Development of a Flight Simulation Training Device and Remote Pilot Station: The URBLOG Unmanned Hybrid Airship Vehicle Case

Laura Sofia Nobre Martins

Dissertação para obtenção do Grau de Mestre em
Engenharia Aeronáutica
(mestrado integrado)

Orientador: Professor Doutor Jorge Miguel dos Reis Silva

junho de 2020

Dedicatory

Alzira Borges Coelho
Salvador Vieira Nobre
Maria Castela Pereira Martins
Ulisses Lopes Ferreira Martins

Diogo Valério Brito

Pintas Tobias Boby

You are dearly missed

"Those who pass by us, do not go alone, and do not leave us alone;
they leave a bit of themselves, and take a little of us."
Aviator and Writer Antoine de Saint-Exupéry

Acknowledgements

The development and conclusion of this dissertation mark the end of a chapter that has been filled with many adventures and special moments. This work represents the fulfilment of many dreams and projects that could not have been possible without the extraordinary people by my side. Their support had a major impact on me and how, why and when this dissertation was performed. Therefore, I would like to express my greatest gratitude to:

Miguel and Tiago, for their friendship from the very first moment, standing with me side by side during all my successfulness and downfalls. Thank you for bearing with me closely for the last nine years!

All the Academic and teaching personnel, at all the stages of my educational path: schools and university. Their teachings made me who I am today.

NIT - Núcleo de Investigação em Transportes, where I met wonderful people that allowed me to explore my areas of interest and embrace new opportunities, in a family-like environment. A research group that made me grow not only as a researcher but also as a person. A special thank you to Maria Emília Baltazar for her directness and honesty, and Luís Trindade, for the mutual support in the URBLOG project.

All the institutions that gave me the conditions and the opportunity to learn and fulfil my curiosity, particularly in flight simulation: Universidade da Beira Interior, Cranfield University and Politechnika Rzeszowska im. Ignacego Łukasiewicza. My dearest and written appreciation to the people of the International Relation offices that guided me through my Erasmus + experience in Rzeszów: Sofia Lemos, Joanna Ruszel, Monika Mistur-Góral and Monika Stanisz. During that year in Poland, not only I had an excellent time expanding my academic and personal skills with an outstanding university program, but also the opportunity to fulfil a lifelong dream of learning to fly. Being in such Aviation related city, allowed me to take that chance, which I will always be grateful.

My course and university colleagues, nationally and internationally, that shared with me the most amazing adventures and moments, including in my Erasmus + experience. Some have stayed in my close circle, others followed different paths, but those moments will last forever. *Dziękuję bardzo* to Joanna Kulczycka for all the friendship and support as my buddy during my stay in Rzeszów.

People I met abroad in conferences and courses, sharing their insights and challenges, making me realize the different perspectives and ideas on so many different topics in Aviation. Some keep in touch; distance is only a number.

My present/current and former work colleagues that happily share their knowledge and show me how vast and complex Aviation is.

The available to perform the Human In the Loop study included in this dissertation. Without them, that study would not be possible.

My friends, that during the last few years accepted and understood my non-availability and gave me strength to carry on.

My family, that is always supportive and interested.

My parents, Ana and Paulo, that gave me wings to fly, but keep the nest open for my return with the most loving heart.

Professor Jorge Silva, that made the last 6 academic years possible the way they were, leading to the conclusion of this work. With his mentorship and competence in different roles, I outgrew myself, reaching objectives I had never thought, accepting unimaginable challenges. His support, trust and guidance led me to join NIT, pursue my interests and fight my difficulties as a student and researcher. His attention to detail and patience made me a more thoughtful professional. His friendship and inspiration kept me going beyond the higher skies and surpass myself.

João, for all the love, friendship, patience, and support. You are my co-pilot.

Thank you

Abstract

With the growing number of passengers and technological advancements, the Aeronautical industry is keen on new and reinvented types of transportation. New interest in airship technology has grown in the past few years to enhance its flight capabilities.

A new solution for urban mobility appeared, with new airship design. This airship, named URBLOG, combines the traditional airship concept with rotorcraft technology. Being a new concept, it requires methods and solutions to reach its new goals.

Simulation emerges as a solution to design, test and validate methods at a low cost when developing a new vehicle prototype. Concepts can be optimized and improve their time to the market. In addition to simulation of the vehicle for design proposes, it is also possible to apply it on Flight Simulator software to understand its flying characteristics and to design its synthetic environment, as a flight simulation training device (FSTD).

In this work, an unmanned version of the URBLOG is firstly designed on the CAD software Blender® and is later implemented in flight simulation software Lockheed Martin Prepar3D®, reflecting the main purpose and characteristics of the vehicle. A virtual cockpit is designed, and the flight simulation training device (FSTD) is defined, which can be integrated into the remote pilot station (RPS) of the URBLOG's remote piloted aircraft system (RPAS). This is developed considering the operator's point of view and the human factors considerations applicable to cockpit design and remote pilot stations (RPS). A basic training programme is then produced to train the unmanned vehicle operator of that station. To verify and validate the programme and that synthetic environment, a human in the loop study is conducted.

Keywords: Airship; Synthetic Environments; Flight Simulation; Unmanned Vehicle Operator; Flight Simulators; Flight Training Devices; Flight Simulation Training Devices Remote Pilot Station; Remotely Piloted Aircraft Systems; Virtual Cockpit; Training; Human in the Loop; Simulation; Human Factors

Resumo

Com o crescente número de passageiros e avanços tecnológicos, a indústria aeronáutica está atualmente interessada em novos tipos de transporte. Nos últimos anos surgiu um novo interesse em dirigíveis, combinando novas tecnologias para aprimorar as suas capacidades de voo. Baseado nesta necessidade, surgiu uma nova solução para a mobilidade urbana, com um novo tipo de dirigível. Este dirigível, de nome URBLOG, combina o modo de voo tradicional de um dirigível com a tecnologia de aeronaves de asa rotativa, e sendo um novo conceito, requer métodos e soluções para atingir os seus novos objetivos.

A simulação do voo aplica-se como uma solução de baixo custo para desenvolver o novo protótipo do veículo, de modo a projetar, testar e validar os métodos e soluções em questão. Estes conceitos podem ser otimizados e melhorados, agilizando a sua implementação no mercado. Além da simulação do veículo para o desenvolvimento do projeto proposto, ao aplicá-lo em *software* de simulação de voo, é possível igualmente entender as suas características de voo e projetar o seu ambiente sintético de treino, como um dispositivo de treino de simulação de voo (FSTD).

Neste trabalho, um protótipo não tripulado do URBLOG é primeiramente projetado no *software* de desenho assistido (CAD) por computador Blender® e posteriormente implementado no *software* de simulação de voo Lockheed Martin Prepar3D®, onde é criado o seu modelo de voo refletindo o seu principal objetivo e características do veículo. É projetado um *cockpit* virtual bem como o seu FSTD, podendo estes ser integrados numa estação de piloto remoto (RPS) do sistema de aeronave pilotada remotamente (RPAS) onde o URBLOG se inclui. Este desenvolvimento é focado no ponto de vista do operador bem como os fatores humanos aplicáveis ao design de *cockpits* e das estações de piloto remoto (RPS). Um programa básico de treino é produzido de modo a treinar os operadores do veículo não tripulado nesse ambiente sintético e validar as suas funcionalidades. Para validar e verificar também esse programa, é criado um teste onde a componente humana, por via de vários utilizadores de teste, é incluída nesse mesmo ambiente sintético, simulando uma possível operação do URBLOG.

Palavras-Chave: Dirigível; Ambiente Sintético; Simulação de Voo; Operador de Veículo Não Tripulado; Simulador de Voo; Estação de Piloto Remoto; Sistemas de Aeronaves Pilotadas Remotamente; Cockpit Virtual; Treino; Simulação; Fatores Humanos

Resumo Alargado

Esta secção resume, em língua portuguesa, o trabalho desenvolvido nesta dissertação de mestrado. É primeiramente efetuado um enquadramento sendo depois abordados os seus objetos e objetivos. No final serão apresentadas as principais conclusões e perspetivas de investigação futura.

Com os crescentes avanços tecnológicos, novos tipos de transportes estão a ser estudados como possíveis soluções para problemas de mobilidade urbana. Devido a essa necessidade emergente, foi iniciado em 2014 um projeto de um dirigível na Covilhã, Portugal. Este projeto, chamado de URBLOG, evoluiu para um Sistema de Transporte Aéreo Multifuncional, sujeito a pedidos de patente nacional (PT 108532 A) e internacional (WO 2016/195520 A). Este dirigível combina o modo de voo tradicional de um dirigível com a tecnologia de aeronaves de asa rotativa, tornando-se um sistema híbrido que pode efectuar voo estacionário e realizar descolagens e aterragens na vertical. Apresentando-se este como um novo conceito, tornou-se necessário realizar um estudo de métodos e soluções para atingir os seus novos objetivos.

A simulação do voo aplica-se como uma solução de baixo custo para desenvolver um protótipo deste veículo, de modo a projetar, testar e validar os métodos e soluções em questão. Estes conceitos podem ser otimizados e melhorados, agilizando a sua implementação no mercado. A simulação de voo aplicada ao veículo no desenvolvimento do projeto torna igualmente possível entender não só as suas características de voo, bem como projetar o seu ambiente sintético de treino de simulação de voo (FSTD). Assim, considerando um protótipo não tripulado do URBLOG, com um comprimento de 8,5 metros, esta dissertação aborda o desenvolvimento e a implementação deste veículo num dispositivo de treino de simulação de voo (FSTD), refletindo o seu principal objetivo e características. Por ser uma aeronave pilotada remotamente (RPA), parte de um sistema de aeronave remotamente pilotado (RPAS), o dispositivo de treino torna-se relevante não só no teste de sistemas, treino do operador do veículo e desenvolvimento do seu cockpit virtual, como também por poder ser parte integrante da sua estação de piloto remoto (RPS).

Este trabalho terá então dois objetivos específicos: o primeiro será a implementação do dirigível num *software* de simulação de voo, com a consequente criação do seu *cockpit* virtual e implementação do ambiente sintético; e o segundo, a definição de um programa básico de treino para os operadores desse ambiente, permitindo também a validação e verificação dos mesmos. Em ambos os objetivos, o foco é a operabilidade do sistema do ponto de vista do operador bem como os fatores humanos aplicáveis ao design de *cockpits* e das estações de piloto remoto (RPS), que podem contribuir para um acidente ou incidente. Este trabalho interconecta, portanto, os ambientes sintéticos, com os dispositivos de treino de simulação de voo (FSTD), as estações de piloto remoto (RPS), o treino dos operadores destas estações, e os fatores humanos aplicáveis.

O protótipo não tripulado do URBLOG foi assim primeiramente projetado no *software* de desenho assistido por computador Blender® e posteriormente implementado no *software* de simulação de voo Lockheed Martin Prepar3D®, onde é criado o seu modelo de voo refletindo o seu principal objetivo e características do veículo. A escolha deste software é feita através de um estudo comparativo com outros *softwares*, sendo justificada pelas possibilidades que este oferece bem como a informação conhecida do protótipo.

Para o desenvolvimento do *cockpit* virtual e do seu FSTD, vários tipos de instrumentos de voo são analisados, assim como os fatores humanos aplicáveis aos *cockpits* e estações de piloto remoto (RPS). O foco do desenvolvimento foi direcionado aos elementos essenciais de controlo do veículo na perspetiva do seu operador, incluindo as interfaces virtuais, como o *cockpit* virtual e as interfaces físicas. Dois tipos principais de instrumentos de voo foram escolhidos e um *head up display* (HUD) foi adaptado para uma constante monitorização dos dados de voo numa visão para fora do veículo. Como os requisitos de vários sistemas do URBLOG não estão definidos, as interfaces físicas escolhidas são produtos comerciais de uso genérico (COTS), embora assegurando um certo número de preceitos e recomendações. Juntas perfazem uma certa configuração, composta por um computador portátil, com o *software* de simulação de voo Prepar3D® instalado, juntamente com uma interface de controlo de voo, onde as duas mãos estão sobre os comandos (HOTAS), um dispositivo de *head-tracking* e um ecrã adicional. Essa configuração foi posteriormente implementada, definindo assim o ambiente sintético.

No entanto, devido à pouca informação disponível sobre os vários sistemas do veículo, foram feitas diferentes suposições para ilustrar o seu conceito no *software* de simulação de voo. Por esse motivo, caso mais dados estivessem disponíveis, outras opções poderiam ter sido selecionadas nesta dissertação. Isso afetaria não só o *cockpit* virtual, como também as interfaces físicas do próprio ambiente sintético, os procedimentos, e limitações de operação do veículo. De igual forma, certas características do URBLOG não puderam ser implementadas, como a propulsão dos rotores instalados nas suas superfícies (tecnologia de aeronaves de asa rotativa), assim como a acoplagem a uma estação, pois o veículo é controlável apenas acima do nível do solo com o motor ligado.

Foi de seguida definido um programa de treino para que o ambiente sintético do URBLOG pudesse ser efetivamente usado. Um estudo de componente humana, por via de vários utilizadores de teste é incluído nesse mesmo ambiente sintético, de modo a verificar e validar tanto a disposição das suas várias interfaces como também esse mesmo programa de treino. Este estudo, realizado por diferentes utilizadores, chamados de operadores, com diferentes níveis de conhecimento, consistiu no efetuar e concluir de uma missão com diferentes tarefas, no programa de simulação de voo onde o URBLOG foi implementado. Para isso, os operadores foram convidados a seguir o manual de operação do veículo, também desenvolvido no âmbito desta dissertação, contendo as suas características, limitações e procedimentos operacionais. Os dados e os parâmetros de voo deste estudo foram registados e comparados com uma referência ótima relativa obtida por um operador externo, mais experiente. Os desvios padrão e medianas de e entre operadores foram calculados, originando 91 gráficos para uma melhor analise.

O programa de treino desenvolvido foi bem-sucedido, levando à verificação e validação não só desse mesmo programa, assim como também do ambiente sintético definido. O manual de operação do URBLOG revelou-se muito eficaz, fornecendo não só informações suficientes para a correta interpretação das características e controlo do veículo, como também do ambiente sintético. O nível de conforto designado pelos operadores durante a execução da missão indica que o ambiente sintético projetado foi adequado.

Os resultados do estudo sugerem que indivíduos com mais experiência de voo virtual podem reagir melhor a esse ambiente sintético do que os pilotos da vida real. Adicionalmente, verificou-se que indivíduos sem experiência de voo, seja ela virtual ou real, conseguem, num curto espaço de tempo, adequar-se e realizar esta missão com sucesso sem treino. Mas, reconheceu-se que com um estudo com um número reduzido de utilizadores de teste, assim como de uma amostra de dados de um único operador externo experiente para a comparação de dados é limitado, e pode induzir resultados menos corretos.

Quanto às recomendações e sugestões, todos os operadores sugeriram melhorias na fase de aproximação e aterragem em relação aos *flaps*. O valor relativo ao seu nível de posição deve ser visível no *cockpit* virtual, devendo igualmente ocorrer a inibição de certas posições durante determinadas fases do voo, especialmente durante a fase de aterragem. Essas sugestões são pertinentes e podem levar de facto a uma melhoria no controlo do veículo, mas dado que a sua implementação seria demorada pois exigiria uma nova análise das interfaces e um novo estudo de componente humana de modo a validar e verificar o seu uso, a sua implementação não foi incluída neste trabalho.

Como os ambientes sintéticos podem ser facilmente adequados para diferentes tipos de alterações, sejam elas virtuais, físicas ou processuais, os seguintes itens podem ser considerados possíveis desenvolvimentos futuros deste trabalho:

- Implementar as sugestões propostas no estudo de componente humana realizado;
- Melhorar o modelo do URBLOG de modo simular a propulsão dos rotores em todas as fases do voo, permitindo o voo estacionário para uma melhor decolagem e aterragem vertical. Incluir igualmente o controlo do leme de direcção, e os compensadores das superfícies de voo nesse modelo;
- Desenvolver um sistema de trem de aterragem ou incluir suportes para a aterragem neste protótipo do URBLOG, de forma a permitir a acoplagem do veículo a uma estação;
- Implementar este ambiente sintético num computador de mesa, com mais possibilidades gráficas para incluir ecrãs adicionais, de preferência permitindo uma visão de 180º. Para isso, é recomendável que o HUD permaneça numa posição fixa em vez de se mover com a visão do operador;
- Reunir dados de pilotos e operadores proficientes de veículos não tripulados neste mesmo ambiente sintético e apresentá-los nas comparações de dados de voo do estudo de componente humana, incluindo também um número maior de operadores de teste na amostra;
- Implementar o URBLOG num outro programa de simulação de voo assim que hajam mais dados disponíveis e comparar resultados, usando o mesmo ambiente sintético e programa de treino, com as devidas alterações operacionais;
- Desenvolver um estudo adicional sobre o impacto do dispositivo de *head-tracking* e ecrãs sensíveis ao toque neste ambiente sintético;
- Incluir outras funcionalidades de automação, como o piloto automático, permitindo analisar o seu efeito no operador, assim como os requisitos necessários à navegação por instrumentos num espaço aéreo;
- Aplicar as noções obtidas no sistema remoto real do URBLOG.

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List of Acronyms

AGL - Above Ground Level

ANAC - Autoridade Nacional da Aviação Civil

ATC - Air Traffic Control

ATD - Aviation Training Devices

ATO - Approved Training Organization

BITD - Basic Instrument Training Device

CAD - Computer-Aided Design

CFD - Computational Fluid Dynamics

CG - Center of Gravity

COTS - Commercial Off-The-Shelf

COVID19 - Coronavirus Disease 2019

CPU - Central Process Unit

CRM - Crew Resource Management

CS-FSTD(A) - Certification Specification Aeroplane Flight Simulation Training Devices

DG -Directional Gyro

DME - Distance Measurement Equipment

DOF - Degrees of Freedom

EASA - European Aviation Safety Agency

FAA - Federal Aviation Administration

FCOM - Flight Crew Operation Manual

FCTM - Flight Crew Techniques Manual

FFS - Full Flight Simulator

FNPT - Flight and Navigation Procedures Trainer

FSQAR - Flight Simulator Quick Access Recorder and Analyzer

FSTD - Flight Simulation Training Devices

FSX - Flight Simulator X

FTD - Flight Training Device

GA - General Aviation

GCS - Ground Control Station

GPS - Global Positioning System

HF - Human Factors

HITL - Human In the Loop

HMI - Human Machine Interface

HP - Human Performance

HUD - Head-Up Display

IAS - Indicated Airspeed

ICAO - International Civil Aviation Organization

ILS - Instrument Landing System

IVAO - International Virtual Aviation organization

IWG - International Working Group

JAA - Joint Aviation Authorities

KIAS - Knots-Indicated Air Speed

LCD - Liquid-Crystal Display

LTA - Lighter than Air

MFD - Multifunction Display

NAA - National Aviation Authority

NASA - National Aeronautics and Space Administration

NAV1 - Radio Navigation Receiver 1

OAT - Outside Air Temperature

OBS - Omnidirectional Bearing Selector

OTW - Out-The-Window

PC - Personal Computer

PCATD - Personal Computer-Based Aviation Training Device

PF - Pilot Flying

PFD - Primary Flight Display

PM - Pilot Monitoring

RAeS FSG - Royal Aeronautical Society Flight Simulation Group

RPA - Remotely Piloted Aircraft

RPAS - Remotely Piloted Aircraft Systems

RPS - Remote Pilot Stations

SOPs - Standard Operating Procedures

SPD - Speed

SSD - Solid State Drive

UA - Unmanned Aircraft

UAV - Unmanned Aircraft Vehicle

VOR - Very high-frequency Omnidirectional Range

VR - Virtual Reality

VRAM - Virtual Random-Access Memory

VTOL - Vertical Takeoff and Landing

ZFTT - Zero Flight Time Training

Chapter 1 - Introduction

1.1 Motivation

The Aeronautical industry is growing as the number of air passengers increases year by year and new ideas for transportation appear. With more eco-friendly and cutting-edge technology, different types of aerospace vehicles are now developed and subjected to accurate studies. Ideas from the past, are now reinvented with new objectives. Mainly used at the beginning of Aviation, airships are now studied, and projects are being carried further to enhance their flight capabilities.

Airships predate traditional aircraft by 50 years and were found most useful in the 1920's and 1930's. Its speed, cutting the travel time with luxurious cabins, where passengers could enjoy fine meals but also combining aerodynamic and aerostatic lift characteristics given by the buoyancy provided by a lighter than air gas, made them a preferable mean of transportation for long distances. With the improvements of fixed-wing aircraft, that evolved to a fast, efficient, and cheaper transportation, together with unfortunate accidents like the Hindenburg disaster, the airship technology became obsolete. But, by combining the traditional concept of an Airship with nowadays technology, new propulsion systems to increase its lifting capabilities, new materials and new avionics, a new opportunity for this type of aircraft is now possible. With operational advantages like hovering and vertical takeoff and landing (VTOL) operation, with consequent reduced ground support and facilities, airships can provide a reduced transport time, particularly relevant in urban areas, often with ground transportation constraints [1].

With the emergent necessity of finding new solutions for mobility issues in urban areas, an airship project was born in 2014 in Covilhã, Portugal. Then called URBLOG project, it evolved to a Multifunctional Air Transport System, subject to national (PT 108532 A) [2] and international patent (WO 2016/195520 A) [3]. This airship, named URBLOG, combines the concept of the traditional airfoil and buoyancy of this type of vehicles with rotorcraft technology applied in its control surfaces, becoming a hybrid system that can perform hovering and VTOL operations. This type of airship, characterized by its ability to land and takeoff without a ground crew of rope-holders, reduces the ground support and consequently the flight duration. This can lead to vast applications, including air surveillance and cargo transportation. Within such a project, it is intrinsic to the application of simulation in several stages. Why Simulation? The industry is constantly developing products and those products require designing and testing. With modelling and simulation lower development cost, it is possible to design, test and validate the product, improving its time to market. Development of a flight simulation training device for a new aircraft enables then the validation and verification of concepts, optimizing cockpit designs and furthermore, the development and enhancement of flying techniques. Flight simulator software together with a physical reproduction of the designed cockpit, flight simulation training device, can be used for flight training. These devices have dramatically reduced the cost of training by providing cheaper, effective alternatives to training on a real aircraft.

1.2 Object and Objectives

Considering an unmanned 8.5 meters long airship prototype in development, the URBLOG of the Multifunctional Air Transport System, the main object of this dissertation will be the development and implementation of this airship model on flight simulator software where the purpose and characteristics of the vehicle are represented, which will allow the development of a flight simulation training device (FSTD). By being a remotely piloted aircraft (RPA), part of a Remotely Piloted Aircraft System (RPAS), this FSTD will be, not only relevant on system's testing, cockpit design and operator training, but it can also be further used as part of the Remote Pilot Station (RPS) once the vehicle is produced.

Therefore, this work will have two specific objectives. The first will be the implementation of the airship on flight simulator software, leading to the definition of its virtual cockpit and the setup of a FSTD that can be further used as part of the remote pilot station (RPS). This study will take in consideration the current software that is necessary to simulate the airship reflecting its purpose, the cockpit layout and instruments needed, the several types of simulation fidelity, lessons learned from other systems and the human factors applicable in cockpit and RPS design. The second objective is the development of the operator's training programme. A basic self-study training programme curriculum will be developed to train the operator to fly the simulated URBLOG in such RPS. A human in the loop (HITL) study will be developed to assess and obtain feedback from test users to verify and validate the training programme and the RPS. Nevertheless, on both objectives, the focus will be the system's operability from the operator's point of view, considering design-related human factors (HFs) errors that may lead or contribute to an accident or incident.

1.3 Methodology

To develop a system, the task should be divided into several steps, which will progressively fulfil all its requirements. But to establish those, the main objective shall be identified so a practical solution can be found and be taken into consideration in every step. In this case, where a new type of vehicle is in development, the requirements are not well defined. Experience and requirements of previous vehicles, including what failed shall be taken into consideration. To be manageable, complex problems must be broken into parts and incrementally addressed. Any change in a system can have extensive implications, and a control station must assure continued adequate situational awareness for crews, so the vehicle is properly and safely controlled. The design should be human-centred to the extent possible. Thus, for this system to be implemented, a broken-down structure will be followed so all the constraints and requirements for each step are put into consideration in Figure 1.1.

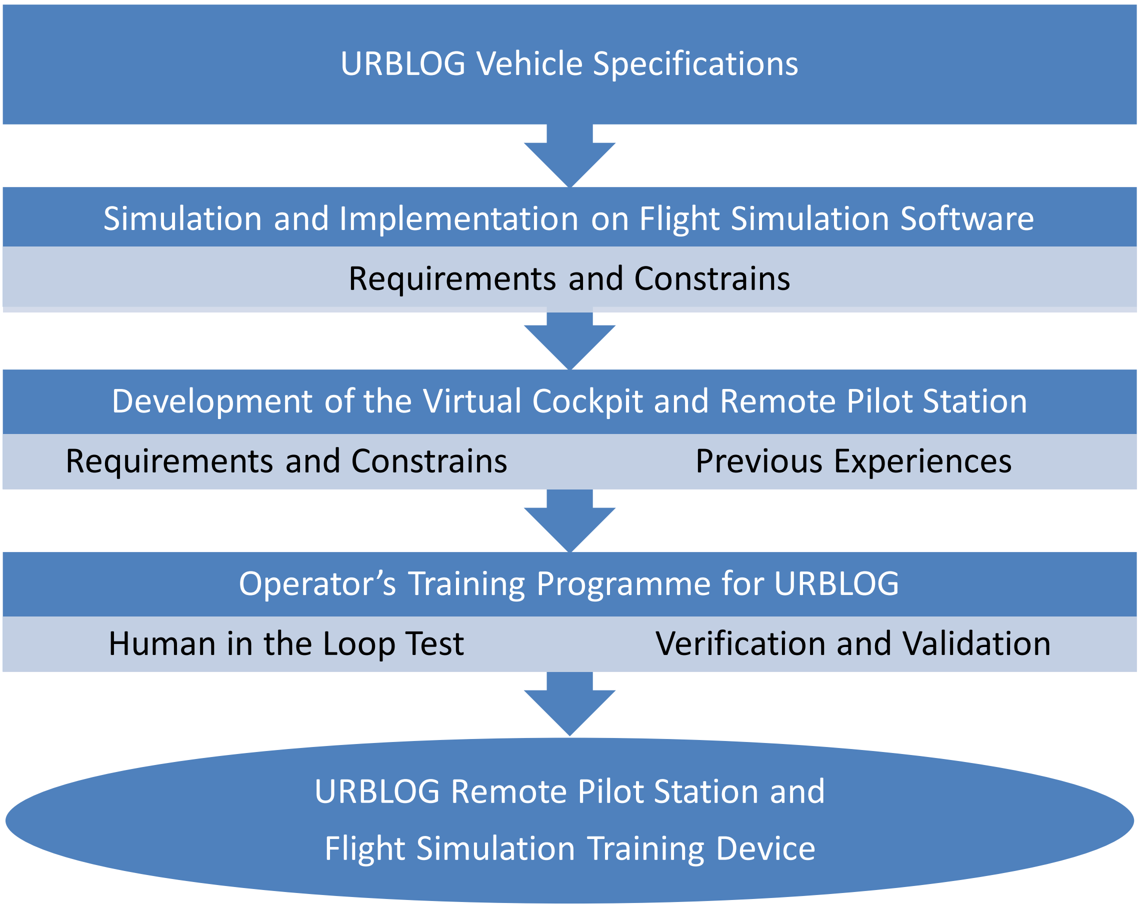


Figure 1.1 - Methodology Overview

1.4 Dissertation Structure

This dissertation is divided into five chapters.

