]. The great advantage of this method is to predict how an airplane will fly, which is not possible with Newtonian model which is based on stability derivatives that we will not explore in this paper.

4.4.1.1. X-Plane by Laminar Research

The first version of X-Plane was released by Laminar Research in 1993. Instead of Microsoft Flight Simulator, the X-Plane is an *«engineering tool that can be used to predict the flight characteristics of fixed and rotary-wing aircraft with incredible accuracy.»* [27:1]. Because of this, X-Plane can be used for pilot training and therefore improve their pilot skills (flying an airplane like a real plane) or for engineers to predict how a certain aircraft concept would fly since it can simulate jets, single and multi-engine airplanes, gliders, helicopters and Vertical Take-Off and Landing (VTOLs) [27]. The scenery for X-Plane covers terrain from 74º North to 60º South Latitude and has 33000 airports to test the airplanes [27]. It is possible to test the Space Shuttle due to a realistic model of Earth Atmosphere and since X-Plane has its own weather engine, it allows the user to download from Internet the real weather. X-Plane has the ability to make the various systems of an aircraft fail like engines, hydraulics, instruments and others reflecting that in flight dynamics (like when an engine fails the asymmetrical thrust make the airplane turn to the side with an engine failure) [27]. X-Plane simulator is very popular in Air Forces, space agencies and aircraft manufactures to test the conceptual aircraft design and flight testing [27]. X-Plane simulator is a software with certification from FAA so pilots flying with PCATD (certified hardware and flight controls) can log hours towards aviation licenses and ratings but with only the X-Plane software that is not possible [27].

4.4.1.2. Microsoft Flight Simulator X and Prepar3D® by Lockheed Martin

The history of this software started in 1975, when Bruce Artwick introduced his Master Thesis. Bruce Artwick concluded that computers in 1975 did not have the capability to handle the mathematical computations for aircraft simulation routines. Just after the presentation of this thesis, Artwick with his Flight Instructor started a company called SubLOGIC that developed a commercial aircraft simulator based on his thesis called FSI Flight Simulator, compatible with Apple II. In 1982, Artwick authorized the Microsoft to use the code of FSI Flight Simulator to produce a version for IBM PC [25]. That version was called Microsoft Flight Simulator 1.01. Microsoft supported this software until 2006, releasing several versions with the last one called Microsoft Flight Simulator X (FSX) [28]. In 2009 Microsoft closed the ACES Game Studio, the publisher of Microsoft Flight Simulator, due to a change in their business strategy [29]. In 2011 the Lockheed Martin released the Prepar3D® based in Microsoft Enterprise Simulation Platform (ESP) that is the commercial-use version of Microsoft Flight Simulator X SP2. To do that, Lockheed Martin negotiated with Microsoft the intellectual property (including source code) and hired members of the original ACES Studio team [30]. The Prepar3D® maintains compatibility with the FSX system but add-ons made to FSX has some limitations when applied in Prepar3D® [31]. The Prepar3D® has 40 high-detail cities and more than 24900 airports [32]. This simulator has an Air Traffic Control engine, weather engine, failure mode and the entire World represented.

Microsoft and now Lockheed Martin have a Software Development Kit (SDK) that enables people with some programming knowledge to development airport scenery, modified terrain, creation of new aircraft flight models, aircraft panels and aircraft design. The policy from Lockheed Martin refers that the code from simulator engine (the core of the software) is closed but the developers can produce add-ons for the simulator. The main programming language is C and for some add-ons are the C++ [31][33]. Prepar3D® uses the Newtonian model like the older versions of the Microsoft Flight Simulator.

Since FSX and the Prepar3D® are the base package for flight simulation, there are many freeware and payware add-ons for that, allowing limitless possibilities when it comes to recreate the real World, making the simulator “as real as it gets”.

4.4.1.3. The FlightGear Flight Simulator

FlightGear is an open source GPL flight simulator developed by volunteers around the World [34]. In 1996, David Murr started this simulator has an alternative to other simulators like Microsoft Flight Simulator. In 1997 Curt Olson made a multi-platform using OpenGL (Direct3D/DirectX will never be supported because it is a proprietary interface restricted to Microsoft Windows Operating System) and the first version of FlightGear was released [34]. FlightGear is compatible with many type of processors and operating systems (OS) like Microsoft Windows (32 and 64 bits), Linux, Solaris, FreeBSD, MacOS, Irix and OS-X and is written in C++ [34]. Since 1996, many things have changed, but the main change was the 3D engine, changing from the Portable Library (PLIB) to OpenSceneGraph [35]. The FlightGear included LaRCsim, a Flight Dynamics Model (FDM) from National Aeronautics and Space Administration (NASA) but was replaced by the University of Illinois at Urbana-Champaign (UIUC) FDM. In 2000, the JSBSim was the default FDM [35]. The engine of the FlightGear is the SimGear that dynamically creates a string like /position/latitude and changes the aircraft to that position [36]. It Is widely used by academic and research environments for development flight simulation ideas since it allows the users to create new and experimental aircraft like gliders, helicopters, fighter jets or commercial jets [35]. To simulate the terrain, FlightGear uses TerraGear. TerraGear is a open-source software that converts the Geographic Information System (GIS) data available in 3D models or maps of the Earth. This software imports 3D models like the Digital Elevation Model (DEM), a set of elevation points on a regular grid. Objects like runways, taxiways, airport beacons, radio transmission towers, landmass outlines, lakes, islands, ponds, urban areas, glaciers, land usage and vegetation are available from various government agencies and are rendered by the TerraGear. [36] The weather effects are presented in FlightGear too, like 3D clouds, wind, lighting effects, time of the day, thunderstorm and other effects [36].