The first chapter is the work Introduction and presents the motivation, the main object and the specific objectives, the methodology and the dissertation structure that will be followed.

In chapter two a state-of-the-art review concerning flight simulation and flight simulation training devices, including how they are defined and regulated by civil authorities. Secondly, an overview regarding Remotely Piloted Aircraft Systems (RPAS), Remote Pilot Stations (RPS) of these systems and the operator's training, including Human Factors aspects relevant to these systems, are performed. The URBLOG is then contextualized as part of a RPAS.

The third chapter includes the implementation of the airship on flight simulator software realised according to its purpose. Processes are described and the software's strengths and limitations are explained to support final choices. Flight instruments required are analysed, as well as the hardware interfaces necessary. It concludes with the interfaces chosen and the layout to be implemented in the RPS.

Chapter four consists of the development of the training programme that will provide the procedures to fly the simulated vehicle in the virtual cockpit layout implemented and in the RPS setup defined. This will consist of validation and verification via human in the loop (HITL) studies by the completion of a virtual mission also developed on the flight simulator software. The test subjects will be inquired before and after the mission, and their performance will be recorded. From this recording, an analysis will be made. The study conclusions will be considered and if possible, implemented in the system.

The fifth chapter is the work conclusions and presents the dissertation synthesis, a few concluding remarks, and some insights and challenges for future research.

Chapter 2 - State of the Art

2.1 Introduction

Towards the development of a new concept, it is necessary to contextualise the objectives of that particular study with what had been already developed in that field.

This chapter will firstly focus on a broad vision of Systems Modelling and Simulation, and then on a literature review of Flight Simulation and Flight Simulation Devices. On a different topic, the most recent airship's cockpits will be analysed as well Remotely Pilot Aircraft Systems (RPAS), in order to define Remote Pilot Stations (RPS), Remote Pilot Licensing and Training and related Human Factors in this type of devices. The conclusion of the chapter will associate the different topics towards the main objectives of this dissertation.

2.2 Systems Modelling and Simulation

When building a new product or finding a solution to a problem, the resolution is supported by a set of elements grouped for a particular reason to achieve a certain objective. This comprises elements and its interconnections, limited by a boundary, which consists of a system. A model will represent the characteristics or behaviours of that system. To implement the final product, Simulation appears as the operation of the system over time, by testing and validating its model, improving its time to market.

The simulation was first applied in the Industrial field through mathematical models to verify and improve either their products or their method of production. During 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 and is a very important tool of management, design, engineering, and training in different kind of fields. Nevertheless, it is important to understand the capabilities and limitations of the simulated model, on the premise that it is necessary to evaluate the level of reliability that is required to achieve the correct balance between fidelity and cost before the implementation of the simulation. Fidelity is the degree to which a model or simulation reproduces the state and behaviour of the real world. It is the measure of the realism of a model or simulation. Simulators are then the hardware or software response to simulate a certain environmental or conditions with the purposes of training or experimentation. Design parameters can be changed quickly and easily while running repeated tests and any dynamic physical system can be modelled mathematically. Virtual physical values can be tweaked while performance is tested [4].

2.3 Flight Simulation and Flight Simulation Devices

Simulation has made a major contribution to the Aeronautical sector. From being applied to Aeronautical engineering to flight training, flight simulation is today a field of aviation. Aeronautical engineering uses simulation mainly to design and evaluate aircraft systems, allowing a full reproduction of the designed aircraft on flight simulator software. This will not only confirm any design problem, but it will also allow manoeuvring studies to verify the flying capabilities. Applying modern technology carefully and scientifically, together with incorporating human-factors evaluations in the early stages of development, on virtual systems, using qualified pilots for the intended use will provide valuable insights [4]. Towards the certification of systems in the development of a new aircraft, flight simulator software and hardware can be combined with a full-scale reproduction or even actual onboard systems of electrics, hydraulics, flight controls and many others in a giant test rig named Iron-Bird, shown on Figure 2.1.

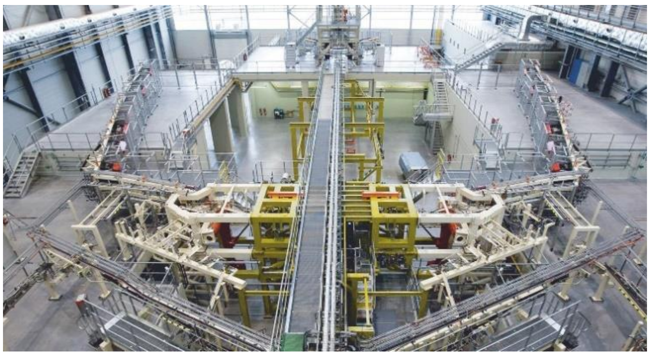


Figure 2.1 - Airbus A350 Iron-Bird [5]

Advanced flight training devices offer advanced high-fidelity performance, thus the results of this simulation where several flight conditions are tested are essential to test and validate the aircraft's systems. For example, for Airbus, even in the age of advanced computer simulations, the Iron Bird maintains a vital role in their testing protocols. Every Airbus aircraft has Iron-Bird as its precursor [5] and several virtual techniques are applied until the final aircraft implementation and its test flight, as seen below on Figure 2.2 for the Airbus A380.

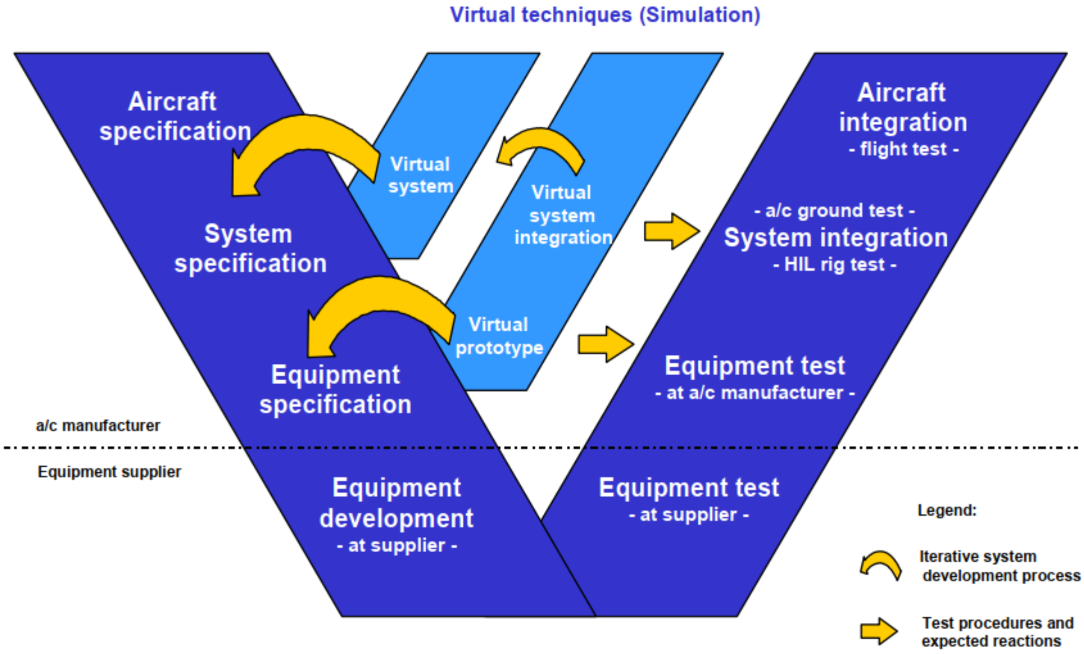


Figure 2.2 - Virtual techniques in the development of the Airbus A380 [5]

2.3.1 Flight Simulation Training Devices

For training purposes, Flight Training Devices (FTD) or Flight Simulation Training Devices (FSTD), are a type of synthetic training devices or environments that allow the visualization and immersion of the environment being simulated. FSTDs appear as a combination of flight simulator software together with a partial or integral physical reproduction of the designed cockpit to be used for flight training.

According to the European Union Aviation Safety Agency (EASA), "FSTDs represent a state-of-the-art pilot training tool which is capable of representing almost any flight and environmental condition. This allows pilots to be trained in very realistic scenarios without compromising safety and ensuring the economic efficiency of the training. (...) Currently, more than 450 FSTDs are qualified by EASA ranging from basic flight procedure trainer (flight and navigation procedures trainer (FNPT)) up to full flight simulator (Level D FFS) under the EASA oversight" [6:05].

Like every activity in the Aeronautical sector, flight training is strictly regulated, especially when it comes to FSTDs. The National Aviation Authorities and each airline that uses this type of devices must ensure that all FSTDs meet certain standards. Differences between each country have been translated to different regulation, and although a process of combining standards, the major Aviation Authorities, US Federal Aviation Administration

(FAA) and the European Joint Aviation Authorities (JAA) - now EASA - ended using different terms for similar FSTDs.

In March 2006, the Royal Aeronautical Society Flight Simulation Group (RAeS FSG) established an International Working Group (IWG) intending to harmonize flight simulation regulation. The results of the IWG meetings was the development of new qualification criteria for the complete suite of Flight Simulation Training Devices (FSTD). This new classification covers the 26 types of Training Devices to 7 types of devices as shown in Figure 2.3.

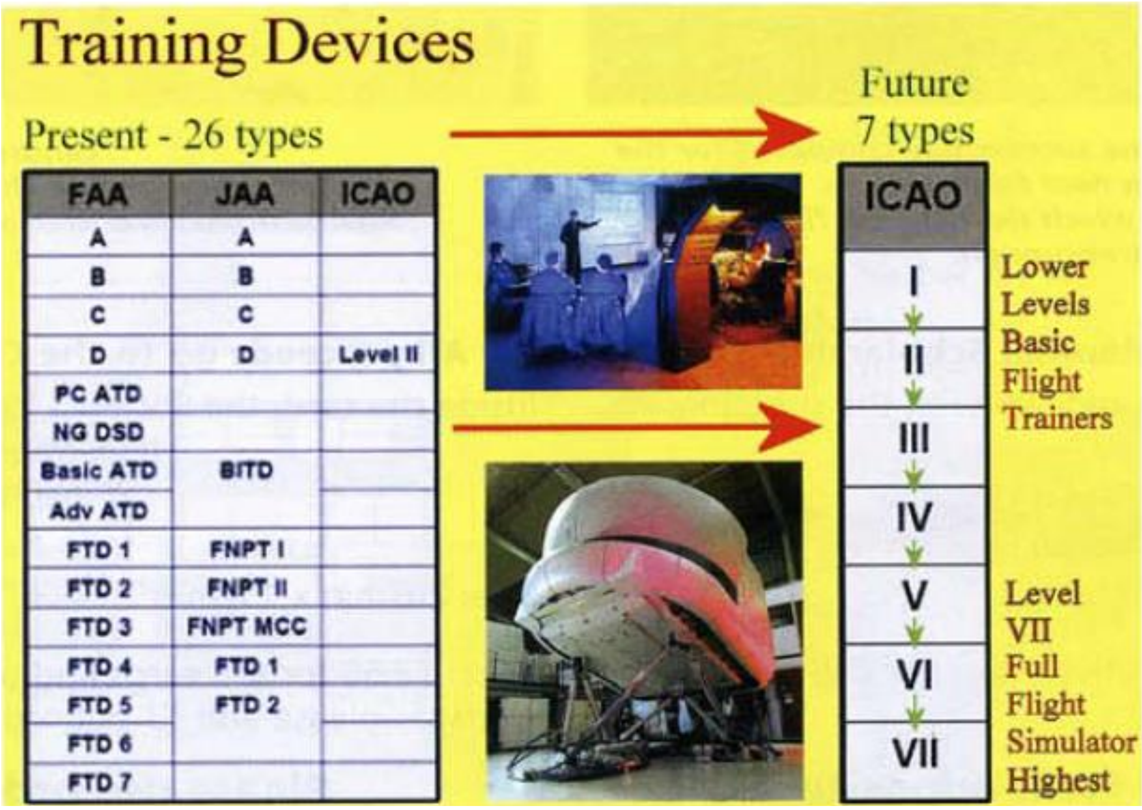


Figure 2.3 - Training Devices, Present to Future [7]

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 [7].

Although many efforts are being conducted, not every authority has adopted these standards. In 2015, the 4th edition of ICAO doc 9625 was released [8].

2.3.2 Flight Simulation Training Devices according to CS-FSTD(A) Regulation

According to the Certification Specifications for Aeroplane Flight Simulation Training Devices (CS-FSTD(A)) [9], the FSTD are divided by level of fidelity. The Portuguese Aeronautical Authority, Autoridade Nacional da Aviação Civil (ANAC) complies with this regulation [10], that states the following:

2.3.2.1 Full Flight Simulator (FFS)

An FFS is 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. Below, in Figure 2.4, is shown the several systems implemented on an FFS.

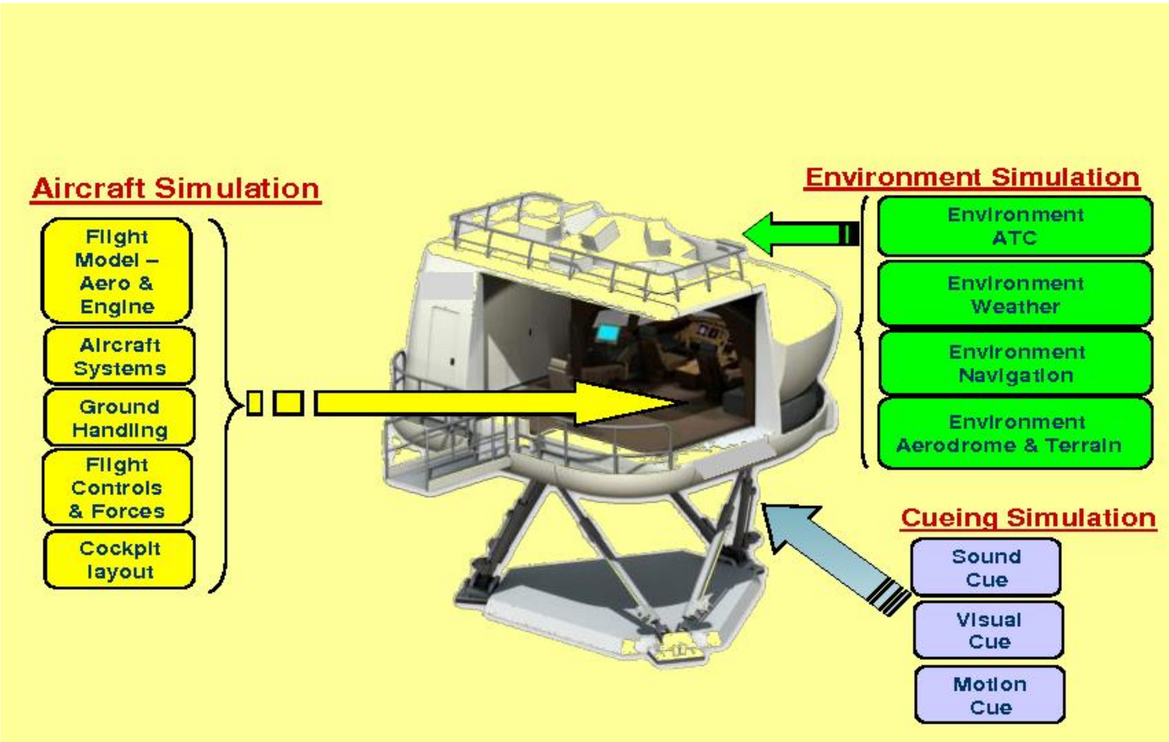


Figure 2.4 - Systems on an FFS [11]

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 FSTD, a pilot can fly a new type of aircraft without having flown that aircraft in real World (Zero Flight Time Training (ZFTT)) and train upset situations. 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 includes a motion system with six degrees of freedom, providing effects like turbulence, wind shear, engine failure and other abnormal situations [11]. As an example, below in Figure 2.5, one FFS for the Airbus A320 model it is shown.

Figure 2.5 - A320 Full Flight Simulator (FFS), outside (left), and inside (right) [12]

2.3.2.2 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 [11].

2.3.2.3 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 in-flight operations to the extent that the systems appear to function as in the aircraft [11].

2.3.2.4 Basic Instrument Training Device (BITD)

A ground-based training device which represents the student pilot‘s station of a class of aeroplanes. 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. This type of classification is primarily used by EASA. In FAA this type of device can be classified as Basic Aviation Training Device (ATD) or Advanced ATD [11].

2.3.3 Flight Simulation Training Devices 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 into seven categories, as in Table 2.1, with a fidelity level defining its type.

Table 2.1 - Qualification levels of Flight Simulation Training Devices (FSTDs) according to ICAO 9625 [11]

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 of 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.*

2.3.4 Flight Simulation Training Devices Classification according to FAA

The FAA categorizes aviation ground trainers into categories as full flight simulators or as flight training devices, in similarity to what is defined by both EASA and ICAO.

Nevertheless, they implemented the aviation training devices (ATDs). As a result of the continuing development in computer technology, flight simulation and visual displays, it led to the popular use of FSTDs and ATDs in General Aviation (GA). The GA community is using this evolving simulation technology to provide increasingly effective pilot training at a reduced cost. These devices can provide an adequate training platform for both procedural and operational performance tasks specific to the ground and flight training requirements for several pilot certificates, depending on their certification. This type of device is called Personal Computer-Based Aviation Training Device (PCATD).

The PCATD consists of three main parts, as seen in Figure 2.6: the PCATD software which provides a partial or comprehensive flight simulation environment on screen; the approved flight controls configuration; and a Personal Computer (PCATD Hardware). It is important to refer that for that certification; the FAA must certify all the number of parts.

Figure 2.6 - PCATD by ELITE Company [13]

These devices are a viable alternative for flight schools wishing to use a flight simulation training device but are not able to afford a more advanced FSTD. PCATDs can provide a controllable environment where the pilot can train and review its performance instantly, by either pausing the equipment or by recording its training. The flight situation can be easily changed, with no risks associated. Flight instructors can effectively teach many operational skills (e.g., instrument flying, traffic patterns, stabilized approaches, emergency procedures, etc.) using ATDs. These procedural and operational skills can then be positively transferred to successful operations in the real aircraft [14].

PC-based simulators can also be a valuable research tool, especially for the studies of human factors and pilot performance, a platform for instrumentation testing and development of new aircraft technologies, crew resource management (CRM) research, crew coordination and training research [15].

In some cases, virtual reality (VR) devices are being associated with these training devices to enhance the immersion of the simulation. Nevertheless, this implementation is yet to be certified for flight training [16].

2.4 Airship Cockpits

Airship cockpits are similar to those of other manned air vehicles. A cockpit is composed of several types of flight instruments and controls that enable the pilot to control the aircraft's attitude, performance and configuration. There is a control column (a yoke) or a joystick that make possible the control of the vehicle, as well of throttles that control the engine's thrust. Other controls can be found as the landing gear level, controlling the landing gear position, or the flaps handle, controlling the flaps position.

Nevertheless, airship control surfaces are generally very large aiming to provide good control response due to its very low flying airspeeds. Combining this with the very long control cables usually required, the forces applied by the pilot can be quite high. The use of fly by wire systems, with electric action on the control surfaces, can improve the control loads as well as possible delays in the response [17].

Recent airship cockpits, as the Zeppelin NT, are highly electronic, with digital glass cockpit panels and fly by wire systems for assisted and precise control [18], as shown in Figure 2.7 and Figure 2.8.

Figure 2.7 - Zeppelin's Flight Instruments [18]

Figure 2.8 - Zeppelin's Glass Cockpit [18]

2.5 Remotely Piloted Aircraft System (RPAS)

A Remotely Piloted Aircraft System (RPAS) is according to ICAO, a remotely piloted aircraft (RPA), associated with one or more remote pilot stations (RPS), together with the command and control links associated and any additional subsystem necessary for that particular system. In general, they are constituted by highly complex unmanned aircraft, piloted from remote locations due to highly reliable communication links, by licensed aviation professionals. The Convention on International Civil Aviation signed at Chicago on 7 December 1944 and amended by the ICAO, defined that any aircraft intended to be flown without a pilot on board was a pilotless, unmanned aircraft. These aircraft include a broad spectrum of devices, from meteorological balloons to RPAS. RPAS are subject to the same requirements and certification standards as manned aircraft operating in an airspace. In other words, RPAS are handled like manned aircraft. In similarity, its remotely piloted aircraft (RPA) can be a fixed-wing or rotary-wing vehicle. Evolving rapidly, these systems are creating a new industry, with large economic potential as they offer a vast range of capabilities, where different types of technologies and designs can be applied, leading to different operational concepts. They have demonstrated their importance in recent military operations, particularly for surveillance and information gathering, but on the civil applications as well. For infrastructure surveillance, firefighting, disaster or environmental monitoring, as in border control and management, they have been proven as an important tool. With the increase of use of these systems, standards are being developed and applied to integrate them safely and efficiently in the highly regulated manned aircraft industry [19].

The URBLOG prototype studied in this dissertation is within the RPAS concept, being a remotely piloted fixed-wing aircraft.

2.5.1 Remote Pilot Stations (RPS)

The remote pilot stations (RPS) consist of the equipment used to command, control and monitor flight of a remotely piloted aircraft (RPA). According to ICAO, designs can range from simple hand-held devices to complex, networked, multi-console configurations. The RPS may be located inside or outside of a building and may be stationary or mobile (installed in a vehicle/ship/aircraft). Whichever type, security, both physical and cyber, must be assured. The RPA is only to be controlled from one RPS at a time, but for international operations—especially those involving long haul flights—multiple, distributed RPS may be employed. The European Defence Agency is now developing a programme towards the standardisation of RPS, taking into account the EASA's certified operations category [19], [20].

RPS range from commercial off-the-shelf (COTS) laptops, to sophisticated purpose-built interfaces housed in shelter trailers or control facilities. Although some RPS possess aviation interfaces (such as joystick or sidestick controllers), most also include interfaces based on consumer electronic devices such as screen-based displays, with pull-down menus and "point-and-click" input devices [21]. Below, from Figure 2.9 to Figure 2.13, different types of RPS are presented.

Figure 2.9 - Remote Pilot Station prototype with a panoramic screen [22]

Figure 2.10 - Portable Ground Station by UAV Factory [23]

Figure 2.11 - Advanced Cockpit Ground Control Station (GCS) [24]

Figure 2.12 - RPS Solution developed by Airbus [25]

Figure 2.13 - ParagonC2 developed by S-Plane [26]

2.5.2 Remote Pilot Licensing and Training

Being a remote pilot can require training and medical certification, as similar to the requirements of a flying pilot license. Although in some countries, only flying zones are regulated (as is the case for Portugal in civil aviation), in some others, remote pilots are required to receive medical certification, complete training, and demonstrate competency before being licensed to fly an RPA. The training requirements and degree of competency required depend upon the complexity of the RPA being flown and the purpose of flight. All remote pilots should possess knowledge of aviation rules, regulations, and procedures, as well of radio-telephony in case of air operations in controlled airspace. Training is given at an Approved Training Organization (ATO) and the National Aviation Authority (NAA) where the RPS is located will issue, renew, or validate remote pilot licences for qualified applicants. The holder of a remote pilot licence and associated ratings and endorsements must not exercise the privileges beyond those issued and must maintain the validity of their licence as required by the issuing authority (in similarity to other pilot licenses) [27].

2.6 Human Factors in Cockpits, Simulators and Remote Pilot Aircraft Systems

With efficient pilot training, comes system familiarization. Nevertheless, no system is fail-proof. There will always be mistakes, either by the system controller or within the system's design, which was created by a human. With the advances in technology, it is possible to improve human performance to some extent with training and experience, but basic human performance remains fixed. In the understanding of the human characteristics and limitations, cockpit and control stations designs have been improved. The human factors engineering principles define how Human-Machine Interaction (HMI) is conducted in a particular system. HMI covers both physical and cognitive interface with the machine. In aviation, this approach has been implemented from the very first steps, where it was necessary to verify stick and rudder positioning and functioning arrangements. Nowadays, it is much more complex, as pilots and aircraft operate near the limits of performance. The pilots must react in ways that are dependent on memory and training for proper responses, and aircraft are allowed small margins of error. Pilot workload has been managed by the use of the newest products in advanced avionics and automation.

Automation can be defined as the execution by a machine agent (usually a computer) of a function that was previously carried out by a human. Automation can either enhance or diminish situational awareness, and there is a need for the designers, operators, and management to understand the risks associated with its use. For automation to truly enhance the task of a pilot, the design must be predictable, consistent, contextually correct, and provide adequate feedback for the pilot to maintain situational awareness at all times [21].

2.6.1 The Remote Pilot Aircraft Systems Case

RPAS are largely automated, nevertheless, they have generally experienced a higher accident rate than manned aircraft. Many of these accidents appear to reflect the unique human challenges associated with piloting an aircraft remotely, in combination with RPS that were designed with insufficient regard for human factors engineering principles. Widespread problems have been identified with control station interfaces. Examples include error-provoking control placement, nonintuitive automation interfaces, reliance on text displays, and complicated sequences of menu selection to perform minor or routine tasks. Some of these problems may have been prevented had an existing regulation or cockpit design principle been applied. In other cases, the design problem reflected emerging issues unique to RPAS that are not covered by existing regulatory or advisory material [21].

While operating an aircraft remotely, where no motion sense is present, it is essential that the pilot can clearly notice aircraft's attitude within six-degrees of freedom of movement as this movement is a function of pilot control inputs. All aural alerting and visual information must be clear and concise, otherwise, the pilot's senses can become overloaded with information. The information must be displayed in a manner that avoids this overloading condition.

In the case of RPAS, personnel tasked with initiating, managing, maintaining and operating the RPAS must have sufficient information to make safe, accurate, and timely decisions to take appropriate actions. They must be suitably qualified and experienced in performing their duties. When necessary, remote pilots must be able to override or modify automated functions, except where such actions cannot be executed safely due to immediacy of the situation (such as an imminent collision avoidance manoeuvre) or where task complexity makes human intervention unreasonable [19] [28] [29].

Error tolerant systems can recognize and correct inadvertent errors by the human operator, and allow easy correction of mistakes. [21]

2.6.2 Responsibilities of the RPA Pilot and Associated Implications

The remote pilot of an RPA can be responsible for conventional aviation duties as also with special challenges that RPAS represent. This can be monitoring and controlling the status of radio links, control hand-offs, flight termination and guidelines to avoid a collision, both with the ground and other aircraft. Since it is a single pilot operation, the role of Pilot Flying (PF) and Pilot Monitoring (PM) are combined. Hence the need to monitor the flight profile, flight instruments, fuel state, engines, radio, etc. constantly. The instrument scan must be carried out very frequently, especially during departure and approach in order to monitor the aircraft state and planned profile. Since it is a light aircraft environment, it requires additional external notion and monitoring [30].
Figure 2.14 below includes most remote pilots' responsibilities that shall be considered while studying the HMI of an RPAS. These are divided into the three main principles of decision making in flying: aviate, navigate and communicate.

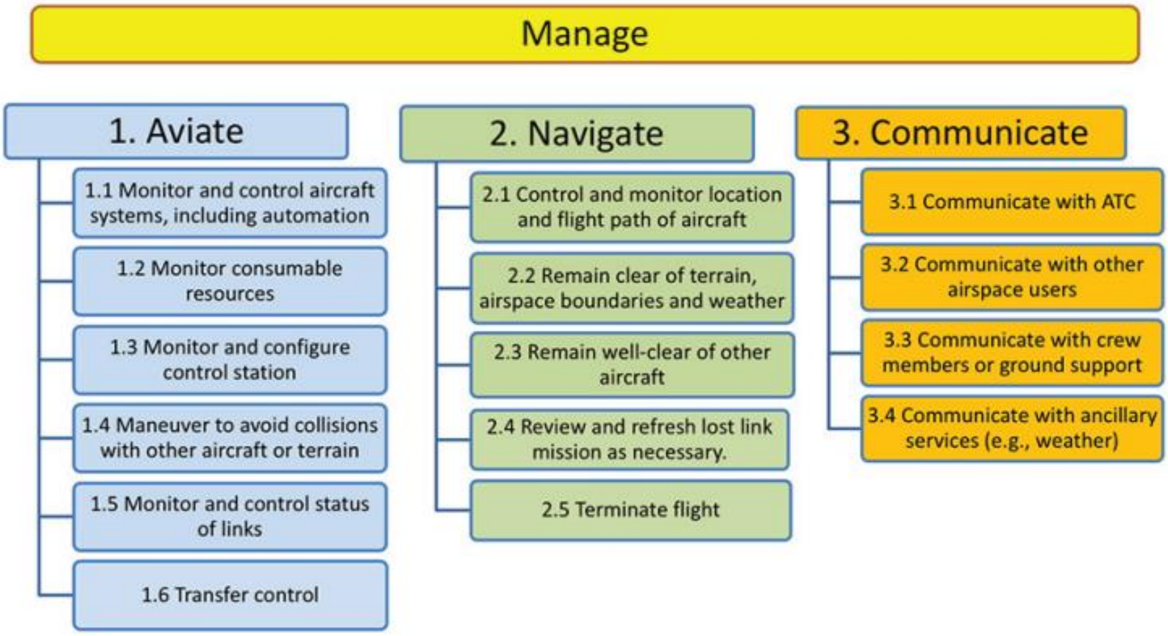


Figure 2.14 - Remote Pilot Responsibilities [20]

The above responsibilities can be associated with several implications that lead to error. The Human Factors Guidelines for Remotely Piloted Aircraft System Remote Pilot Stations' document [21] define special considerations regarding its implications. In this dissertation, it will be focused on human factors related implications, as below:

Loss of Natural Sensing

The loss of natural sensing is due to reduced awareness of the aircraft state as the pilot does not have access to the rich sensory clues or sensations, as visual or auditory, making it more difficult to the pilot to have awareness of the state of the aircraft or recognize his/her input. In the absence of an out-the-window view, the pilot must rely on alternative sources of information. Operations that may appear to be conducted identically to those performed by manned aircraft, are often operated under significant limitations by the RPAS pilots. Text-based displays are normally implemented on RPS intending to compensate for the lack of sensory clues, but then it reduces the focus of the foveal vision. Heavy reliance on textual information, complicated sequences of menu selection required to perform a task, and screen displays that can be obscured behind pop-up windows or dialogue boxes can easily be critical on a high workload phase. The pilots must be able to see and hear the information relating to the monitoring tasks. Even if no sound from the remote vehicle is received, sound from aural warnings shall be loudly heard.

The Unique Environment of the Remote Pilot Stations

The advanced RPS is likely to resemble an office rather than a cockpit. The physical environment of the RPS, including noise levels, access controls, temperature control, and lighting should be controlled and studied as it should be a comfortable work environment, with intuitive operation. Nevertheless, the relative spaciousness of the RPS compared to a traditional cockpit of manned aircraft enables additional screens to be added easily for instance. The proliferation of information on several displays can affect the pilot's performance, in this way it is necessary to determine whether the addition of a display to the RPS is, in fact, relevant and if operationality is compromised.

Reliance on Automation

Generally, on a conventional aircraft, automated systems control the aircraft's movements during most of the flight. Nevertheless, the pilot has the ability to turn-off or minimize the use of the automated systems and apply manual control of the aircraft. Most advanced RPA relies entirely on automated systems for basic flight control and do not provide options for pilot manual control. Flying an RPA has some resemblance to the Pilot Monitoring functions in a conventional aircraft. In the context of flight operations, monitoring is defined as the observation and interpretation of the flight path data, configuration status, automation modes and on-board systems appropriate to the phase of flight. It involves a cognitive comparison against the expected values, modes, and procedures. As the RPA pilot is most of the time monitoring the automation, makes it of critical management importance.

Widespread Use of Interfaces based on Consumer Products

Most RPS work with diverse commercial off the shelf devices (COTS), as keyboards, mouse, and displays based on computer screens. These interfaces have not been designed according to aviation regulations or standards. In some cases, the interfaces operate on consumer computer software. By having this type of equipment, the RPS is likely to suffer from a lack of consistency and other integration issues. This may result in increased crew training requirements, reduced efficiency, and an increased potential for operator errors. The similarity of either physical or virtual control can lead to delayed response or inadvertently misuse. Levers or buttons of similar shape situated close to each other should be avoided, by having a different appearance and mode of action. The seating position must be adjusted to the eye position of the pilot, enabling the pilot to view the internal displays and controls whilst maintaining an adequate view of the external conditions.

2.7 Conclusion

By using simulation, it is possible to have a system's behaviour 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 by the use of synthetic environments like flight simulation training devices.

A flight simulator training device is economical when compared with the advantages it provides: it allows the verification and testing of prototypes' design, it is safer than training on a real aircraft; it is cheaper to maintain and it can be used more frequently. With the right devices, simulators allow the correct training and the instruction of recovery techniques, with a decent amount of feelings without great risk. Depending on its fidelity, a flight simulation training device does not necessarily require an extensive replication of a certain aircraft. Believability can come exclusively from a visual system, completed with basic hardware. Training can be adjusted to fit different skill levels, from beginner to advanced. For verification and validation of new concepts, it can be adapted for different types of virtual, physical, or procedural changes.

Technologies and innovations emerging in the aviation industry are noticeable on aerial vehicles like airships and RPAS, with high levels of digitalisation and automation. RPAS, where remotely piloted aircraft are controlled remotely by an operator, the controls range from complex systems to commercial off the shelf interfaces. Mainly relying on automation for the completion of their purposes, it can pose new questions on the interactions between humans and automation. Operators shall manage the interfaces and interdependencies of the system's components having in consideration the total aviation system, being it the RPAS and the surrounding environment. Thus, it is important to understand the remote pilot responsibilities and major liabilities to train the operators accordingly while taking into account the applicable human factors when designing a synthetic environment or a RPS. As the URBLOG prototype studied in this dissertation is within the RPAS concept, the concepts reviewed will be taken into consideration towards the objectives of this work.

Chapter 3 - Case Study I: Development of the Synthetic Environment for URBLOG

3.1 Introduction

Once contextualized in the industry and academia, it is possible to start the development of our particular case study, which is firstly the Development of the Synthetic Environment for URBLOG.

In this chapter, the implementation of the airship on flight simulator software is realised according to the airship purpose. Actions to achieve such are described and the software's strengths and limitations are explained to support a final choice. Instruments required for a safe and controlled flight are analysed and selected, as well as the hardware necessary to create a synthetic environment, in the form of a flight simulation device similar to a PCATD, that can be further used in the remote pilot station. It culminates with the hardware equipment chosen for that purpose and the layout to be implemented in the remote pilot station.

3.2 URBLOG Vehicle Specifications

The URBLOG vehicle is the airship to serve as the Multifunctional Air Transport System vehicle [3]. The first design, represented in Figure 3.1, features a rigid structure with a sustaining fuselage and a gondola. With a length of 75 meters, 30 meters of wingspan, 15 meters of height, and 5 electric engines, its dynamic control in cruise flight is achieved by deflection 4 main surfaces (wings) and vertical stabilizers, propelled by an engine of large diameter on the rear of the aircraft. Static control is achieved by using 4 rotors located on the wings, plus the deflection of the rear engine.

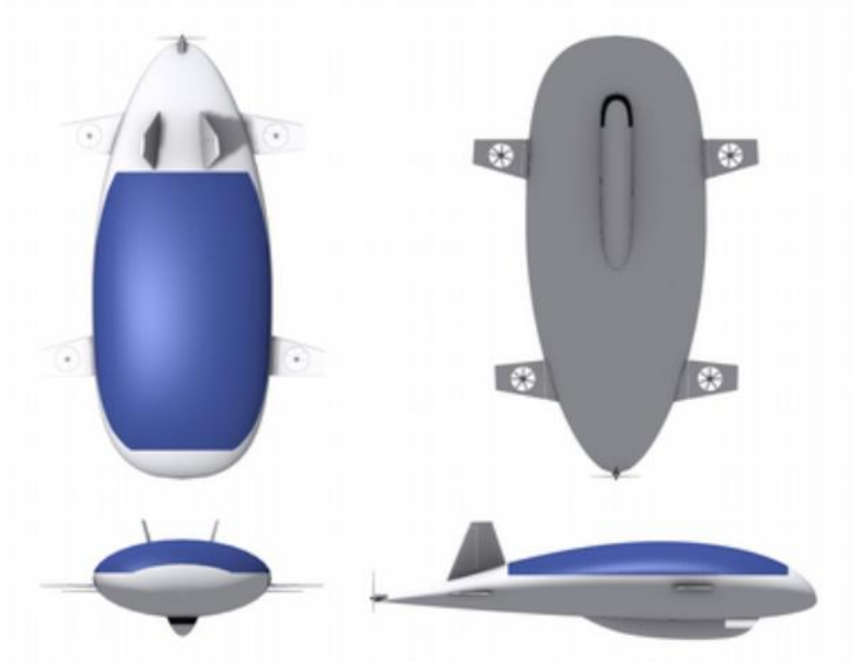


Figure 3.1 - URBLOG Proposed Design [31]

As one of the purposes of this aircraft is to serve as a cargo vehicle, the major challenge to face is to maintain the buoyancy balance between empty and full load. Thus, it relays on what is called a hybrid concept, as it applies to aircraft that is lifted simultaneously by conventional means (heavier than air systems such as helicopters and aeroplanes) and by Lighter than Air (LTA) methods, by gaining their lift from a lifting gas less dense than the surrounding air, as in the case of balloons and blimps. This translates the possibility of vertical takeoff and landing (VTOL).

As the project evolved, it was decided to conduct this study on a smaller version of the vehicle and as unmanned. Thus, new dimensions were considered below in Table 3.1.

Table 3.1 - Dimensions of the smaller version of URBLOG

Dimensions	
Length	8.5 meters
Wingspan	5.4 meters
Height	2.4 meters

A new version of the URBLOG, based on the design above, had then to be modelled to be further implemented. This URBLOG rigid body design version was modelled through the computer-aided design (CAD) software Blender®, that is a free and open-source 3D computer graphics software toolset used for creating animated films, visual effects, art, 3D printed models, motion graphics, interactive 3D applications, and computer games [32]. Blender®'s features include 3D modelling, UV unwrapping and texturing, making it a useful modelling tool to create objects for flight simulation. Although being free, it has a steep learning curve. Books, like the Virtual Aircraft Volume II by Witold Jaworski [33] and Youtube tutorial videos "How To Use Blender For Making Flight Simulator X Models (FSX) Blender2FSX" by kpgamemods [34] were used as a guide to develop URBLOG model on Blender®.

Based on blueprints, and as the design was being developed, each file version was saved. The version of Blender® used was 2.77.1a. The final version of the model was file number 54. The final result is shown in Figure 3.2 and Figure 3.3.

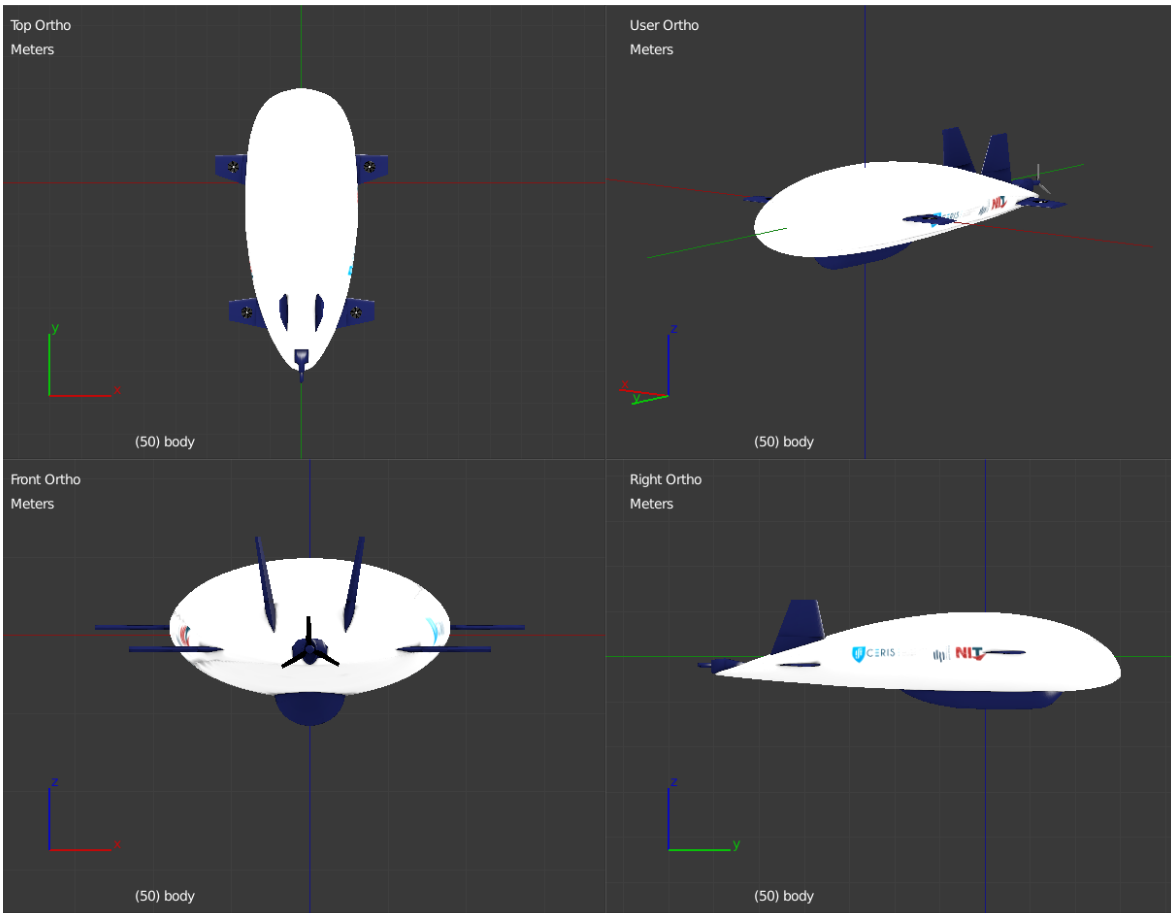


Figure 3.2 - URBLOG Views

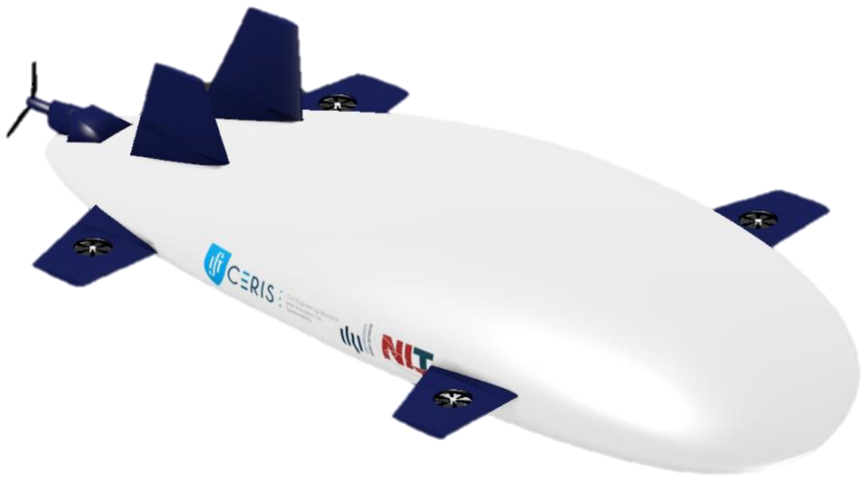


Figure 3.3 - URBLOG 3D Model View

3.3 Simulation and Implementation of the Vehicle on Flight Simulator Software

Over the years, simulation has appeared as a cost-benefit method for both validation and training method, as mentioned in Chapter 2 - State of the Art. The software has been developed to simplify and accommodate the different requirements of the Aeronautical industry and academy. There, it is possible to conduct experiments on new and advanced concepts, research on human factors and new training techniques.

As PCATD devices appeared, with personal computers as its main hardware, the cost of the software for these devices was vastly reduced. With the improvement of processing capabilities, either graphic and speed-related, as well with the easy access to modelling software, the implementation of scenarios, airports and aircraft on flight simulator software became accessible to the interested user. Nevertheless, to proceed with the simulation of an aircraft model, the availability of its aerodynamic behaviour defines the best flight simulator software to implement the model. In this case, being an ongoing academic project, this data is studied through several master dissertation, for instance, "Simulação Numérica de um Veículo Aéreo: Determinação dos Coeficientes de Sustentanção, Resistência Aerodinâmica e de Momento de Arfagem" dissertation [35], developed in 2017, with a model created on Blender®. Although that thesis has already been finished, the topic shall be further developed to validate data and together with other aerodynamics, propulsion and systems studies, it will enable the full simulation of the vehicle. The complete implementation of

URBLOG on simulation relies on these different studies, since in simulation, as in reality, every aspect is inter-connected. However, as currently few data are available, and considering the objectives of this dissertation, the simulation will rely on data available from other vehicles already implemented on simulation software, providing the opportunity of exposing the purposes of the operation of the URBLOG vehicle. Nevertheless, once all URBLOG theoretical studies are completed, data integration with the simulation and the RPS developed within this dissertation will then provide a mean of evaluating URBLOG's likely behaviour, its exposure to abnormal situations and the possibility of training.

As mentioned previously, the aerodynamic behaviour defines, in large scale, the flight simulator software where the air vehicle shall be implemented. This can change depending on the stage of the project as different software implements the aircraft differently, especially as aerodynamics that can rely mainly on two methods: the Newtonian model or the Computational Fluid Dynamics (CFD) model. The Newtonian model has the advantage of being easier to implement but less realistic in stall attitudes, tight turns and other abnormal situations of flying. The Newtonian Model uses steady-state derivatives [36], as below:

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

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

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

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

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

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

Where:

$C_D = Airplane\ drag\ coefficient$

$C_L = Airplane\ lift\ coefficient$

$C_M = Airplane\ pitching\ moment\ coefficient$

$C_l = Airplane\ rolling\ moment\ coefficient$

$C_Y = Airplane\ side\ force\ coefficient$

$C_N = Airplane\ yawing\ moment\ coefficient$

$\beta = Sideslip\ angle$

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

$0 = At\ zero - lift\ state$

$\alpha = Angle\ of\ attack$

$i_h = Horizontal\ tail\ incidence\ angle$

$\delta_e = Elevator\ deflection$

$flaps = Due\ to\ flaps$

$spoiler = Due\ to\ spoiler$

$\delta_a = Aileron\ deflection$

$\delta_r = Rudder\ deflection$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

This method is present on Lockheed Martin Prepar3D® (P3D) software, (pronounced "prepared") [37], which is a commercial product used for simulation and training. It has many vehicles implemented, together with complete World scenery environment, simulated weather, navigation aids database and simulated air communications. Pilots, organizations, and academia use Prepar3D® for immersive, experiential learning as it allows users to create training scenarios across aviation, maritime, and ground domains. It provides pilot-like experience with vivid and lively graphical scenarios in different weather conditions and seasons. The implementation of an aircraft in this software can be easier than in other flight simulator software as there is a wide number of open source systems that can be either be used or based on if authorised. Some of these systems, either air vehicles or add-ons, are already inbuilt in the software, others were developed by users or by the simulation industry, which is proactively supported by Lockheed Martin. A good degree of realism can then be achieved in a rather user-friendly approach. Once the aircraft rigid body model (mdl file) is created on CAD software compatible with P3D, the aircraft configuration (cfg file) and flight model (air file) can be arranged either by text editor software or by external software that can illustrate those configurations, for instance, the Center of Gravity (CG) or where the landing gear is located.

As for the Computational Fluid Dynamics (CFD) model, it 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. With this method, the flight simulator software, like X-Plane [38] can compute the forces applied to the aeroplane in a more detailed method. This offers the possibility to investigate the approximate flying behaviour of a newly developed aircraft without having to build and test a prototype. Nevertheless, at this point, the advantages of using this software would not be relevant as we do not possess any information regarding URBLOG's systems and aerodynamics. Also, as X-Plane has its own in-house software for CAD model developing, it does not enable the use of the model in other CAD software to develop the model. Considering that using a 3rd party software as Blender® for the development of the CAD model enables its application on other software, for instance, on CFD analysis, which is not particularly related to flight simulation itself but which was the case on the dissertation concluded last year [35], this would be a limitation. Being so, this software was excluded.

On the other hand, there is FlightGear [39], which is vastly used by academics as it is open source, being freeware, and its connection to simulation software as MATLAB/Simulink®. This software uses different flight dynamics models, depending on the aircraft and user choice. The most recent dynamic model and the default one is JSBSim, based on nonlinear equations of motion. The YASim model relies on geometric information and not in aerodynamic coefficients, providing the best results when it comes to the modelling of new aircraft design, especially for rotorcrafts and helicopters. As already mentioned, to resemble the simulation with the real or expected configuration, aircraft systems shall be already defined, or at least its coefficients. On the URBLOG case, as reduced information is available at this stage, and the Flight Gear implies a steep learning curve, this software was unconsidered. [40] However, it is recognized that its capacities can be of help once URBLOG systems are further studied, especially the use of MATLAB/Simulink®.

Considering the above, the URBLOG airship development was decided to be executed on the Lockheed Martin Prepar3D®. With the addon Blender2FSX/P3D Toolset, it is possible to export Blender® files settled for P3D software. By using external software, it is also possible to adequate its dynamics and translate the URBLOG purpose. Four types of flight dynamics editor software are available for this purpose: two freeware, AirEd and Aircraft Airfile Manager [41], and two payware as a package, AirWrench and AirWizEd [42]. The flight dynamics, performance, engine definitions and all physical specifications of the vehicle can be changed through these programmes, in which the payware versions have better visualisation and calculation of the specifications, offering a more detailed approach. As they differ on presentation and detail, they shall be used all together to achieve the conditions required, especially when following specifications from other vehicles, which is the case.

Per information available, the simulation was conducted as represented in Figure 3.4.

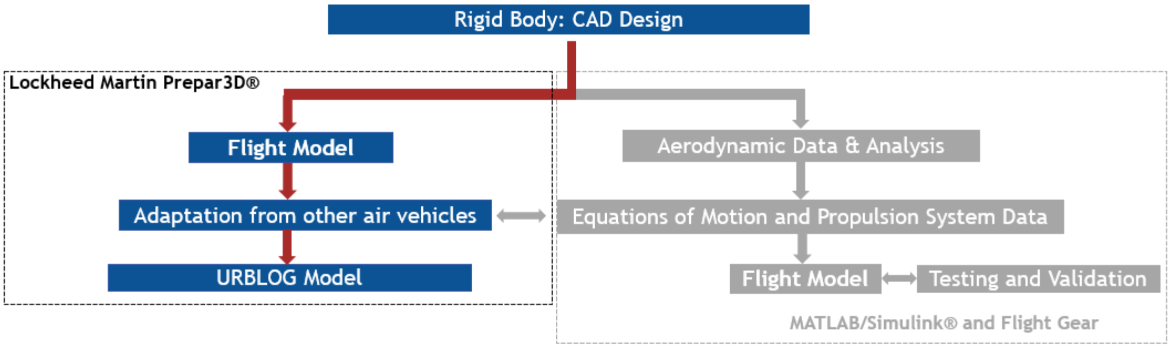


Figure 3.4 - URBLOG Simulation outline

The model (mdl file) was prepared for the installation on P3D in accordance with the kpgamemods' videos [34] and then installed according to the P3D addon installation guide for addon aircraft [43]. A P3D default aircraft configuration file was used as base for its installation and the aircraft cfg file associated was configurated per URBLOG specifications through the several flight dynamics editors mentioned above. Since there is a low number of information available of URBLOG's systems, its files were defined with the conditions that could enable a controlled flight as close as possible to its ideal characteristics to comply with the vehicle's purpose, particularly the buoyant lift and VTOL possibility. That was achieved through several tests of trial and error, by reviewing and combining default and addon aircraft configurations.