The first FDM in FlightGear was based on LaRCsim from NASA and it was sufficient for the most common situations in flight but in abnormal situations like deep stalls, spins or steep turns, it demonstrated an incorrect aircraft behaviour [36]. So FlightGear decided to support different flight models. JSBSim is the default FDM software since 2000 developed by Jon Berndt. This model can be used to model the Cessna 172 or the X-15 [36]. The YASim model is another FDM based in geometric information and not in aerodynamic coefficients, providing the best results when it comes to the modelling of a new aircraft design, especially for a rotorcrafts and helicopters [36]. There is also a FDM developed by Christian Mayer for a hot air balloons [34]. Last but not least there is the FDM by UIUC which initial idea was the modelling of aircrafts in icing conditions. The team has now the challenge of modelling nonlinear aerodynamics, resulting in more realism in extreme aircraft attitudes, like stall or high angle of attack in flight [34]. Although FlightGear is not certified by the FAA, the development team is making all the efforts to add it to the FAA-approved software for a PCATD flight training device [36]. The FlightGear is a freeware flight simulator and in constant development due its open source, make it a valuable tool used by universities and other research groups.

5. Case Study – Hybrid Airship Flight Simulation Design

When talking about aerospace vehicles, we find different categories. One is the vehicles lighter than air (LTA), where we find airships. Mainly used in the beginning of Aviation, the airships attract the present organizations and researchers to develop further studies regarding its flight capabilities. While most vehicles use their propulsion system to maintain themselves in the air - the heavier than air vehicles, the LTA vehicles use lighter than air gases to make them lift from the ground and a propulsion system to make them move in the air. In the past few years new ideas have come up and new concepts are being developed in order to increase the LTA lifting abilities, by combining its concept with the traditional airfoil and rotorcraft technology applied in other air vehicles, becoming a hybrid system [37]. This will create operational advantages like hovering and VTOL operation, reducing the ground support and necessary facilities, allowing a reduced transport time. Airships can also have several designs and structure types but we will focus on one in particular: the rigid airship, shown in figure 4.

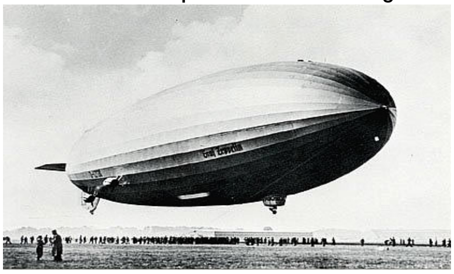

Figure 4 - Example of a Rigid Airship, Graf Zeppelin II [40]

The rigid airship consists in an internal stiff framework supporting the gondola, the propulsion system, the empennage and ballonets with lighter than air gas – normally helium – enabling the proper lift (buoyancy) and trim capacity adequate for each flight phase [38]. The gondola is suspended in the lower part of the airship where the cockpit and crew/passengers/cargo facilities are located. The propulsion can be made by several forms and it can also be associated with the empennage, consisting in fins, rudders and elevators that provide the dynamic and steering needed to successfully control this vehicle [39].

At University of Beira Interior, we are conducting a research regarding this kind of vehicles. The main objective is to simulate the flight of a rigid hybrid airship, studying its design, control, dynamics and stability (specially its buoyancy and static lift) in order to achieve the results necessary to apply it properly on a real World prototype. The National Aerospace Laboratory (NLR) in Amsterdam has already applied this studies to a standard rigid airship using a PC based desktop environment tool. At NLR this tool was developed using the MATrix LABoratory (MATLAB)/Simulink software to support the flight dynamics and control. MATLAB is a computer software that combines the mathematical computation with advanced visualization; Simulink is a MATLAB add-on that enables the simulation of dynamic systems and the evaluation of the system performance [41].
With this type of software, together with a PCATD software and the knowledge associated we believe that this will lead to the creation of a virtual simulation tool for this type of airships, which will also fund the testing of further systems regarding the avionics and the airship manoeuvring with the development of a flight training device.

6. Conclusion and Future Work

By simulating a technical system, its behaviour can be tested before it is built. This avoids costly redesigning in case of possible errors that would otherwise only be found when operating the system. It also allows training, developing, strengthening and reinforcing habits which are conducive to the increased safety of the operation, making it possible for operators to incorporate these habits naturally when carrying out their daily work. Because of that, flight simulation is used nowadays to teach, learn and research. If we want to design and develop a new aircraft concept, we should use a flight simulation software based on CFD, but if we want a platform for an aircraft enough documented and tested we can use a simulator based in Newtonian model, allowing an accurate representation of the aircraft in study.
Regarding our project, we will start by designing the airship with CAD software and discuss the ideal propulsion system, using modelling and simulation to develop the data for its control and stability. Once that is achieved, that data will be connected to a PCATD software in order to simulate the airship in a virtual World environment, developing the necessary flight controls and avionics. The PCATD software chosen will be the FlightGear, with its open source limitless facilities and Prepar3D® due its learning curve. Finally, with this accurate digital

representation of the prototyped airship, a flight training facility can be produced for teaching, flight training and studies on pilot behaviour.

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