An external view of the URBLOG implemented on P3D is seen in Figure 3.5.

Figure 3.5 – URBLOG on P3D Software

At this point, URBLOG simulation will not permit the docking of the vehicle. Any simulation will then be done above ground level (AGL), with the vehicle powered up.

The electrical propulsion rotors installed on the wings are not simulated in this version. The rear propulsion system is the only source of thrust.

3.4 Development and Implementation of the Virtual Cockpit and Remote Pilot Station

A virtual cockpit is essential on a synthetic environment as a flight training device. It is the visual element that enables the realisation of the tasks in a controlled environment, where the user can perceive information of the system, in this case, from the RPAS, and control it adequately. Once the virtual cockpit is designed in this kind of systems, it can be either used for training purposes, together with hardware interfaces or be also integrated on the actual remote pilot station. Having that in consideration, those two possible uses are taken into account and it is developed a layout of a remote pilot station to be included in this synthetic environment.

3.4.1 Instruments

In similarity to what is present on manned flew aircraft, the flying characteristics as the aircraft's speed need to be available to the person flying the vehicle. A variety of instruments have been developed to inform the flight crews regarding the flight and environment parameters. The condition of the aircraft, engine, components, the aircraft's attitude, weather, cabin environment, navigation, and communication are the main topics reflected on the instruments that are present on a cockpit to assure safe operation. For flying, there are three basic types of instruments, classified by the job they perform: flight instruments, engine instruments, and navigation instruments [44].

3.4.1.1 Flight Instruments

The main function of the flight instruments is to show current information on aircraft speed, altitude, vertical speed, attitude, heading, and turning/banking. Traditionally, they are analogue cockpit gauges arranged in T configuration and they are essential to a controlled flight. There is an altimeter that displays aircraft's height regarding a barometric pressure; the airspeed indicator, indicating the airspeed usually in knots; and heading indicator, a form of a compass that indicates the aircraft's direction in relation to the magnetic North; and an attitude indicator, that transmits the aircraft's attitude towards the ground and the sky by its position in relation to an artificial horizon. The different types of attitude are shown in Figure 3.6.

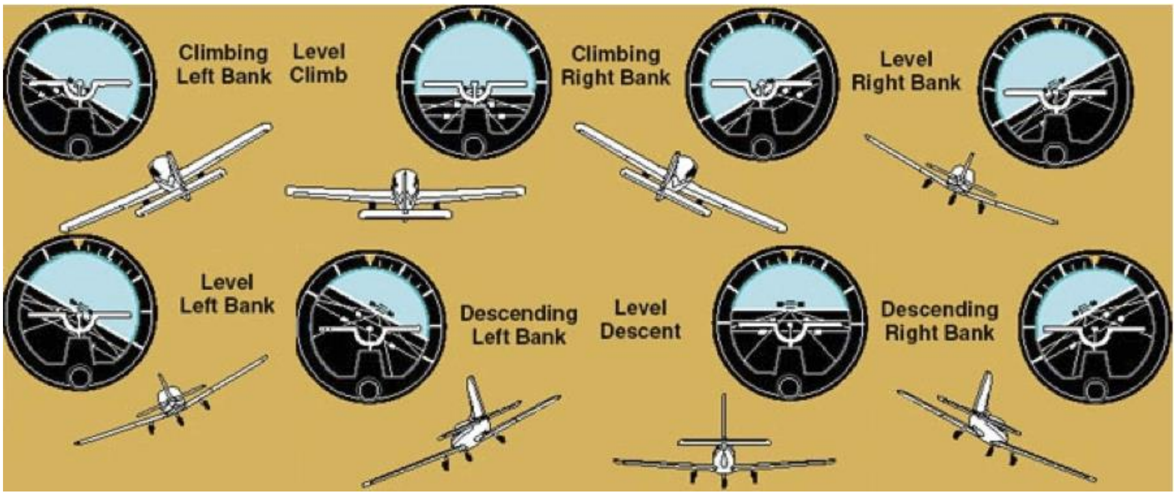


Figure 3.6 - Attitude Indicator (or Artificial Horizon), in several indications [45]

Additionally, a turn coordinator providing information about the direction and rate of a turn, and whether the turn is being flown coordinated; and a vertical speed indicator that measures the rate of climb or descent, transforms this so-called “Basic T”, into on a “Six Pack” as in Figure 3.7 These instruments are normally arranged so the top centre position directly in front of the pilot is the artificial horizon [44].

Figure 3.7 - Traditional Six Pack [Adapted from 46]

3.4.1.2 Navigation Instruments

This type of instruments contributes with information so pilots can guide the aircraft along a defined course. This group of instruments includes compasses of various kinds, some of which incorporate the use of radio signal to provide navigational aid while flying the aircraft from one airport to another. Other navigational instruments are designed specifically to direct the pilot’s approach to landing at an airport. Some traditional navigation instruments have been progressively replaced in modern aircraft. Global position systems (GPS) use satellites to pinpoint the location of the aircraft via geometric triangulation [44].

3.4.1.3 Engine Instruments

Engine instruments are those designed to measure operating parameters of the aircraft’s engine(s). These are usually quantity, pressure, rotation speed and temperature indications. They are often placed in the centre of the cockpit where it is easily visible for all the flight crew.

3.4.2 Glass Cockpit

With advancements in technology, the traditional cockpit gauges were replaced by electrical substitutes in glass cockpits, like in Figure 3.8. Normally, within two large liquid crystal display (LCD) screens, all the information provided by the traditional individual gauges are now displayed in the primary flight display (PFD) and the multifunction display (MFD). These panels have a collection of buttons, keys, and knobs used to operate each unit. The controls allow the pilot to enter information and program the avionics panels to accomplish the desired operations or tasks.

Figure 3.8 - Glass Cockpit [44]

PFD present the basic flight instruments, such as the airspeed indicator, the altimeter, the attitude indicator, heading indicator and vertical speed indicator, dynamically combining much information. This makes possible the addition of enhancements as trend indicators and symbols to assist in the case of an upset situation, which can be defined as a visual warning system as well. In Figure 3.9, the relation between the analogue gauges and the instruments shown on a PFD.

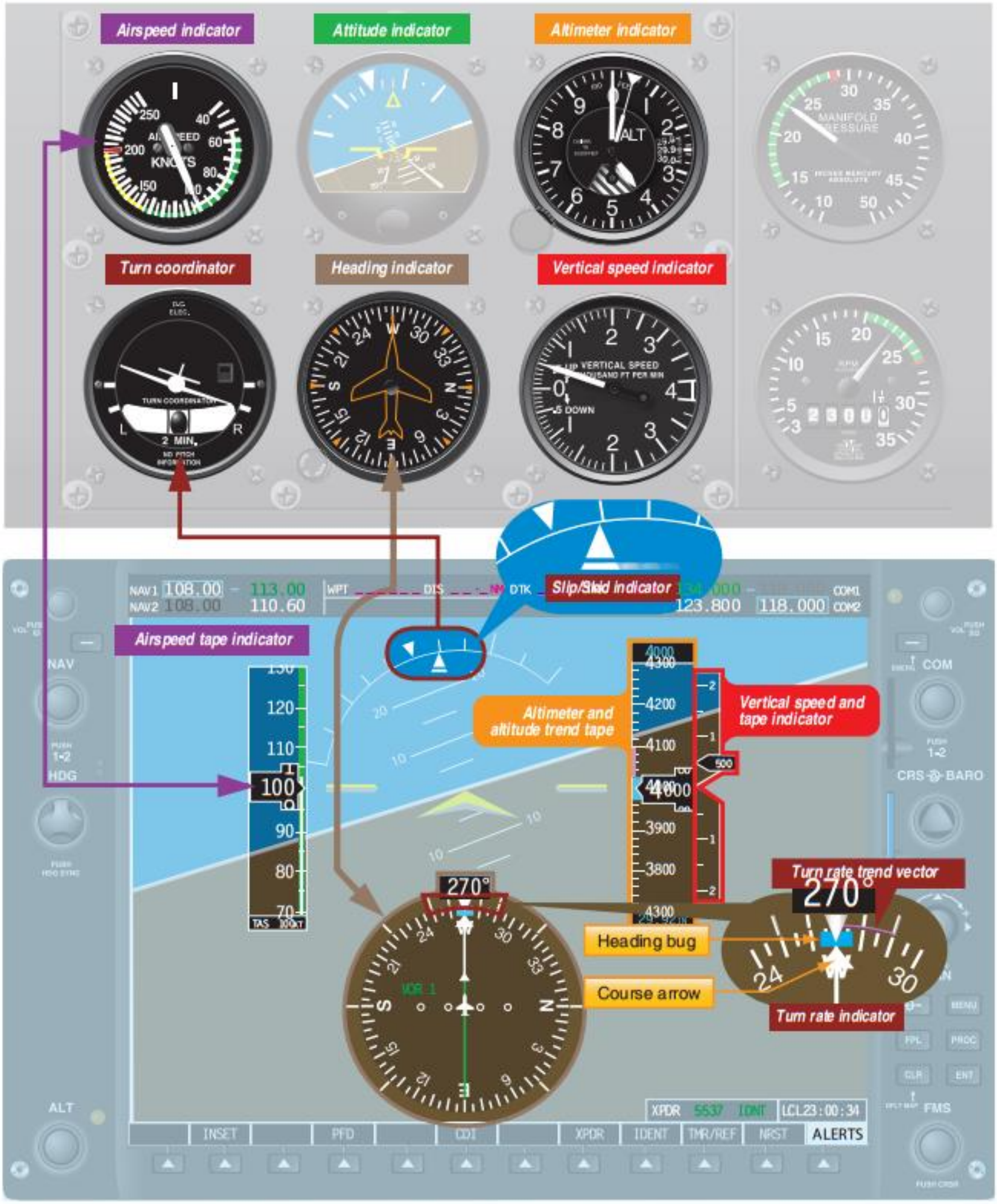


Figure 3.9 - Analogue Gauges related to PFD instruments [47]

Another important feature of the PFD is its ability to gather information from other aircraft systems and present it to the pilot in the integrated display. For example, the PFD in Figure 3.10 presents many useful items about flight status. The top bar shows the next waypoint in the planned flight route, the distance and bearing to the waypoint, and the current ground track. The outside air temperature (OAT) is shown in the lower-left corner and the transponder code and its status are shown with the current time in the lower right corner.

This PFD also allows the pilot to tune and identify communication and navigation radio frequencies at the top of the display [48].

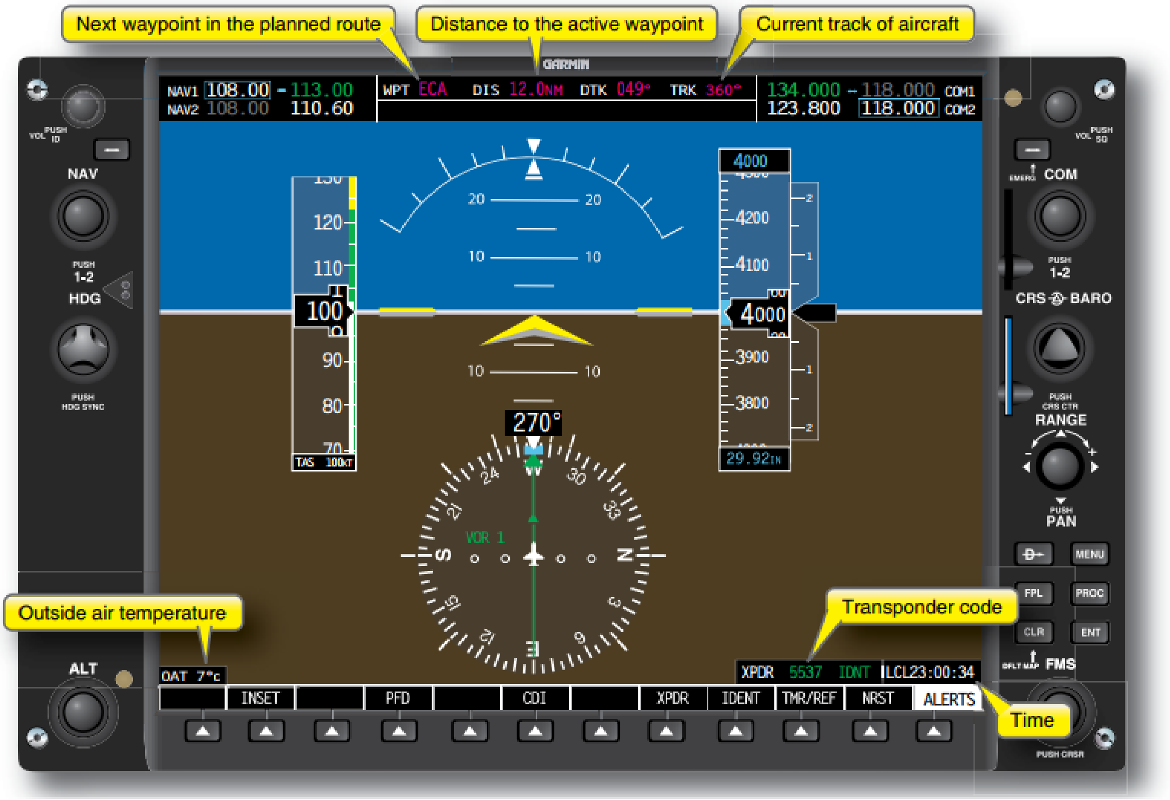


Figure 3.10 - PFD [48]

The MFD presents a moving map display on the right side and engine instrumentation on the left It can also show other traffic, the route in place, weather and terrain avoidance. The navigation is based on the navigation receivers installed on the aircraft, as the global positioning system (GPS) and the Very high-frequency Omnidirectional Range (VOR).

With all these functionalities available, it is possible the use of autopilot to complete a certain route and altitude. Depending on the configured navigation, the aircraft will progress into the next waypoint in the programmed flight route. Although pilots are required to be comfortable with all information needed to complete a flight (being it regarding the aircraft, systems, route or weather), this type of system can reduce workload. Previous control inputs are now automated when configurated correctly and monitoring is in place at all times [48].

3.4.3 Remote Pilot Station (RPS)

A remote pilot station (RPS) needs to be designed considering the operator's awareness of UAV's current situation, in which control can be done with little effort. As a vast amount of data needs to be represented in real-time, it must be in a form that can be easily interpreted. Information must be carefully selected to avoid overloading the operator, and automation shall be available at several degrees [49].

The graphical interface shall be kept on the simple form, where important flight parameters are visualized resembling a cockpit to improve is interpretation, and others displayed in the form of numbers. Instruments and controls with related functions shall be grouped in a logical arrangement which reduces the instrument scan time and lowers the operator's workload [50].

This is also in line with the Human Factors Guidelines document [21] mentioned previously that defines the main data to be available to the operator, as below in Figure 3.11.

HUMAN FACTORS GUIDELINES FOR REMOTELY PILOTED AIRCRAFT SYSTEM REMOTE PILOT STATIONS

Information content of displays

I_2.1.1 RPA ownship position. The RPS should provide a representation of the RPA's position. The display should provide:

- I_2.1.1a Representation of RPA within the airspace.
- I_2.1.1b Heading of RPA.
- I_2.1.1c Altitude of RPA.
- I_2.1.1d Airspeed of RPA.
- I_2.1.1e Attitude of RPA.
- I_2.1.1f Position of RPA relative to other aircraft, terrain, and obstacles.

I_2.1.2 Programmed flight plan and predicted flight path of RPA. The RPS should provide a representation of the predicted flight path of the RPA based on the flight plan programmed into the flight management system based on the assigned flight clearance. This information should include:

- I_2.1.2a Indication of RPA current position along programmed flight path.
- I_2.1.2b Predicted flight path relative to RPA and other traffic, terrain, and obstacles.
- I_2.1.2c Distance to waypoints along flight path.
- I_2.1.2d Indication of position in flight path when new commanded altitude will be attained.
- I_2.1.2e Indication of turning radius and path when making turns along flight path.

Figure 3.11 - Cockpit Display Content [21]

In Prepar3D®, once the aircraft model is implemented, the virtual cockpit can be designed, using either gauges or panels included in the programme or external sources. These external elements can be developed in house or be open-sourced, available to download from an addons provider.

For the actual stage of URBLOG, where no engine parameters or communication interfaces are defined, the main elements that are relevant in this study, are the flight and navigation instruments, essential to the control of the vehicle.

For both flight and navigation instruments, due to the clear graphic interface and by being inbuilt on the P3D software, the PFD and MFD are defined as the main cockpit instruments to assess the flight status data. These instruments are in line with the recommended content of figure 3.10 and with the automation management that might be present in an advanced phase of the RPAS. Although during this study the P3D software and its instruments are not subject to any validation studies, its training capabilities and replication of the real functionalities and limitations are widely recognized, making it an appropriate choice.

Besides the instruments in the virtual cockpit display of the RPS, a constant outside view has to be integrated into this system. Within this display, the imagery of the out-the-window (OTW) world is shown and controlled by the operator so that the current orientation and position of the monitored aircraft and future overflying areas are constantly visualized. Its control can be achieved by either a manual input on a hat switch on the joystick, an increased number of physical displays, a virtual reality headset or by head tracking devices.

An additional Head-Up Display (HUD) with a classical artificial horizon level shall be integrated into the OTW view, by being overlap in this view. This allows the operator to receive information while looking straight ahead, instead of looking to the main instruments, improving the sensing of the operator.

For the URBLOG case, it will show the orientation the vehicle concerning the artificial horizon, altitude, heading, speed, vertical speed and thrust applied.

This HUD was adapted from the freeware *gaHUD* gauge developed by Bob Kellogg, available on FlightSim.com [51]. Being possible to modify it, which is allowed by its developer, minor changes were done to add description next to each data, i.e., word SPD next to the speed values. The opportunity to change its configuration can be beneficial during the evolution of this project, including the adding of additional functions. At this point, no change of its functions was required and all additional functionalities remain as the original version, which is the following:

"An indicator bug for the Nav1 OBS setting will appear on the DG strip. If you set the localizer course on the OBS, this will help to see the effect of crosswinds on an approach. It is also the reminder of what course you should be flying, unless on backcourse.

The vector bars for airspeed and altitude are intuitive. They turn clockwise when airspeed/altitude is increasing, and counter-clockwise when decreasing. And the speed of rotation suggests the magnitude of change. (...)

When the winds exceed 5 knots, the wind information will appear near the upper right corner. When your Nav1 is receiving a localizer, the appropriate ILS bars will appear, along with the nav ident and dme if available, and the outer and middle marker beacons will light up." [51].

The final look of the HUD is shown in Figure 3.12.

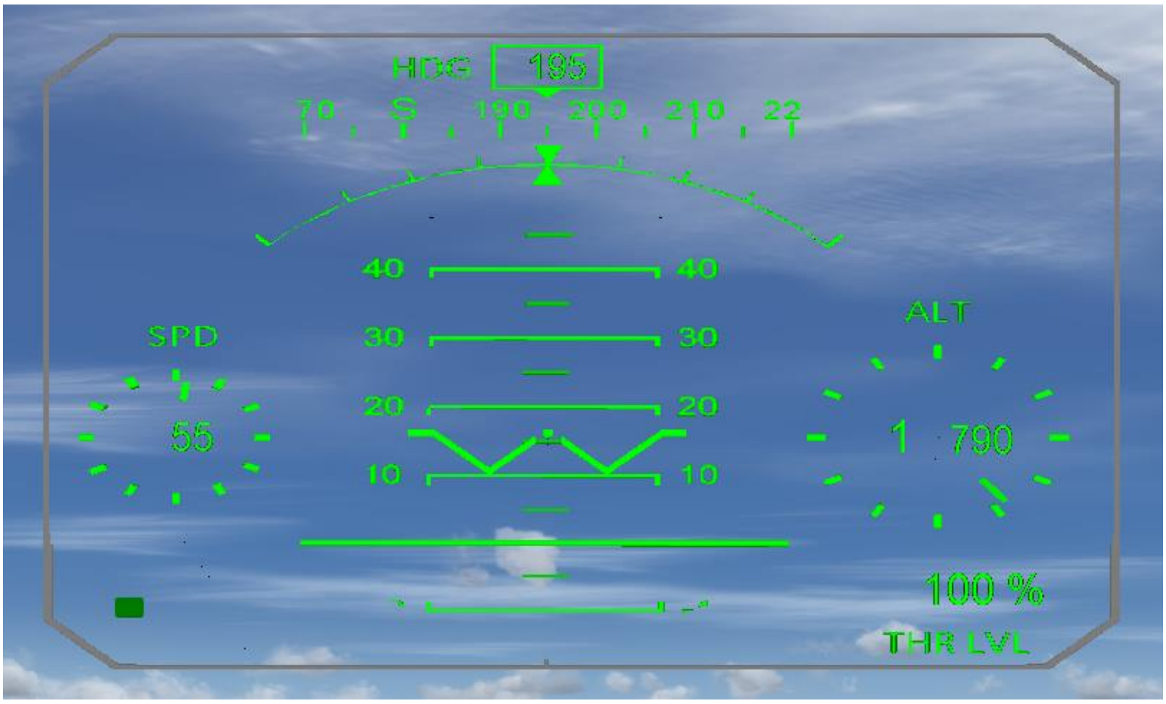


Figure 3.12 - HUD

As for the manual control of the vehicle, since URBLOG systems are still not defined and no regulated interfaces are available, COTS products are considered effective to achieve the expected results in this RPS development. The COTS interfaces must be consistent, with a small number of configurations required, and be composed with distinctive functions.
The control of an aircraft is usually performed by either a joystick or a control yoke. The control yoke is usually similar to the one on a light or Boeing aircraft. Its base is a box that

supports a column where is yoke is installed. It is in front of instruments and inputs are permitted on both forward, aft and side of the yoke, to adjust both pitch and bank attitude of the aircraft, respectively. These inputs are usually given by both hands on the yoke.

A joystick is a vertical grip like the sidesticks on Airbus aircraft or fly-by-wire aircraft systems. The grip is attached to a base, with the same functions as the control yoke, but it is controlled with only one hand. It is usually located in one of the sides related to the instruments, not obstructing its view, requiring much less space.

In terms of controllability, the joystick is more sensitive but at the same time, it provides apparent neutral stability compared to the yoke as it requires less movement from the user, only depending on the movement of the wrist. The yoke requires arm movement to control it, which can lead to poorer control feel. A larger area of neutral stability makes the pitch and bank control easier [52]. In COTS equipment, both these devices can have additional switches and control wheels to substitute keyboard inputs. However, a joystick or a yoke shall have a reduced number of active buttons to diminish the inadvertent selection of modes but it shall include a 'Point Of View' hat switch that will allow the manual control of the OTW view.

The thrust is set on a COTS throttle interface usually within the base of either the joystick or control yoke, although it can sometimes be separated by a cable or even be an individual system. The thrust of each engine is controlled by an individual throttle, but if no or little information is known regarding the propulsion system a single throttle can control the total number of engines.

A COTS joystick and throttle shall be of high precision, ergonomically-designed and with a weighted base for greater stability. This base will allow the correct movements both forwards and aft, as well as to the sides in order to control both pitch and bank attitude respectively. The drift can be controlled by joystick vertical axis, that will avoid the need of rudder pedals to control the aircraft's yaw. The resistance and feel of the joystick shall be adjustable.

Any other input shall be given through a computer mouse, keyboard and if available, touch functionalities in displays. Any joystick or yoke button that is assigned a function should be spaced from other buttons, in order to avoid inadvertent pressing.
By taking in consideration design features of the flight decks on cockpits, the RPS should ensure that [53]:

- it provides a safe working environment for its operator (no sharp edges or the risk of a short circuit, for example), with an adequate level of comfort (external noises, lights and vibrations shall be reduced to the minimum possible);
- space is available to store charts and checklists required to fulfil the flight mission;
- equipment is installed in its desired position for the duration of the flight;
- seats should provide comfortable support for the body, which can include lumbar support, armrests and headrests.

These are complemented by the good posture recommendations on how to sit properly at a computer [54]:

- The chair height shall be adjusted so feet are flat on the floor and knees are in line (or slightly lower) with the hips;
- When sitting, sit up straight, with hips far back in the chair;
- The keyboard and mouse shall be close and directly in front of the person operating the computer;
- The monitor should be directly in front, with the top of the screen roughly at eye level, if possible;
- Sit at least with an arm's length away from the computer screen.

By gathering all these instruments, constraints and characteristics into the RPS for the URBLOG case, a final system is defined as the one presented in Figure 3.13.

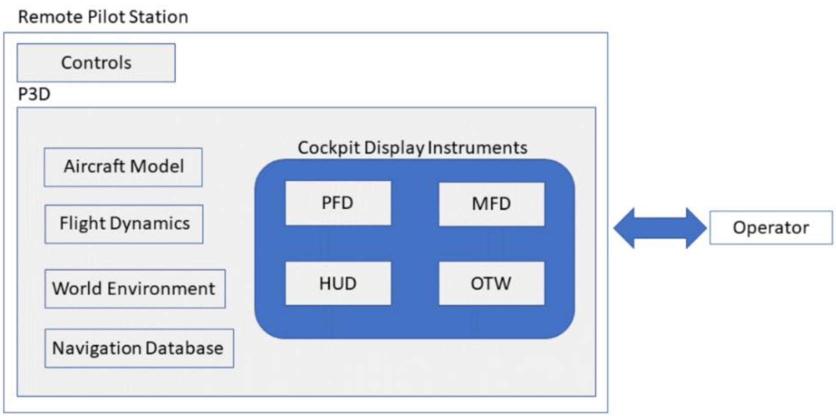


Figure 3.13 - Schematic of the URBLOG Remote Pilot Station Synthetic Environment

3.4.4 Implementation

In order to comply with the RPS system previously studied and to take into consideration all the factors mentioned in both Chapter 2 - State of the Art and the precedent subchapters, a low-cost COTS equipment was chosen for the main implementation of this synthetic environment.

For the PCATD, a laptop with the following specifications:

Processing Unit: Intel Core i7-7700HQ, 8 threads - 2.8 GHz
Graphics Card: NVIDIA: GeForce GTX 1050 Ti, 2 GB VRAM
Memory: 16 GB
Hard Drive: 500GB SSD
Display Resolution: 1920 x 1080 x 60 hertz, 15.6 inches screen
Operating System: Windows 10 Home, Version 1903

The flight simulator software:

Lockheed Martin Prepar3D® v4 Professional
Version 4.3.29.25520
SimConnect Version 4.3.0.0
License ID: 3140707
License Status: Licensed

To control the aircraft:

Thrustmaster T-Flight Hotas X Flight Stick (right-handed) - Compatible with PC and gaming devices, this joystick has programmable buttons and a hat switch for panoramic view; enables high-precision inputs with adjustable resistance; has a detachable, real-size, ergonomically-designed throttle control; and has a weighted base for increased stability.

In order to see both OTW view and the instruments, an additional display was needed. To enhance the visualization of this system, it was decided to include an iPad as external monitor and a head tracking device.

The head tracking device recognizes the operator's head in the different axis by its optical tracking system. Then these inputs are converted into the local coordinate system of the flight simulator software by addon software, which will allow changes in the view perspective by a head tilt. This is possible with the software FaceTrackNoIR V200 [55], together with a web camera, which has payware drivers. As better results are seen with the PlayStation® PS3 Eye camera because it records up to a maximum of 120fps, it was also included in this system and adapted for PC. As result of the higher framerate, achieving better results, it requires a higher processing power from the computers' CPU, which in this case, was adequate.

Nevertheless, to provide good results, some recommendations are given:

- Lighting should be indirect from a source above and behind the monitor;
- The cable should be directly connected to the computer and not by a hub;
- Webcam should be ideally placed below the monitor.

In the need of an additional screen for the visualization of the instruments, the iPad with its touching facilities provides additional functionalities to this system.

With the payware software Duet [56], available online on the Apple Store, together with the free Duet desktop app, the iPad recognises the computer through the cable and extends the Windows screen, transforming it into a high-performance touchscreen display with no lag. This software, together with the Prepar3D®, allows the touch functionalities of the instruments, i.e. inputs and changes can be given directly on the screen.

The Duet version on Windows for this tests is the v1.8.2.1 and iPad version is v2.2.5.

The iPad is a 6th generation, with IOS version 13.3.1. The cover that supports the tablet in the horizontal position is the Targus THZ737GL-50, with several angle positions available.

All this equipment shall be installed above a table, displayed according to Figure 3.14. The iPad is positioned in front of the laptop, and both iPad and laptop screen angle shall be adjusted to the operator's perspective. The camera shall be centred to the operator and placed above the screen due to the physical characteristics of a laptop.

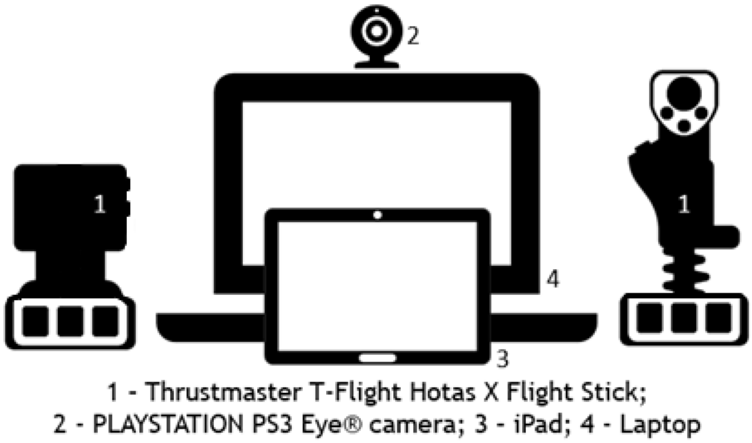


Figure 3.14 - Layout

The physical setup is shown below, in Figure 3.15.

Figure 3.15 - Physical Setup

3.5 Conclusion

In this case study, the URBLOG vehicle was presented, with all its available characteristics. Being an ongoing project, with few data available, the development of a synthetic environment as a flight simulation training device (FSTD) of this vehicle relies on the experience of other cases to represent its objectives. This indicates that a series of assumptions and tests were needed to be able to illustrate its concept. Several flight simulator software options were equated, with their advantages and disadvantages weighted, and an option was chosen. A model of the URBLOG was firstly designed on CAD software, later implemented on Prepar3D® software, with certain limitations. The vehicle can only be used above ground level powered on, not simulating the docking of the device. Rotors installed on its control surfaces are also not simulated.

For the development of the virtual cockpit and station, several types of instruments were reviewed and human factors applicable to both cockpits and remote pilot stations were considered. As the propulsion system is not fully studied, neither the communication interfaces needed, the development was focused on the essential elements to control the vehicle from the perspective of its operator without automation, including both virtual and hardware interfaces. Two main types of instruments were chosen, and a HUD was adapted for better interpretation on an OTW view. The adapted HUD and the head-tracking device to control the OTW view enhance the human sensing of the operator. As the requirements for the URBLOG systems are no defined, COTS equipment was used for the hardware interfaces, although assuring a certain number of requirements and recommendations. A layout was designed, having in consideration the possible environment of a RPS. It is composed by a personal laptop computer with Prepar3D® installed, together with a HOTAS flight control system, a head tracking device, and an additional screen. It is then implemented as synthetic environment, and the final setup is shown.

Chapter 4 - Case Study II: Operator's Training Programme for URBLOG

4.1 Introduction

In order to develop a training programme, it is important to have in consideration how the pilot training is developed and how it is validated. In this chapter, training concepts are introduced, leading to the specific case of the URBLOG. A training programme is defined so the setup defined in Chapter 3 - Case Study I: Development of the Synthetic Environment for URBLOG can be effectively used. A human in the loop (HITL) study is then used to verify and validate both programme and the setup. This study consists in the accomplishment of a mission with different tasks on flight simulator software performed by different operators, in which flight data information and parameters are recorded.

Data from this study is treated in spreadsheets and results are displayed graphically. The results include: the comparison of the median against optimum-relative results, in which its difference will be defined by the standard deviation; the comparison of the medians obtained of all operators; and finally, flight data from all operators is compared in particular mission' tasks.

4.2 Training Programme Development and Process

Pilot training is normally divided into two phases: initial and advanced training.
The initial training is when pilots are instructed to become pilots, understanding topics as flying techniques, aircraft specifications, airspace rules and meteorology, either on single-engine or multi-engine aircraft, based on either visual flying or aircraft instruments.
The advanced training is when the pilot is directed to a specific model, normally for professional use [57]. For both stages of tuition, pilots are required to act according to a set of procedures. These procedures reflect the best practices, manoeuvres and handling techniques between the aircraft and the pilot. It shall reflect the actions needed for both normal flight when all systems operate normally, and abnormal situations, i.e. system failure; and are normally performed using "READ & DO" principle [58].

Introduction of new technology, a new type of operation or a new type of pilots (for example, former military-trained pilots), often call for a change in the procedures. That is why the procedure design program shall be as accurate as possible, to take in consideration five points [59]:

- what the procedure is designed to accomplish;
- when and/or under what conditions the procedure should be executed;
- who is responsible for executing each step in the procedure;
- how, in detail, the procedure is to be performed;
- how to confirm that the procedure has been accomplished properly.

Every procedure has a primary requirement - if the procedure is followed, the specified goal will be achieved. That is why it is important to have a clear and easy training practice.

For instance, a learning procedure that includes several simple steps is easier to train than a procedure that includes fewer, complicated steps. The same with procedural sequences heading to a logical progression of steps as they are easier to teach than arbitrary sequences. If a procedure is difficult to learn, training the procedure will put a strain on the individuals tasked with performing the procedure, which can put at risk the real accomplishment of the task and the consequent safety of the flight [60].

To standardize the procedural methodology, the procedures that are performed frequently assuring the normal operation of the aircraft are stated as the Standard Operating Procedures (SOPs). These procedures are defined per flight phase and described in chronological order. Their actions are easily memorized and easy to apply. Nevertheless, they are checked against checklists [58].

Checklists assure that these procedures are done correctly and can also include how the checklist is to be executed (e.g., silent, challenge-and-response). Like any plan of action, once a prototype checklist has been developed, it must be analysed and tested for feasibility and practicality by training [60].

When developing an instructional or training process, it is necessary the following [61]:

1. characterize the training populations, identifying specific training needs;
2. determine training objectives - the goal of the training;
3. determining course content and the training methods to meet training objectives;
4. develop an assessment methodology.
5. ensure that instructor qualification is ideal and can successfully comply with the training implementation;

6. assure a proof of concept by verification and validation of the training, followed by a detailed course outline based on the results, where changes can be incorporated.

The URBLOG, being a new type of device, requires that the provided training is according to the above. At this stage, procedures shall reflect the basic control of the vehicle and basic system functions, not requiring advanced flying skills. Being so, the training process is defined as the following:

1. Training Population: Real pilots, virtual pilots and non-pilots with Aeronautical knowledge. Population with different flying experience will provide inputs regarding its relevance for flying the URBLOG;
2. Training Objectives: Fly the URBLOG successfully, in a defined path, according to SOPs, in a stable flight;
3. Course Content and Training Method: An operating manual, including a checklist, was developed to assure that the current SOPs can be followed by the operator to fly the URBLOG by its best practices. This document will provide complete information and will be the basic curriculum necessary to train the operator in order to perform an assessment in simulation by a Human in the Loop (HITL) study. This study consists of a mission, that the operator is asked to comply with;
4. Assessment Methodology: The time used to perform the mission will be recorded, as well as several parameters of the simulated flight. The analysis and the assessment results will be detailed later on the next subchapter, 4.3 - Human In the Loop (HITL) Study;
5. The instructor will be the developer of this training and study, knowledgeable of the vehicle, flying and technical aspects;
6. The proof of the concept will be based on the results of the mission by the different population, which can provide outputs for a detailed course outline.

By having the training process defined, the study can now be conducted.

4.3 Human In the Loop (HITL) Study

Model testing is essential to validate if the system implemented fulfils its purpose. This can be achieved by using a variety of methods, one of those being the Human In the Loop (HITL) studies, where people are part of a system. This type of studies is complex as the need to collect many different types of data has to be adequate, so the integrity of the simulation is maintained. Interferences should be minimal, or inexistent, to avoid changing how the human, the operator, performs its actions. Achieving the necessary balance between gathering the necessary data and maintaining the fidelity of the simulation requires careful planning and execution [62].

In order to conduct this study, it was necessary to divide it and define the main measures and requirements that could successfully provide results. In every step of the process, the presence of the instructor is needed, constantly available to provide support and coordinate the study.

4.3.1 Setup

In Chapter 3 - Case Study I: Development of the Synthetic Environment for URBLOG, an RPS was defined for the operation of this vehicle. However, during this HITL study, Worldwide contingencies were in place due to a virus outbreak (COVID19), thus there was a limitation of performing the study in the same location, conditions, and setup. To accept possible remote participants, they had to ensure they were familiar with the software and had the following interfaces available for the study:

- Personal Computer (PC), with Windows 10;
- Lockheed Martin Prepar3D® v4;
- Joystick, ergonomically designed and stable;
- Availability of install complementing software for data recording, screen sharing and voice conference.

The head tracking device and the iPad for extended functionalities and viewing had to be excluded for these cases, as they imply the purchase of both hardware and software. Therefore, it was decided that only the HUD will be used as a panel during those cases.

For the cases where physical testing is possible, the setup used is the one implemented in the previous subchapter 3.4.4 - Implementation.

4.3.2 Pilot Questionnaire

A questionnaire was developed to collect information about the target population to assure that the test subject population was homogeneous and unbiased. The study has to be adequate for the population in which the training is oriented. The participants of this study need to be chosen based on their Aeronautical know-how and different real and virtual flight experience. Demographic information can also be relevant thus it shall be taken into consideration. The following questions were asked:

1. Age Range
2. Sex
3. Real-life pilot?
4. If yes, which license(s)?
5. Total Flight Hours (approximate)
6. In which type of controls do you have more experience - yoke or joystick?
7. Have you flown with Glass Cockpit displays?
8. Are you a flight simmer?
9. If yes, how much do you fly every month?
10. Which is the type of controls used - yoke (1) or joystick (2)?
11. Do/did you fly Aero Models?
12. Have you ever used a joystick or yoke to control an aircraft on flight simulator software?

As a result of the Worldwide contingencies (COVID19), the number of participants had to be reduced but reassured that would be representative of several types of background. With the intention of contacting possible remote participants, members of a flight simulation community, the International Virtual Aviation Organisation (IVAO), were asked to individually answer to the above questionnaire. This flight simulation community is an "(...) online platform for flight simulation enthusiasts to enjoy their hobby in a simulated real-world environment, in company of other people, flying or providing Air Traffic Control services." [63]. Based on the answers obtained during the first quarter of April 2020, the proficiency and know-how required of IVAO members, together with the interfaces available to perform the study remotely, two members of IVAO were selected as participants. They performed the study in the second quarter of that month. As the COVID19 measures enabled physical proximity within safeguards, one of the chosen subjects was available to perform it physically.

Nevertheless, to include the case of an operator without either real or virtual flight experience, but with Aeronautical knowledge, an external participant was invited to physically complete the study.

Each participant was defined as "Operator" and is associated with a number. The answers to the questionnaire can be found below, in Table 4.1.

Additionally, it was requested that a subject familiarized with these studies, with both virtual (as an IVAO member) and real flight experience would perform the mission. It is defined as Operator X to distinguish from unfamiliarised subjects and the results of the missions attempts performed will be used as an optimum-relative reference during flight comparisons.

Table 4.1 - Pilot Questionnaire

Questions	Operator 1	Operator 2	Operator 3	Operator X
1. Age Range	50-60	20-30	30-40	20-30
2. Sex	F	M	M	F
3. Real-life pilot?	No	Yes	No	Yes
4. If yes, which license(s)?	-	PPL	-	PPL
5. Total Flight Hours (approximate)	-	70	-	60
6. In which type of controls do you have more experience - yoke (1) or joystick (2)?	-	1	-	1
7. Have you flown with Glass Cockpit displays?	-	No	-	Yes
8. Are you a flight simmer?	No	Yes	Yes	Yes
9. If yes, how much do you fly every month?	-	5h	20h	5h
10. Which is the type of controls used - yoke (1) or joystick (2)?	-	2	2	2
11. Do/did you fly Aero Models?	No	No	No	Yes
12. Have you ever used a joystick or yoke to control an aircraft on flight simulator software?	No	Yes	Yes	Yes

These operators were given the URBLOG operating manual, as included therein in Appendix A - URBLOG OPERATING MANUAL Version 1.0 to draw their attention to the characteristics and limits of the vehicle, as well the procedures to be followed. This operating manual was developed to provide all the information and procedures necessary to fly the simulated URBLOG in this study, including the configuration of the head tracking device, on Appendix A.1. The structure of this manual is based on the Airbus Flight Crew Techniques Manual (FCTM) [58], the Airbus Flight Crew Operation Manual (FCOM) [64] and a guide for RQ-4A Global Hawk simulator, developed within a dissertation [65]. The standard operation procedures (SOPs) checklist follows the design of the procedures included in P3D default aircraft. The glass cockpit information is extracted from Garmin's G1000 Integrated Flight Deck Pilot's Guide [66].

After their interpretation of this operating manual, the operators shall read Appendix A.2, included in such document, that presents the URBLOG mission and its tasks. During this period and throughout the mission, constant communication is present between the operator and the instructor, which is the person overviewing and setting the study.

4.3.3 Mission and Tasks

A mission was developed to include several tasks that simulate the objectives of URBLOG during air surveillance. It has an approximate duration of 8 minutes and 30 seconds, and the operator is asked to perform it three times. This is done to avoid a surprise effect and to verify if an improvement is achieved after repeating the tasks. The initial training in every aircraft consists of the adaptation of the operator or pilot to its controls and systems, which will be analysed within this study. No Air Traffic Control (ATC) instructions are simulated in this mission.

The mission was designed having the purpose of creating a relatively short visual flight rules (VFR) flight, where the operator shall follow a nearby road to the airport, by complying with the gates implemented, like the one represented on Figure 4.1. These gates define the flight path required for this mission. They are approximately 500 feet in height per 500 feet in length.

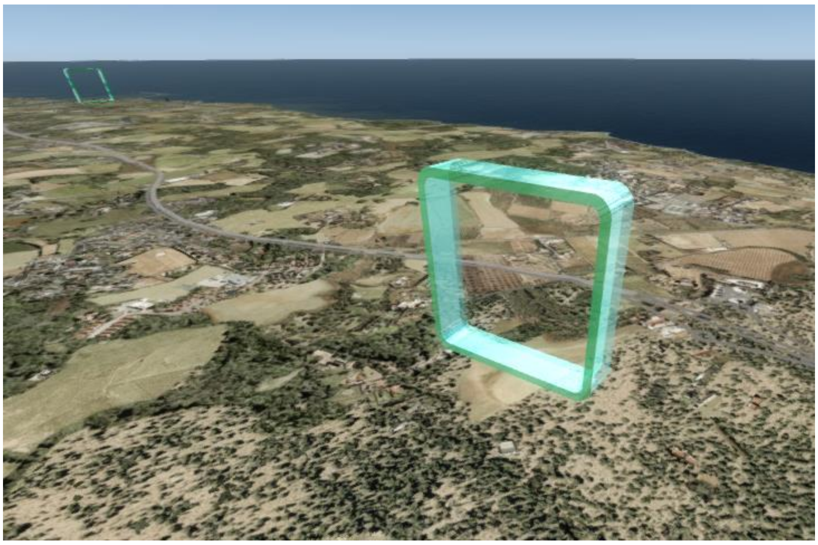


Figure 4.1 - Mission Gates

The flight includes a departure and arrival at a civil airport available on the Prepar3D® software, in this case, from and to Oporto airport (ICAO: LPPR) in Portugal. Initial flight parameters are equal in all mission attempts. These parameters include weather conditions, geographic location, altitude, heading, power setting and speed. The initial weather conditions are clear skies with no wind, and the vehicle's engines are powered.

The main tasks to be completed are in Table 4.2.

Table 4.2 - Mission Tasks

URBLOG Mission
Vertical Takeoff from runway 35 LPPR
Transition from vertical flight to horizontal flight
Climb for 1st gate interception
Climb for 2nd gate interception
Cruise flight for 3rd gate interception, visually following the road
Descend for 4th gate interception
Visual approach to runway 35 LPPR
Transition from horizontal flight to vertical flight
Landing on runway 35 LPPR

The mission was configured on Prepar3D® inbuilt mission designer, SimDirector. This software is defined as following: "SimDirector is Prepar3D®'s scenario creation tool designed to provide a premiere scenario creation experience from start to finish." [67].

Several objects were configured to define each task, as well as the definition of gates. In total, 82 objects were necessary to establish this mission, as seen in Figure 4.2.

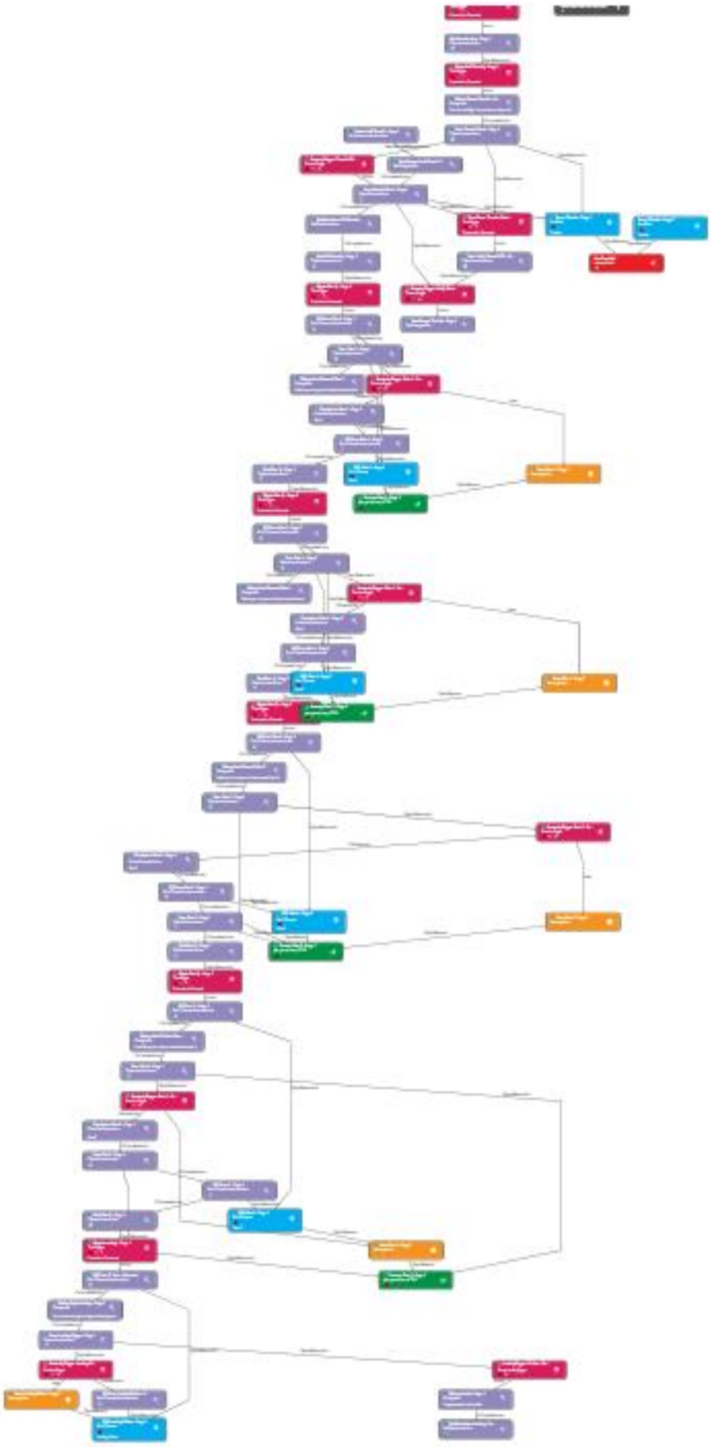


Figure 4.2 - Sim Director URBLOG Mission Overview

The final mission scenario resembles a traffic pattern, although with deviations in order to simulate the air surveillance over a main road. It is shown in Figure 4.3. Short turns are purposely required during this mission, increasing its difficulty.

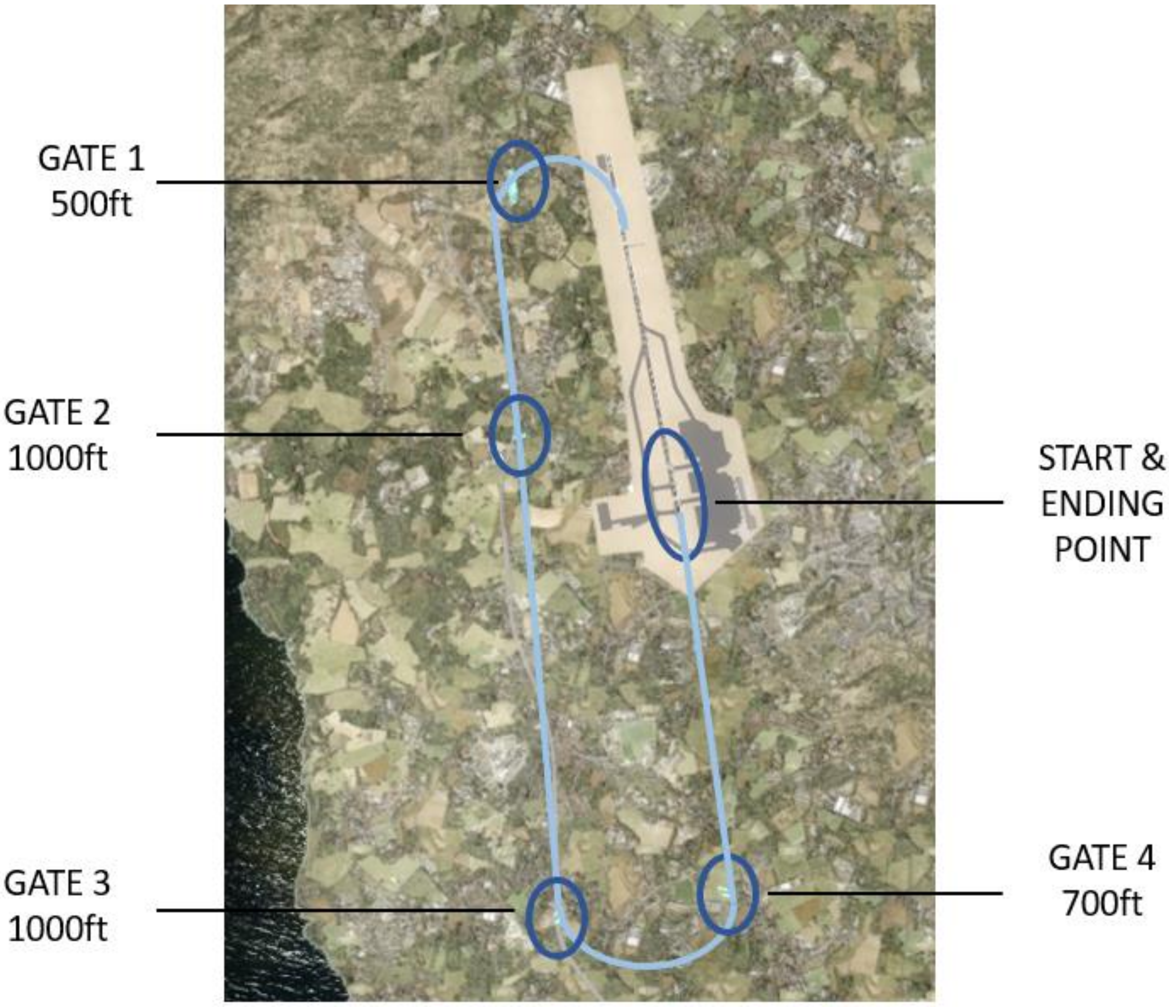


Figure 4.3 - Mission Scenario

4.3.4 Data Collection and Mission Accomplishment Definition

To analyse the performance of each operator, for each mission, flight parameters are recorded. This is accomplished by a standalone software called *Flight Simulator Quick Access Recorder and Analyzer* (FSQAR) [68], and it shall be initiated by the instructor shortly before the start of each mission and ended after landing. According to its definitions, it records data four times per second when the aircraft is below 100 feet above ground level (AGL) and once per second when below 2000 feet AGL. This allows a more detailed analysis of the takeoff and landing. For the clarity of this study, each moment recorded is defined as an instance, regardless of the frequency of the recording. At the end of each mission, the data will be available for post-analysis on a spreadsheet file on Microsoft® Excel® for graphical analysis.

90 parameters are recorded in the spreadsheet. The parameters used for this study present in the spreadsheet, with each unit, are the following:

- OnGround - 1 or 0, depending if the aircraft is touching the ground, or not, respectively;
- VSpeed - Vertical Speed, in Feet per Minute;
- IAS - Indicated Airspeed, in Knots;
- Alt - Indicated Altitude, in Feet;
- Pitch - Pitch Angle, in Degrees, in which positive values represent positive attitude in relation to the aircraft's centre of gravity (CG);
- Bank - Bank Angle, in Degrees, in which positive values represent bank to the left, in relation to the aircraft's centre of gravity (CG);
- HMag - Magnetic Heading, in Degrees;
- Lever - Throttle Level, in Percentage;
- Lat - Latitude, in decimal Degrees;
- Lon - Longitude, in decimal Degrees.

Additionally, a snapshot with the route performed on each flight will be taken from P3D Flight Analysis' Map.

From these files, it will be possible to analyse and compare the flight parameters for each recorded flight. Particular flight instances can be defined for a detailed analysis. Based on these data, the assessment of missions is performed.

The accomplishment of the mission translates that all the Aeronautical s are followed, a stable flight is conducted, and that the operator can comply with all the tasks. The SOPs deviations and unstable situations as crash, stall or failure to land will lead to a negative assessment and the consequent failure of the mission.

For the remote participation of operators of the mission, it is necessary to use screen sharing and voice conference. By using both, it is possible to control the operator's remote station to configure both mission and FSQAR configuration, while voice communicating.

4.3.5 Post Flight Questionnaire

At the end of the test, operators are asked to answer the following questions, including an open-answer question:

1. Are the pitch and bank adjustments difficult to perform?
2. Is the airspeed difficult to maintain?
3. Is the airspeed difficult to set?
4. Were you able to understand the attitude of the aircraft?
5. Is the head tracking distracting (if applicable)?
6. Do you believe you conducted a stable flight?
7. What was the overall comfort level of using this simulator? From 1 to 5, being 1 bad and 5 great.
8. Do you have any other comments, thoughts, or suggestions you would like to make regarding this simulation?

If the participants are not comfortable with the simulator, it can indicate that there might have been decision-making errors due to the discomfort level, instead of their full capabilities of operating it.

Once all participants had their setup defined and after having read all documentation, including the clarification of any possible doubts, the tests of this study were performed.

4.3.6 Data Analysis

After the conclusion of the tests included in this study, the instructor retained the recorded flight data, together with the routes performed and the duration of each mission attempt. The post flight questionnaire answers were saved.

Firstly, direct quantitative data was analysed.

The answers to the questionnaire can be found below, in Table 4.3. However, Operator X is not included in this Post Flight Questionnaire as its answers can be interpreted as biased.

Table 4.3 - Post Flight Questionnaire Answers

Questions	Operator 1	Operator 2	Operator 3
1. Are the pitch and bank adjustments difficult to perform?	No	No	No
2. Is the airspeed difficult to maintain?	No	No	No
3. Is the airspeed difficult to set?	No	No	No
4. Were you able to understand the attitude of the aircraft?	Yes	Yes	Yes
5. Is the head tracking distracting (if applicable)?	No	-	No
6. Do you believe you conducted a stable flight?	No	Yes	Yes
7. What was the overall comfort level of using this simulator? From 1 to 5, being 1 bad and 5 great.	4	4	4

8. Do you have any other comments, thoughts, or suggestions you would like to make regarding this simulation?	A	B	C

Answer A	Difficult landing process as it is not possible to verify the at which level the flaps are. Only a certain number of flaps shall be available.
Answer B	Flaps position should be visible on the instruments and inhibited when not allowed.
Answer C	As it is not possible to identify the flap position, it can lead to inadvertent selection. Flap information shall be visible and if possible, certain positions inhibited during the approach phase.

For each operator, flight times were recorded, as below in Table 4.4.

Table 4.4 - Flight Times Recorded

	Operator 1	**Operator 2**	**Operator 3**	**Operator X**
Mission 1	6 minutes	8 minutes and 13 seconds	9 minutes	8 minutes and 32 seconds
Mission 2	10 minutes and 31 seconds	7 minutes and 50 seconds	8 minutes and 43 seconds	8 minutes and 36 seconds
Mission 3	8 minutes and 16 seconds	7 minutes and 38 seconds	8 minutes and 37 seconds	9 minutes and 10 seconds

Operator 3 and Operator X perform the missions with alike durations. Operator 2 accomplishes the missions with a shorter duration, which can be associated with a higher airspeed verified in the values of the recorded parameter. Operator 1 has a variety of durations that shall be analysed in detail having in consideration all the recorded information for those mission attempts.

The recorded routes for each Operator are represented below, from Table 4.5 to Table 4.8.

Table 4.5 - Flight Routes Recorded for Operator 1

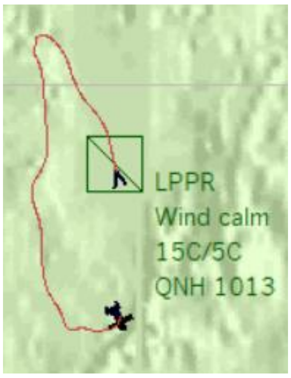
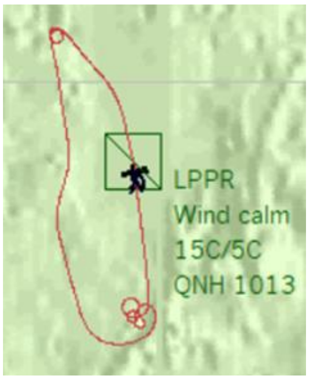
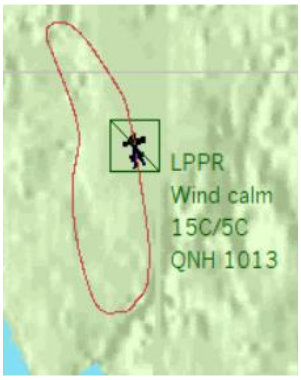
Operator 1		
		
Mission 1	Mission 2	Mission 3

Table 4.6 - Flight Routes Recorded for Operator 2

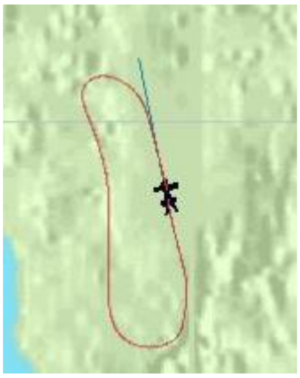
Operator 2		
		
Mission 1	Mission 2	Mission 3

Table 4.7 - Flight Routes Recorded for Operator 3

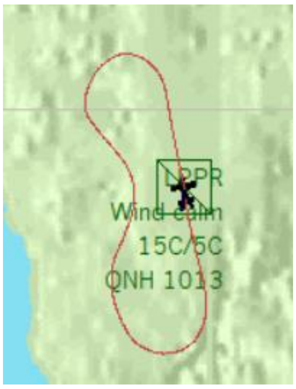
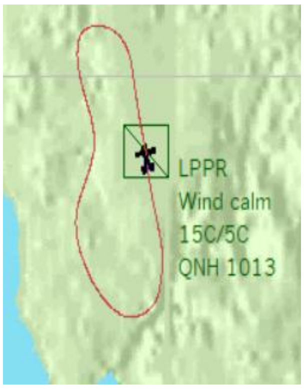
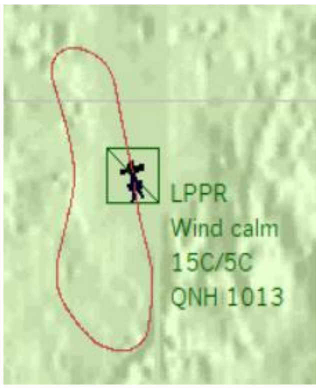
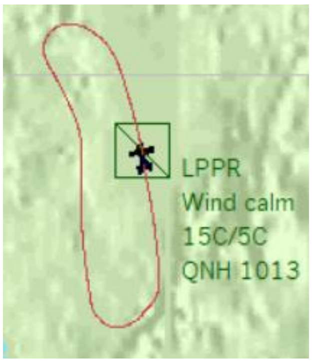
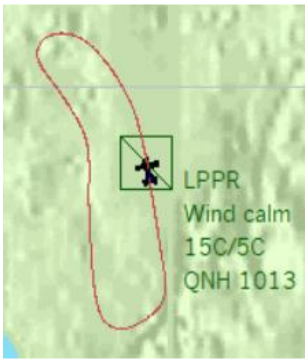
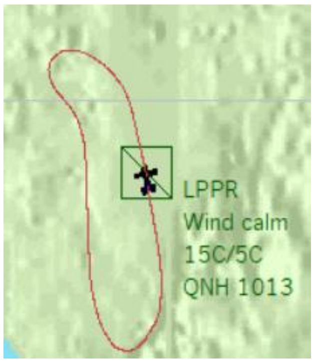
Operator 3		
		
Mission 1	Mission 2	Mission 3

Table 4.8 - Flight Routes Recorded for Operator X

Operator X		
		
Mission 1	Mission 2	Mission 3

From these recorded routes, it is already possible to identify that at least one mission attempt of Operator 1 was not accomplished, having crashed in-flight, which is compatible with the duration recorded for that particular attempt, shown on Table 4.4. Operator 2 and Operator 3 have a similar flight route, while Operator 1 and Operator X also share some similarities.

It is also relevant to mention that every attempt was considered valid, despite the level of success. It is acknowledged that the first attempt to fly the URLOG may show some surprise effect and the last flight may already show more proficiency. However, the last and third flight could not be considered exclusively for this study as it might not represent the several attempts since the flying and operational techniques were not corrected during the study. Any incorrect technique will prevail, and the operator can grow complacent. Complacency translates that the person conducting routine activities outside SOPs is not aware of actual dangers or deficiencies of acting outside those standards. Such normalized loss of awareness of potential dangers on routine operations places safety at risk. [69]

For the analysis of the recorded flight data on spreadsheets, and as each operator's mission attempt had a different duration, a common starting and ending point was defined. The starting point for this analysis corresponds to the anterior instance where the lever position changes from its initial location. The ending point is the first instance where the indicated airspeed corresponds to zero knots, as this occurs when the URBLOG stops on the runway. Each flight was also trimmed: the initial instances with no inputs given and final instances on the ground where the speed is equal to zero were deleted.

The analysis was divided into two different categories and depending on the category, two or three different subcategories:

- Flight - where the flight is analysed as a whole, providing information on how stable it was, if SOPs were followed and if the operator was able to perform the mission successfully. In this analysis, it is possible to verify the success of the mission;
- Task - where certain mission tasks are analysed in detail and provide more detailed information on how they were performed.

Two calculations methods used in statistics were used to perform this analysis: the median and the standard deviation.

The median is, according to Eurostat, "(...) the middle value in a group of numbers ranked by size. It is the number which is exactly in the middle so that 50% of the ranked numbers are above and 50% are below the median." [70]. The decision of using the median method instead of the mean is justified by the mean being the exact average between the numbers and would not show the tendency between the three flights. The median measures the central tendency. Two flights towards to a higher number and one flight towards a lower number will have together a median towards the higher number as it was the most frequent.

The median is calculated as follows:

$$Md = l_i + \left(\frac{E_{Md} - F_{ant\_acum}}{f_{Md}}\right) h \qquad (7)$$

$$li = \text{ the lower class containing the median}$$

$$f_{Md} = frequency\ of\ the\ class\ containing\ median$$

$$E_{Md=\frac{n}{2}}\ is\ the\ median\ element$$

$$h = width\ of\ the\ class$$

$$F_{ant\_acum} = less\ than\ comulative\ frequency$$

The standard deviation (σ) measures the dispersion of the data around the mean. The more concentrated, the smaller the standard deviation [71]. It is calculated as below:

$$\sigma = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}} \qquad (8)$$

$$x_i = \text{ individual value}$$

$$\bar{x} = mean\ of\ values$$

$$n = number\ of\ values$$

Having those calculations into consideration, the subcategories of the analysis correspond to the following:

1. Comparison of the three flights performed by each operator and the consequent calculation of the median;
2. Comparison of the calculated median of each operator versus the calculated median of the operator X, including their standard deviation;
3. Comparison of the median of each operator versus the median of the operator X.

For the Flight category, only subcategory 1 and 3 are used. For the Task category, all three subcategories are calculated.

To be recognizable during the analyses, next to each parameter recorded name or calculation it was added the number correspondent to the mission attempt. Then, following the same principle, the operator number was added in the name of the median and in the calculated standard deviation.

4.3.6.1 Flight Comparison

The objective of flight comparison analysis is to verify how stable was the flight, if SOPs were followed, and if the operator was able to perform the mission successfully.

From Figure 4.4 to Figure 4.10 it is possible to verify the Operator 1 data per mission, that originated a calculated median value. The same data for other operators is present in Appendix B - Flight Comparison Data.

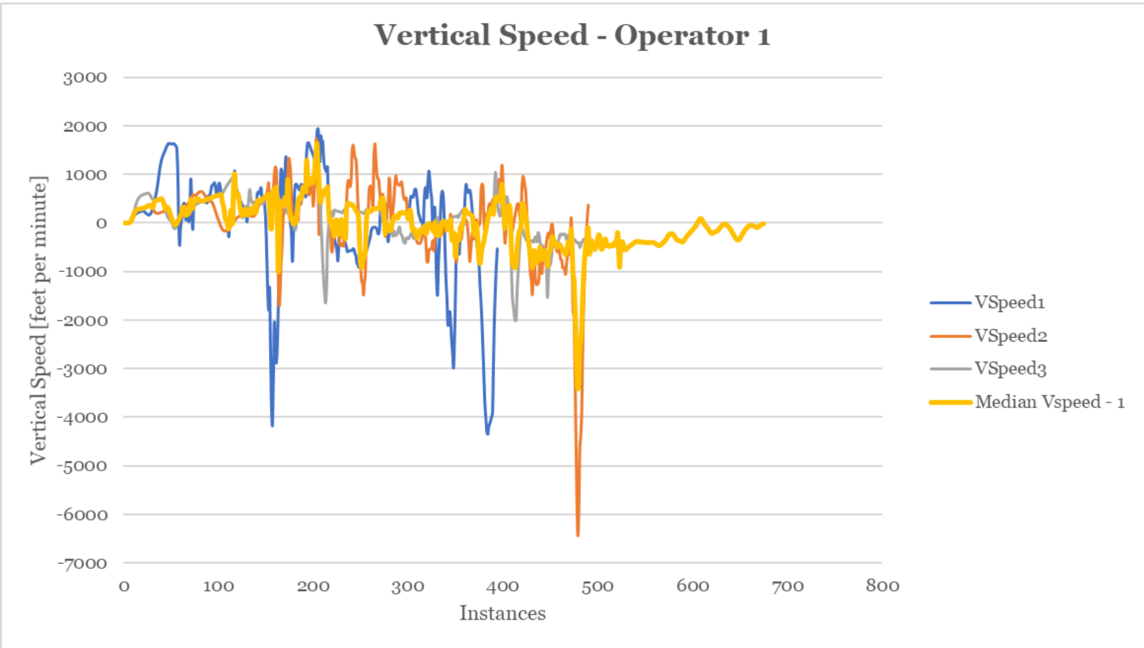


Figure 4.4 - Operator 1 missions comparison and median values of vertical speed

Operator 1 has a great amplitude of vertical speed values during each mission (Figure 4.4), however on the 3rd mission, the values remain between -2000 and 2000 feet per minute, which can indicate familiarization with the operational and flying technique for this vehicle. However, it is also possible to identify that on the 1st and 2nd mission attempt, following a peak value, zero value is achieved. This indicates that the vehicle crashed, failing the mission. Only the 3rd attempt of the mission was successfully performed.

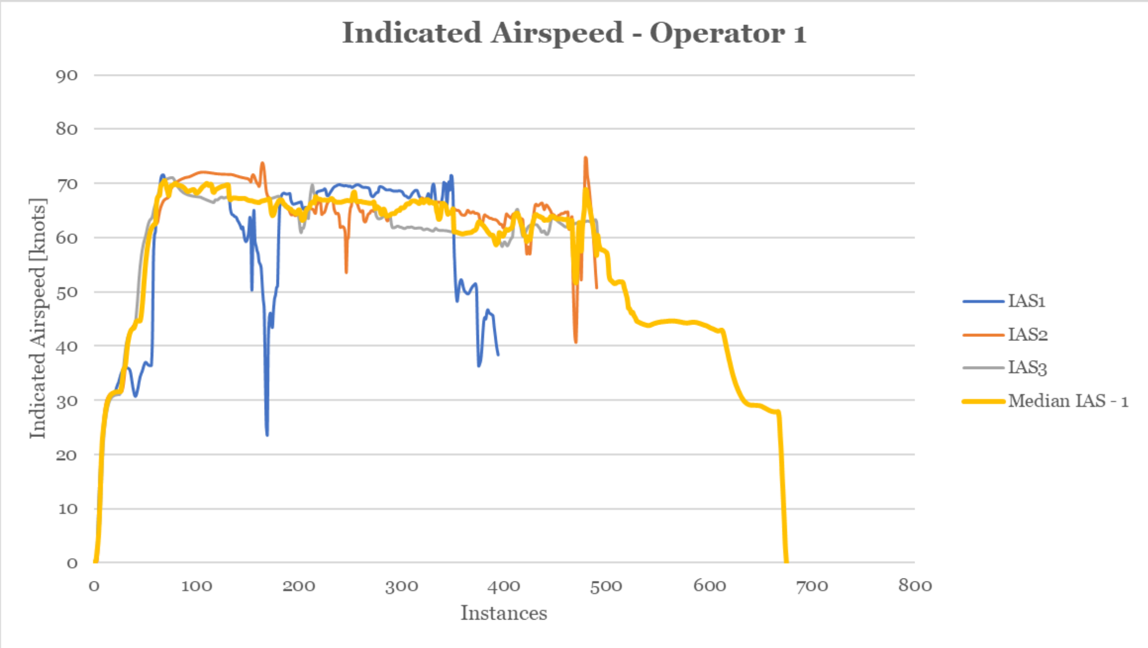


Figure 4.5 - Operator 1 missions comparison and median values of indicated airspeed

During the 1st and 2nd mission attempt, Operator 1 conducts more speed changes in relation to the 3rd attempt (Figure 4.5). There are 2 peaks on the 1st attempt, the last one correspondent to a crash as no more speed instances are recorded. On the 2nd attempt, the last recorded instances are represented by peaks, that lead also to a crash. The 3rd attempt of the mission was successfully performed, with adequate speeds. The Operator 1 mainly flies the cruise below or at the recommended cruise airspeed (65 Knots of Indicated Air Speed, KIAS).

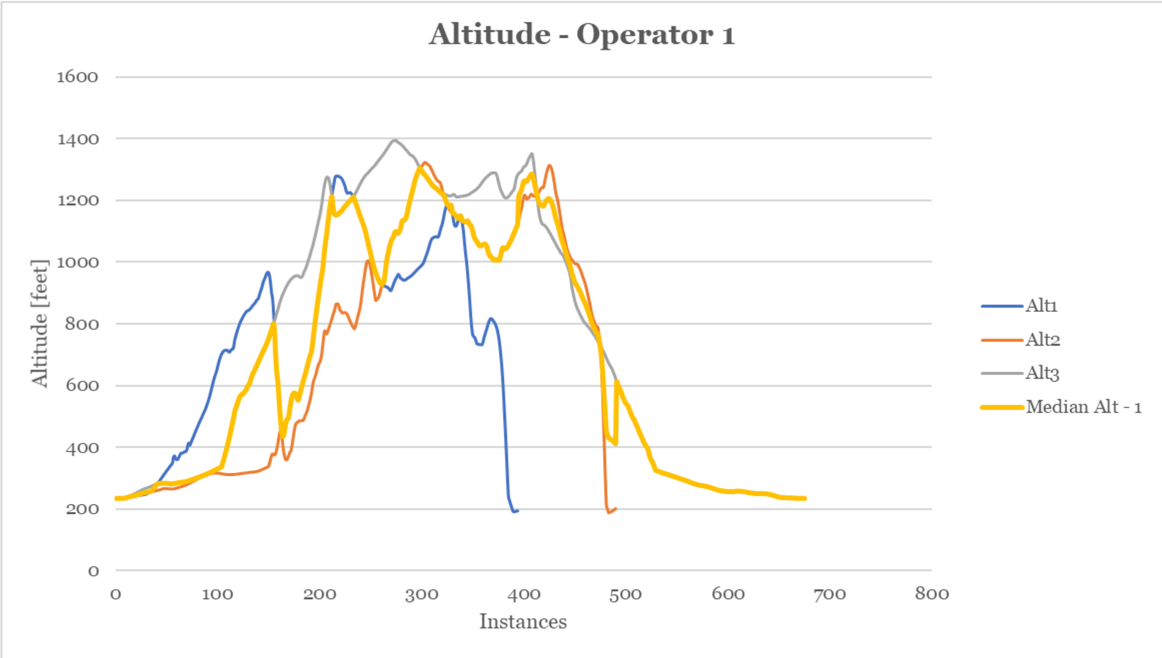


Figure 4.6 - Operator 1 missions comparison and median values of altitude

Operator 1 during the 1st and 2nd attempts performs more accentuated climbs and descents (Figure 4.6), which is according to the Vertical Speed analysis on Figure 4.4, including the identified crashes. On attempt 3, Operator 1 conducts smoother altitude changes, especially during the approach.

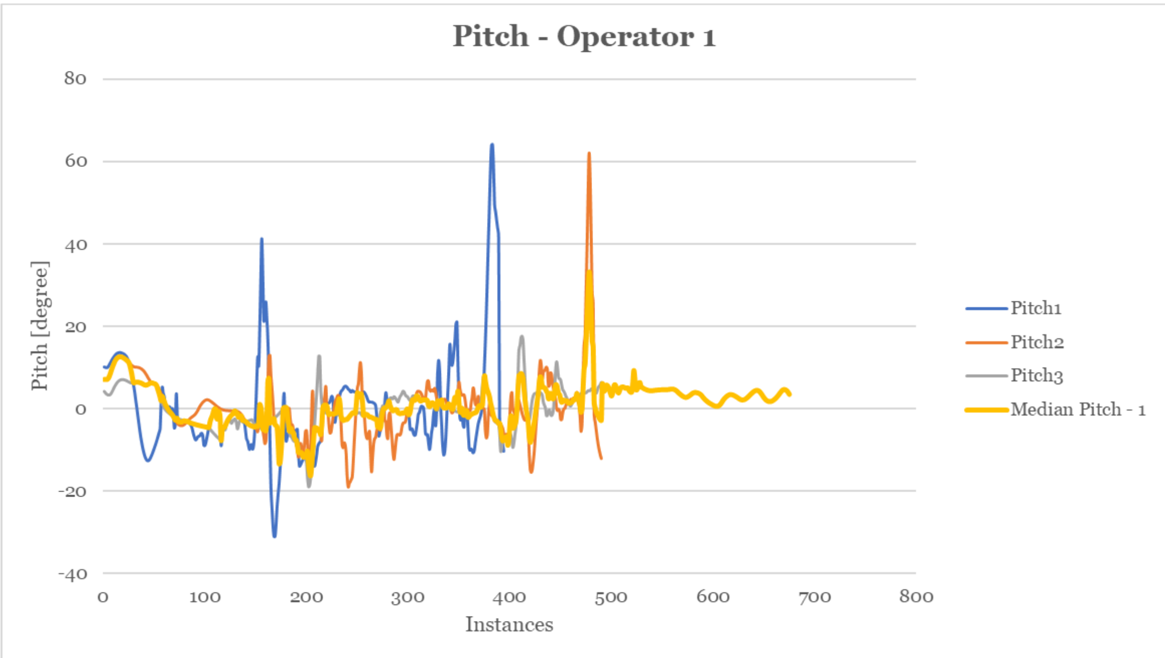


Figure 4.7 - Operator 1 missions comparison and median values of pitch angle

Operator 1 during the 1st and 2nd attempts performs more accentuated pitch inputs, reflected in the pitch attitude (Figure 4.7), which is according to the Vertical Speed analysis on Figure 4.4 and the Altitude analysis on Figure 4.6, including the identified crashes, with high maximum values reached on those moments. On attempt 3, Operator 1 performs smoother pitch changes.

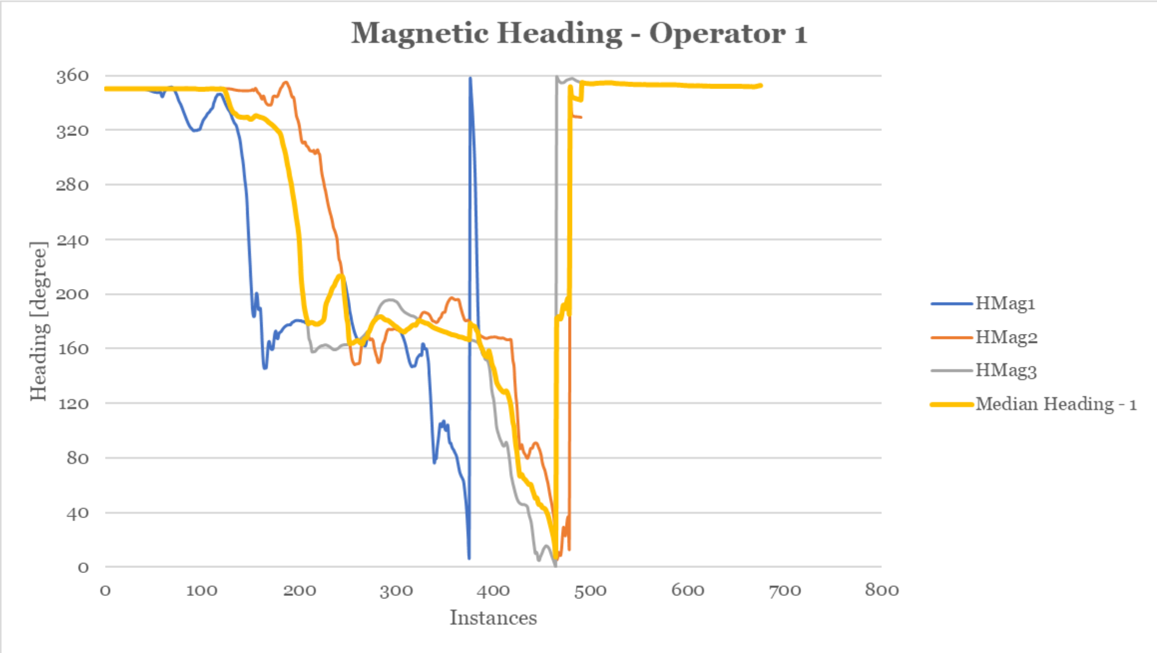


Figure 4.8 - Operator 1 missions comparison and median values of magnetic heading

Operator 1 during the 1st attempts performs a quick heading change (Figure 4.8), that can be associated with the instances precedent of a crash. On the 2nd and 3rd attempt, the heading values reached identify that the mission route was followed, but on mission attempt 2, the final approach heading is not maintained for the following instances inputs. This shows that, although the final approach heading was reached, it was not possible to maintain, causing a crash during the approach.

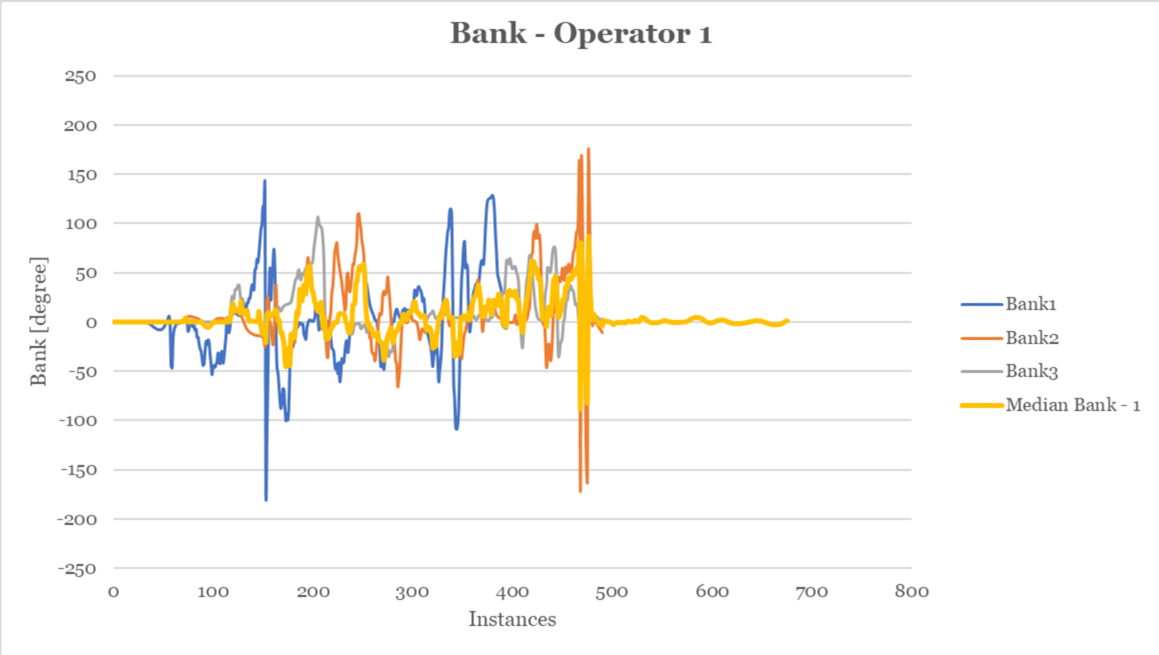


Figure 4.9 - Operator 1 missions comparison and median values of bank angle

Operator 1 reaches accentuated banks during the 1st and 2nd attempts, representing unstable flights (Figure 4.9): on the 1st attempt is visible several bank changes during initial climb, indicating unstable takeoff. Maximum values reached on the attempt 2 represent the crash, which is can be interpreted as a consequence of the performed unstable flight. On attempt 3 however, the Operator 1 performs smoother bank changes, particularly during the approach.

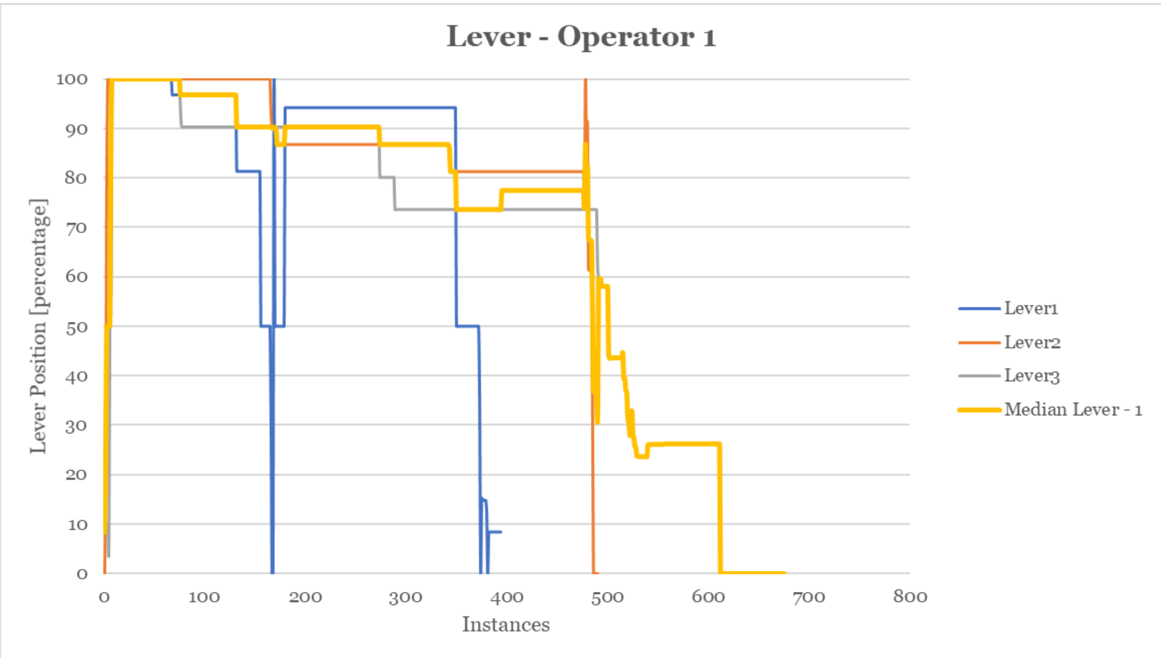


Figure 4.10 - Operator 1 missions comparison and median values of lever position

Operator 1 performs several lever position adjustments during cruise flight (Figure 4.10): on the 1st attempt, several quick and extreme changes are performed, one leading to a crash; on the 2nd attempt, the crash is preceded by a maximum level position, which can indicate a tentative plan of recovering from an unstable state. On attempt 3 however, the Operator 1 lever inputs are smoother and in line with the SOPs defined. In every attempt, the lever position for takeoff is correct.

From Figure 4.11 to Figure 4.17 it is possible to verify and compare the median for each operator.

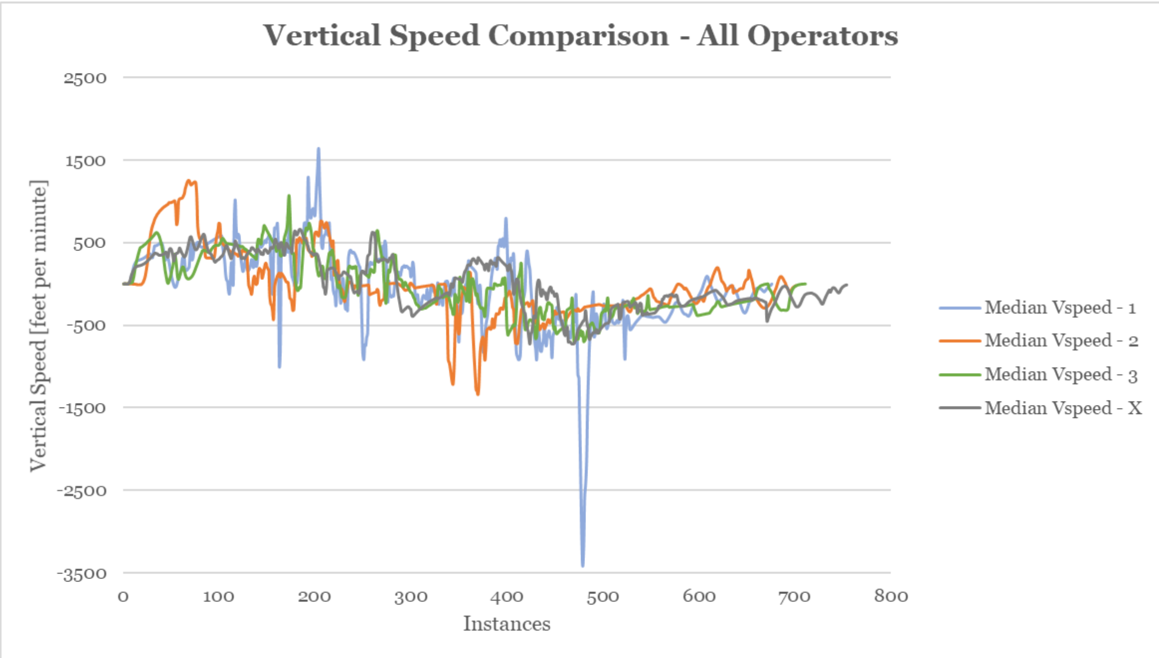


Figure 4.11 - Comparison of vertical speed median values for all operators

Operator 1 median shows a great amplitude of values, which can be related to the crashes of the two mission attempts of that Operator (Figure 4.11). Operator 2 has also some variations when compared to Operator X, especially during initial climb where it is performed with higher values of vertical speed. Operator 3 median is the most comparable to the Operator X median.

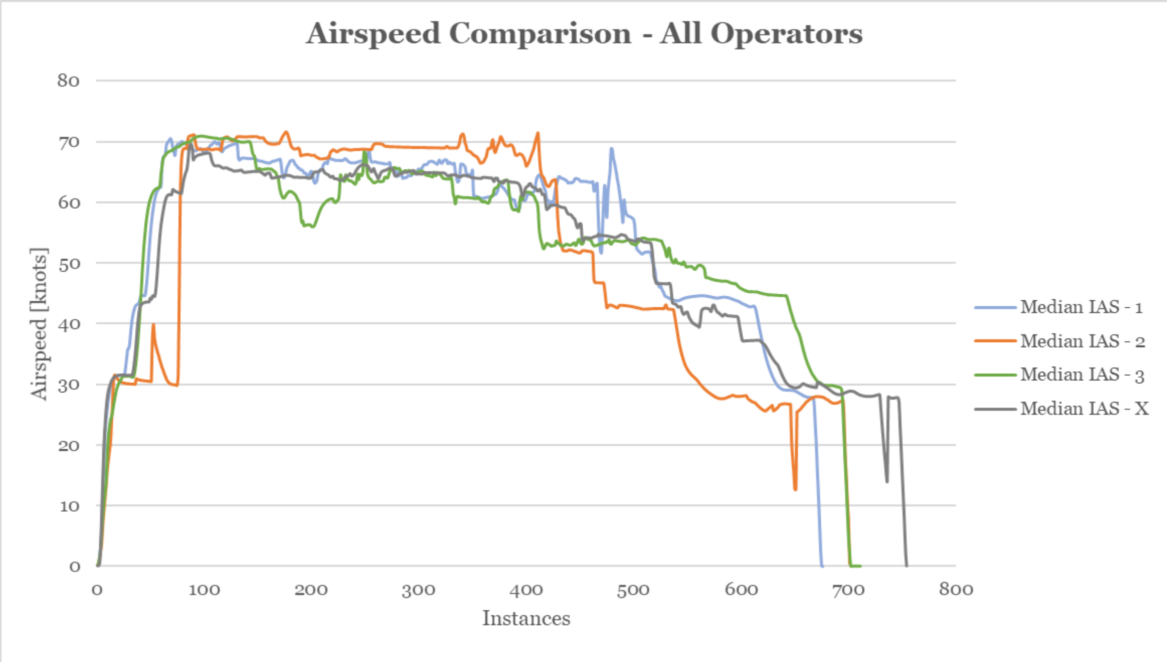


Figure 4.12 - Comparison of airspeed median values for all operators

Operator 2 median shows that during the initial climb and approach (Figure 4.12), lower speeds were flown, in comparison to the Operator X. However, during cruise, Operator 2 flies at a higher speed than the recommended cruise airspeed. During the approach, Operator 3 also flies at a higher speed than the Operator X. Operator 1 is the most similar to Operator X.

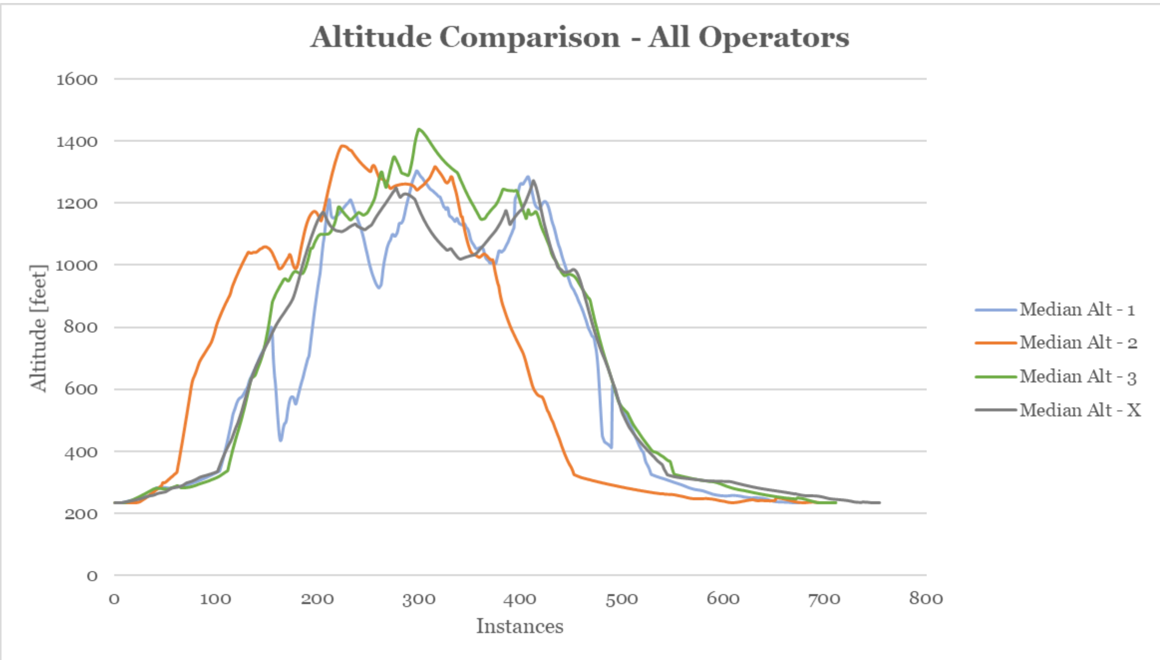


Figure 4.13 - Comparison of altitude median values for all operators

Operator 1 median shows a great amplitude of values, which can be related to the crashes of the two mission attempts of that Operator (Figure 4.13). Operator 2 achieves higher values in a shorter amount of instances, which can be related to the vertical speed during those instances, as seen in Figure 4.11. Operator 3 median is the most similar to the Operator X median, although achieving higher altitude valuers during the cruise.

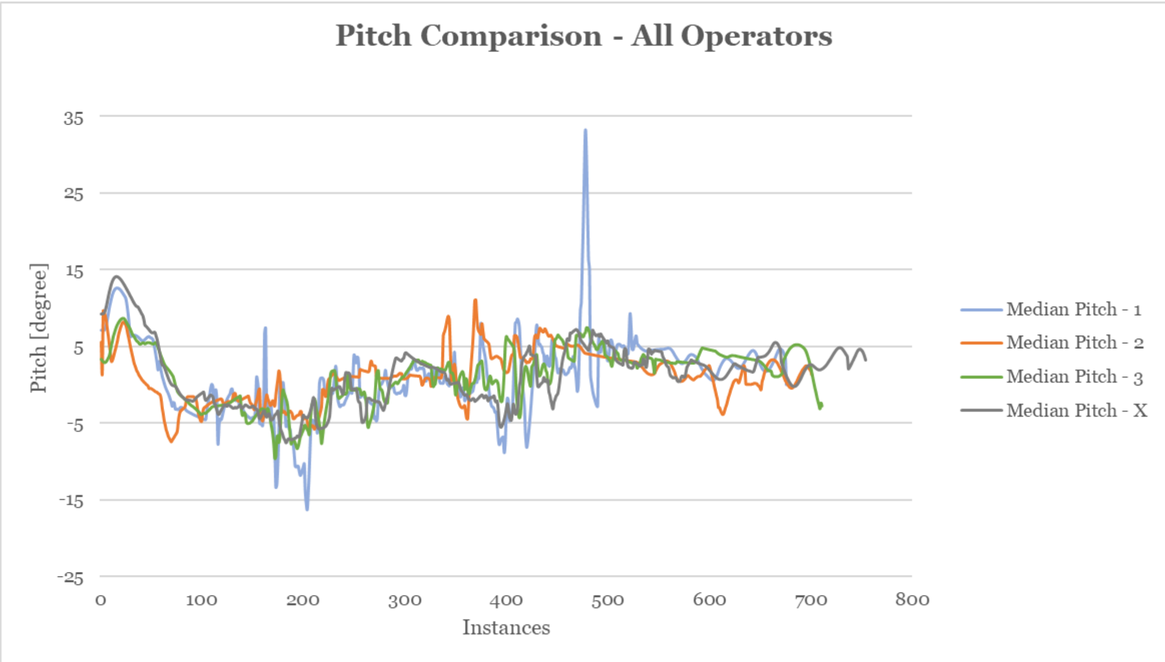


Figure 4.14 - Comparison of pitch angle median values for all operators

Operator 1 median shows a great amplitude of values, which can be related to the crashes of the two mission attempts of that Operator (Figure 4.14). During the initial climb and approach, Operator 2, performs those phases with lower values of pitch in comparison with the other Operators. Operator 3 median is the most comparable to the Operator X median.

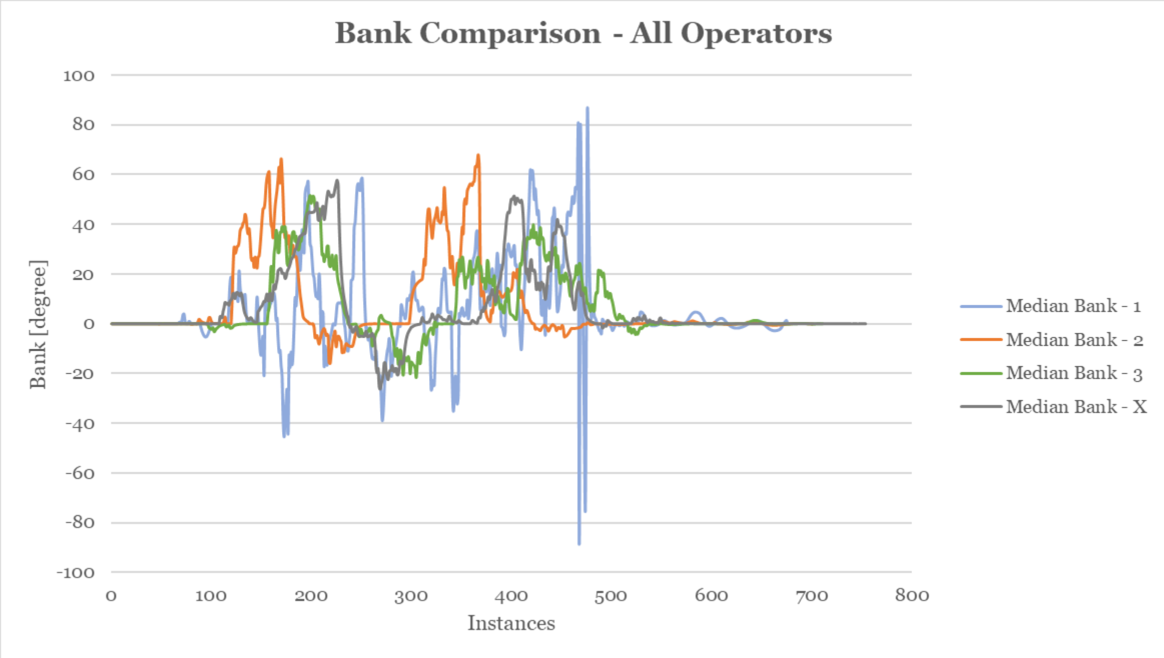


Figure 4.15 - Comparison of bank angle median values for all operators

Operator 1 median shows a great amplitude of values of bank, which can be related to the unstable flights, precedent to crashes (Figure 4.15). During the initial climb and approach, Operator 2, performs those phases with accentuated values of bank in comparison with the other Operators. Operator 3 median is the most similar to the Operator X median.

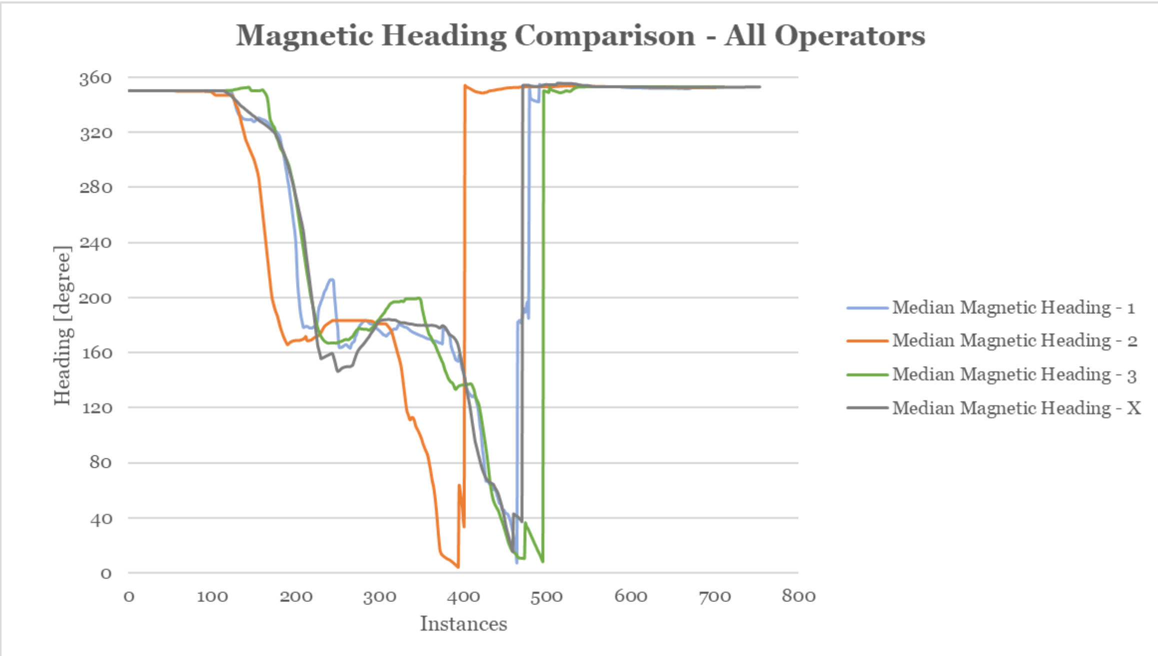


Figure 4.16 - Comparison of magnetic heading median values for all operators

Operator 2 median shows that headings are achieved earlier than other Operator's medians (Figure 4.16). This can be associated with the higher cruise speed in which the Operator 2 flies, as shown in Figure 4.12, meaning that the heading was achieved more rapidly due the accentuated banks. Both Operator 1 and Operator 3 medians are similar to the Operator X median.

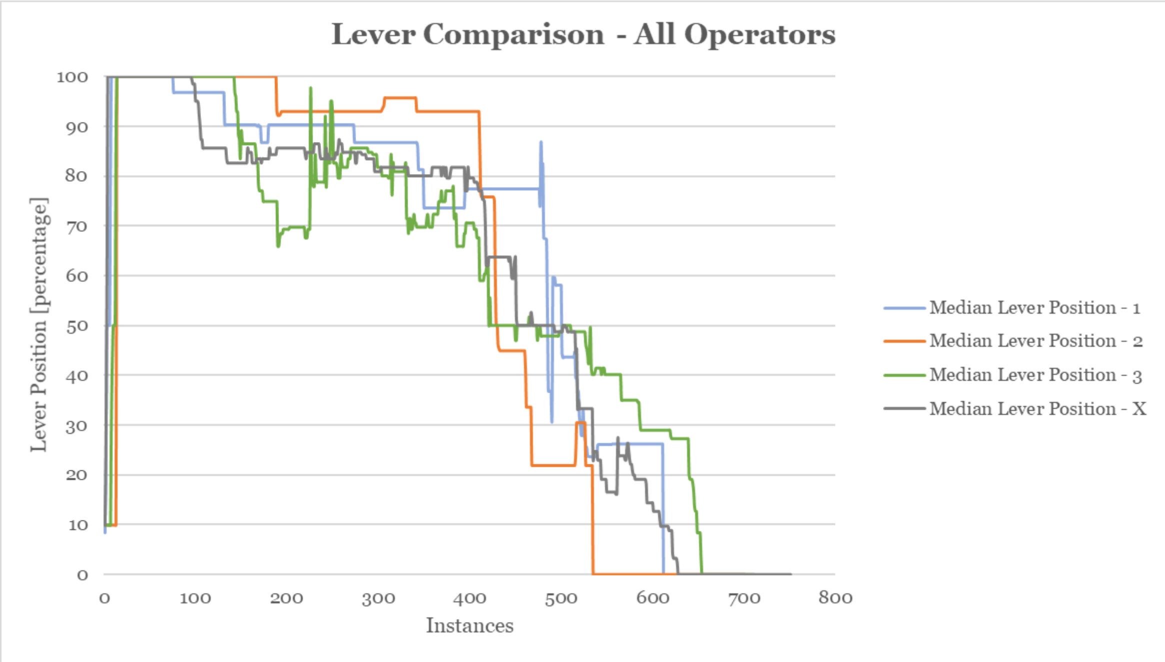


Figure 4.17 - Comparison of lever position median values for all operators

Operator 1 median show peaks of lever positions that are precedent to the crashes (Figure 4.17). Operator 2 performs small variations of lever positions trough the flights, with reduced lever position during the approach. This can be associated with the fact that this Operator flies the cruise at a higher speed, as seen in Figure 4.12, than the other Operators, meaning that to reduce speed, the Operator reduced the lever position earlier than the other Operators. Operator 3 median shows more changes of lever position during cruise than the Operator X, approaching with higher lever position during the approach. All Operators, set the takeoff lever position correctly, accordingly to the SOPs. The initial value of 10% can be related to the sensitivity of the throttle device used.

4.3.6.2 Task Comparison

The objective of task comparison is to analyse it in detail and provide more information on how they were performed. For such, it is first necessary to define which tasks are of interest for such and how many instances are necessary to define their period of analysis. Having into consideration the frequency of the QAR recording and the objectives of the study, the tasks and instances were defined according to Table 4.9.

Table 4.9 - Number of Representative Instances per Task

Mission Task	Number of Instances
Vertical Takeoff from runway 35 LPPR	50, from the first recorded instance
1st Gate interception	30 [-15;+15]
2nd Gate interception	30 [-15;+15]
3rd Gate interception	30 [-15;+15]
4th Gate interception	30 [-15;+15]
Landing on runway 35 LPPR	50, from the last recorded instance

To compare the flight data in specific points of the mission, the data from each flight had to be equally set for the analysis. As a reference, the data was equally spread according to recorded instances of Operator X, regardless of the number and position of instances in the recording in each mission attempt.

To analyse the gate interceptions, the Lat and Long recorded values were used. The coordinates of each flight were compared with the gate's coordinates, present in Table 4.10, to find the interception of the gate.

Table 4.10 - Gate Position

	GATE 1	GATE 2	GATE 3	GATE 4
Latitude (Decimal Degrees)	41,25955 N	41,24126 N	41,20683 N	41,20768 N
Longitude (Decimal Degrees)	8,69511 W	8,69442 W	8,69074 W	8,67416 W
Minimum Altitude (Feet)	500	1000	1000	700
Heading (Degrees)	259	168	136	017

Although it is understood that for graphic comparison, graphics shall have the same scale limits, using that visualisation on these analyses would difficult its survey as different maximum values are reached with variable extreme points.

From Figure 4.18 to Figure 4.24 it is possible to verify the Operator 1 data per mission task, that originated a calculated median value. The same data for other operators is present in Appendix C - Task Comparison Data. Tasks were highlighted in the first figure for better understanding.

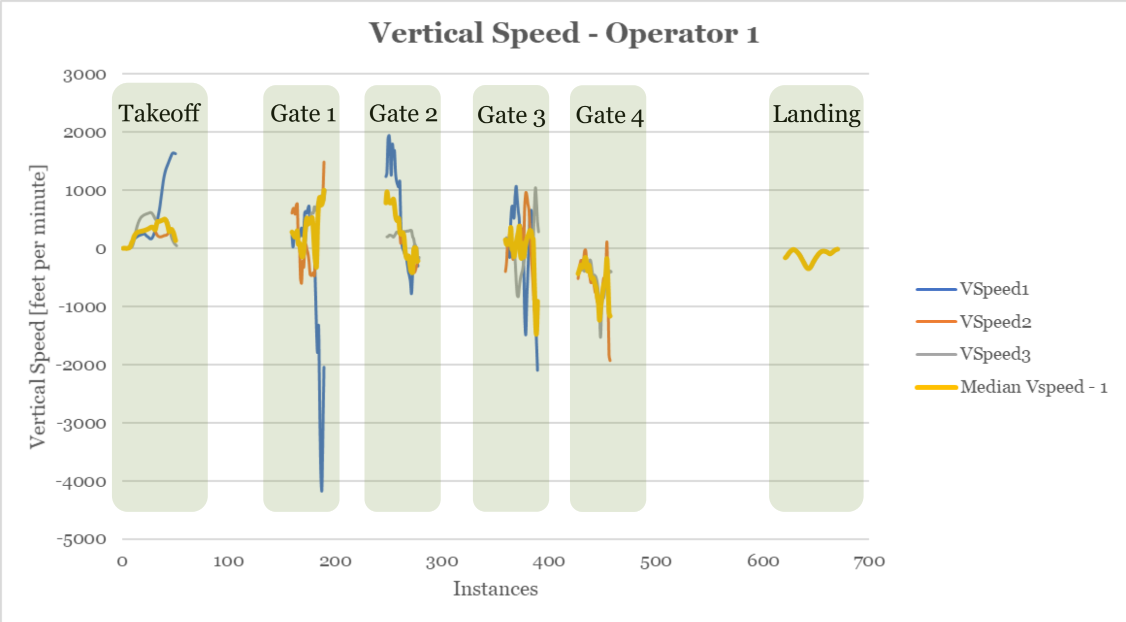


Figure 4.18 - Operator 1 missions comparison and median values of vertical speed per task

It is observed that during mission attempt 1, a greater range of values is achieved, with accentuated changes (Figure 4.18). In the other mission attempts, values achieved are similar, with small variations.

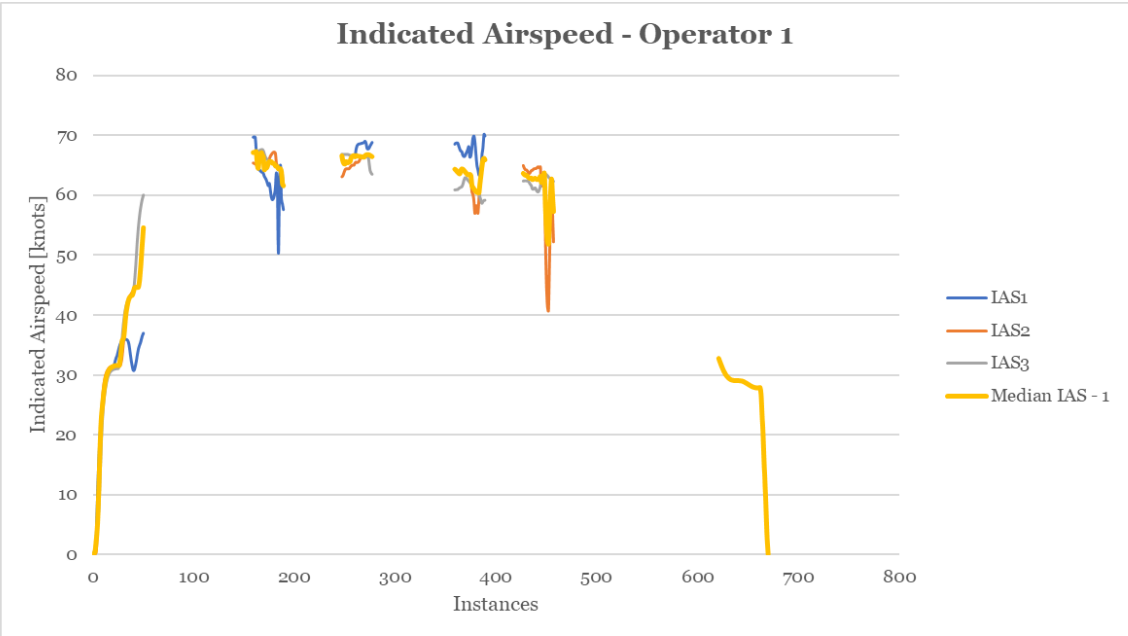


Figure 4.19 - Operator 1 missions comparison and median values of indicated airspeed per task

The mission attempt 1 has a greater range of values when compared with attempt 2 and 3 (Figure 4.19). On both attempt 1 and 2, is possible to observe repetitive peaks, that can be related to the unstable flight precedent to the crashes. During takeoff on the mission attempt 1, the airspeed value is lower than the other attempts.

Figure 4.20 - Operator 1 missions comparison and median values of altitude per task

On the mission attempt 1 and 3, is observed a greater range of values when compared with attempt 2 (Figure 4.20). Values of the 1st attempt tend to be lower in comparison with the other attempts.

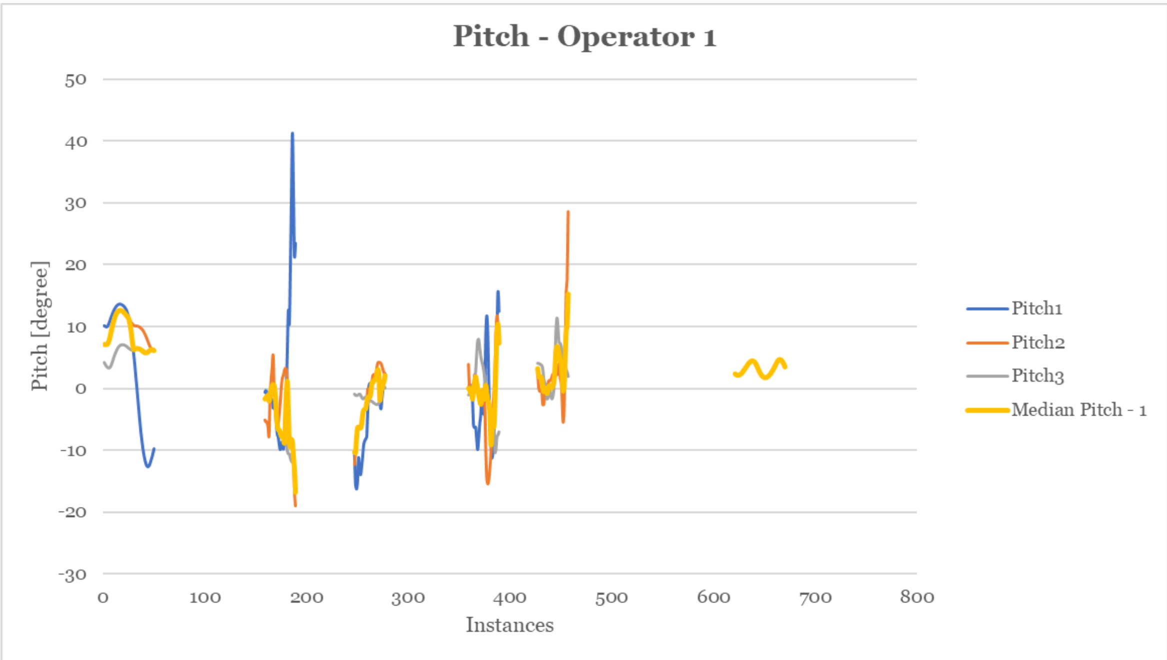


Figure 4.21 - Operator 1 missions comparison and median values of pitch angle per task

On the mission attempt 1 and 2, is observed a greater range of values when compared with attempt 3, with accentuated peaks (Figure 4.21). This translates an unstable flight on those two attempts.

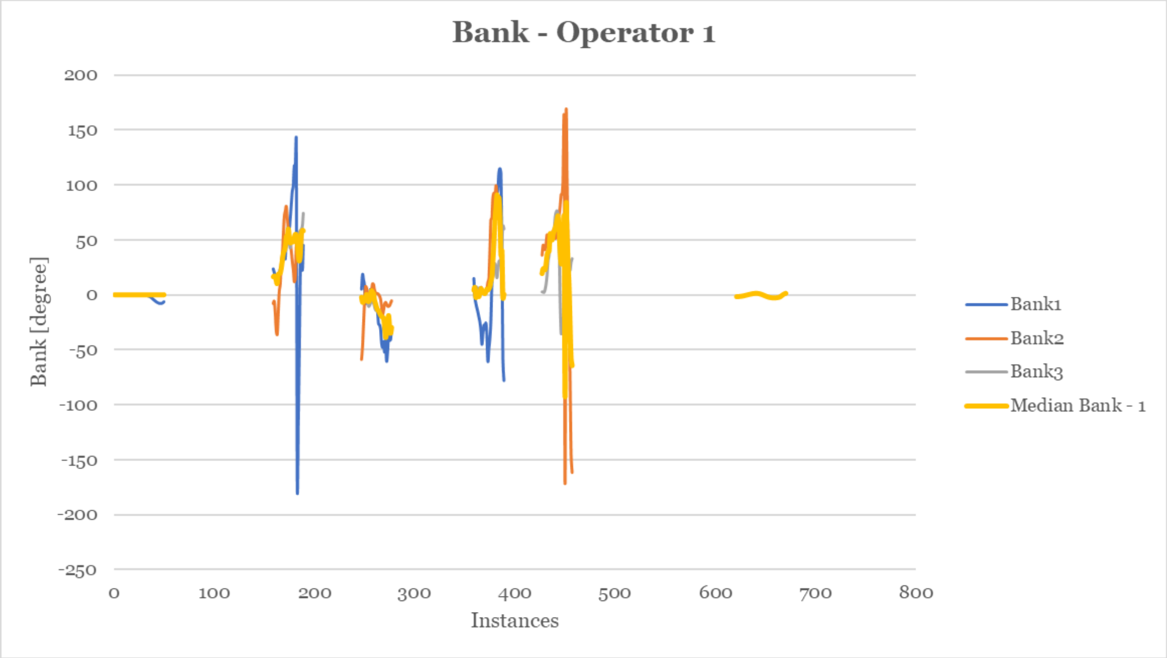


Figure 4.22 - Operator 1 missions comparison and median values of bank angle per task

Commonly to Figure 4.21, on the mission attempt 1 and 2, is observed a greater range of values when compared with attempt 3, with accentuated peaks (Figure 4.22). This translates an unstable flight on those two attempts.

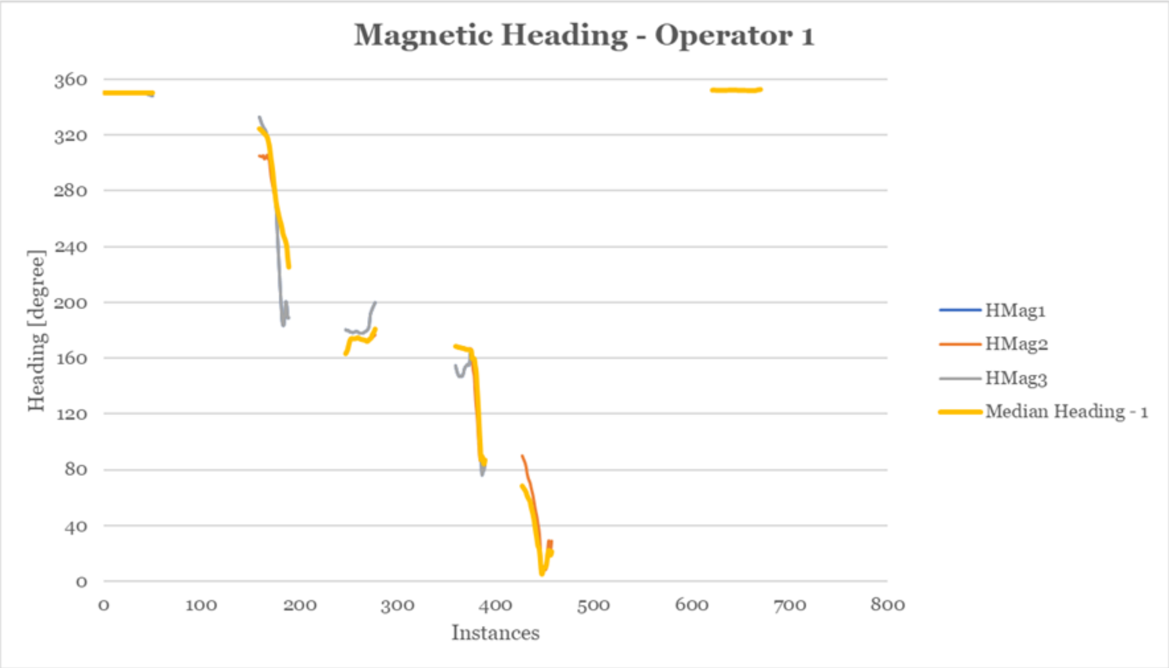


Figure 4.23 - Operator 1 missions comparison and median values of magnetic heading per task

Although in every attempt, the heading gates are reached, on mission 3, is observed a greater range of values when compared with attempt 1 and 2 (Figure 4.23). This can be related to the bank attitude observed in Figure 4.22, in which the mission attempt 3 is flown.

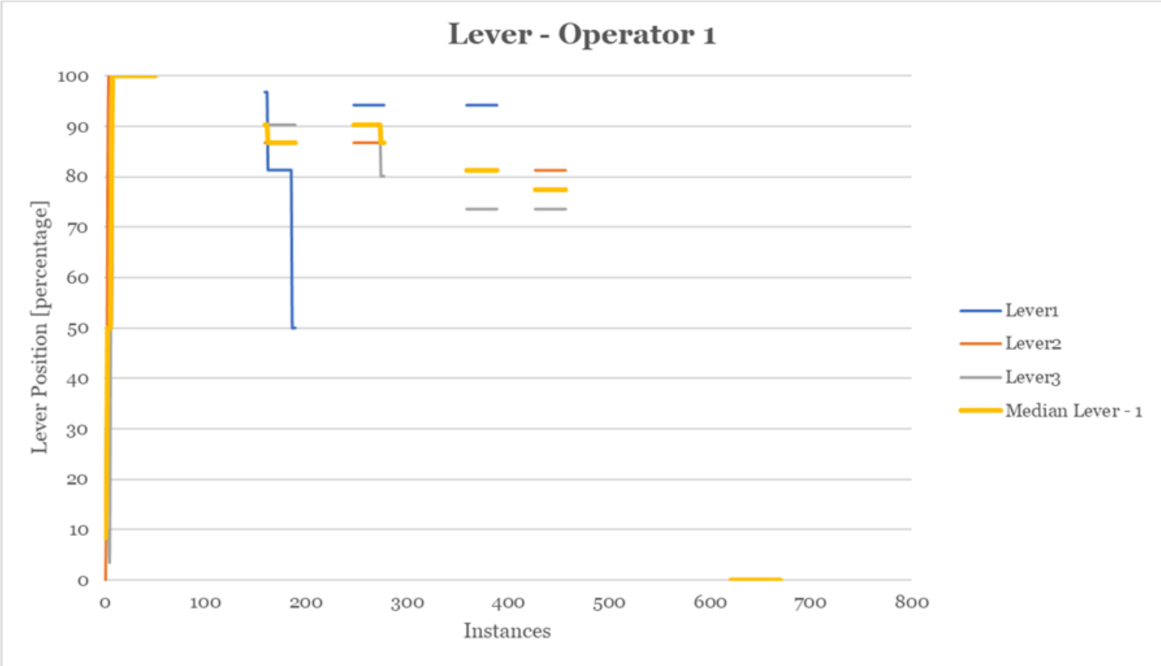


Figure 4.24 - Operator 1 missions comparison and median values of lever position per task

On mission attempt 1, it is observed that higher lever positions were set (Figure 4.24). However, on the interception of gate 1, the values of the 1st attempt vary abruptly, coincident with an unstable flight. On takeoff, the level position set is according to the SOPs in all attempts.

From Figure 4.25 to Figure 4.31 it is possible to verify the Operator 1 median data compared with Operator X for each task, including its calculated standard deviation. The same data for other operators is present in Appendix C - Task Comparison Data. Tasks were highlighted in the first figure for better understanding.

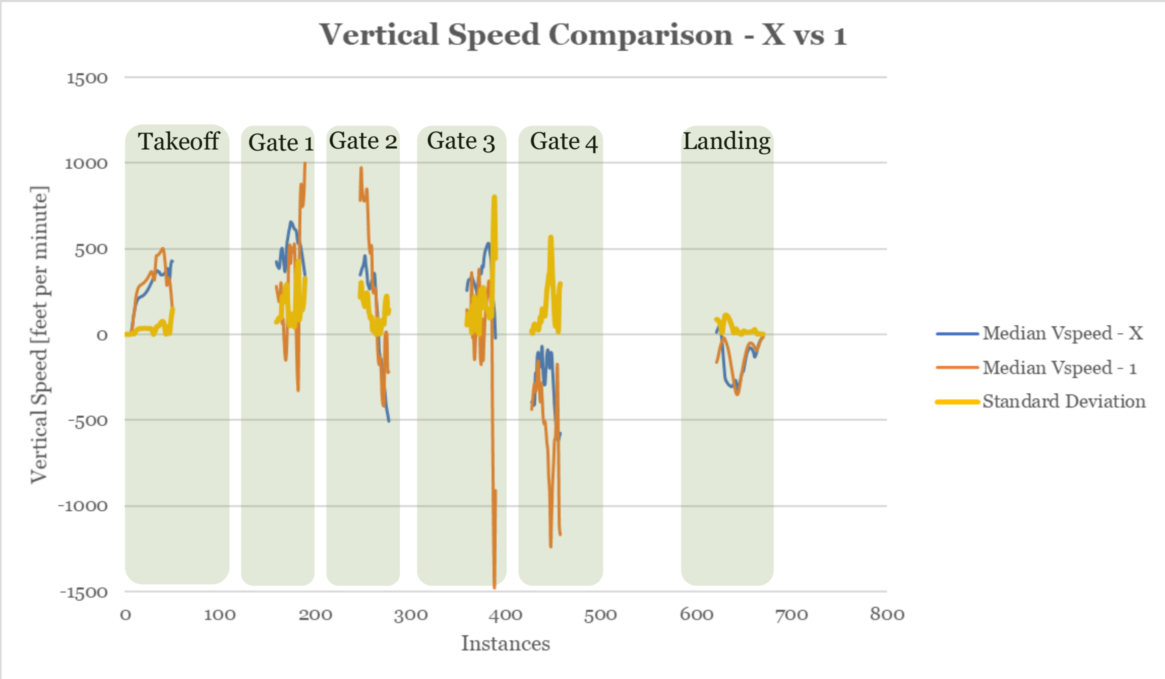


Figure 4.25 - Operator X vs Operator 1 missions comparison and standard deviation values of vertical speed per task

It is observed that during the interception of the gates, the Operator 1 median, shows a greater range of values when compared with the median of the Operator X (Figure 4.25). Thus in those instances, a larger standard deviation is seen. During both takeoff and landing, the medians show approximate values.

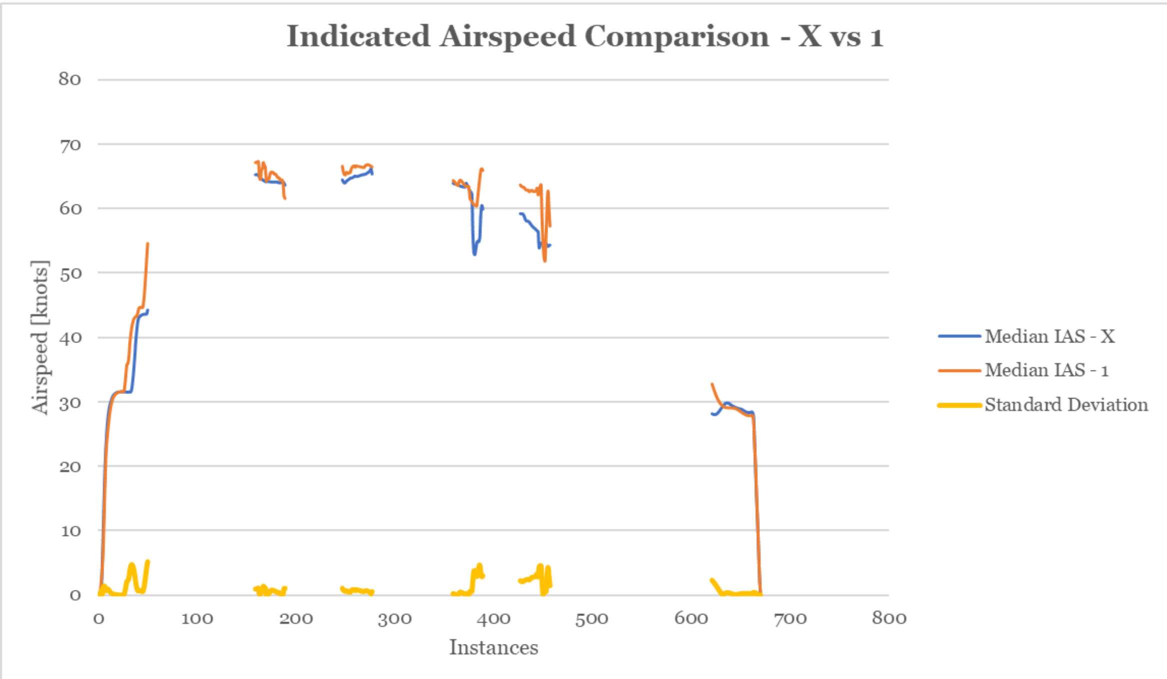


Figure 4.26 - Operator X vs Operator 1 missions comparison and standard deviation values of indicated airspeed per task

It is noticed that during the interception of the gate 3 and 4 (Figure 4.26), the Operator 1 median, shows a greater range of values when compared with the median of the Operator X, because of that, a larger standard deviation is seen. During both takeoff and landing, the medians show approximate values.

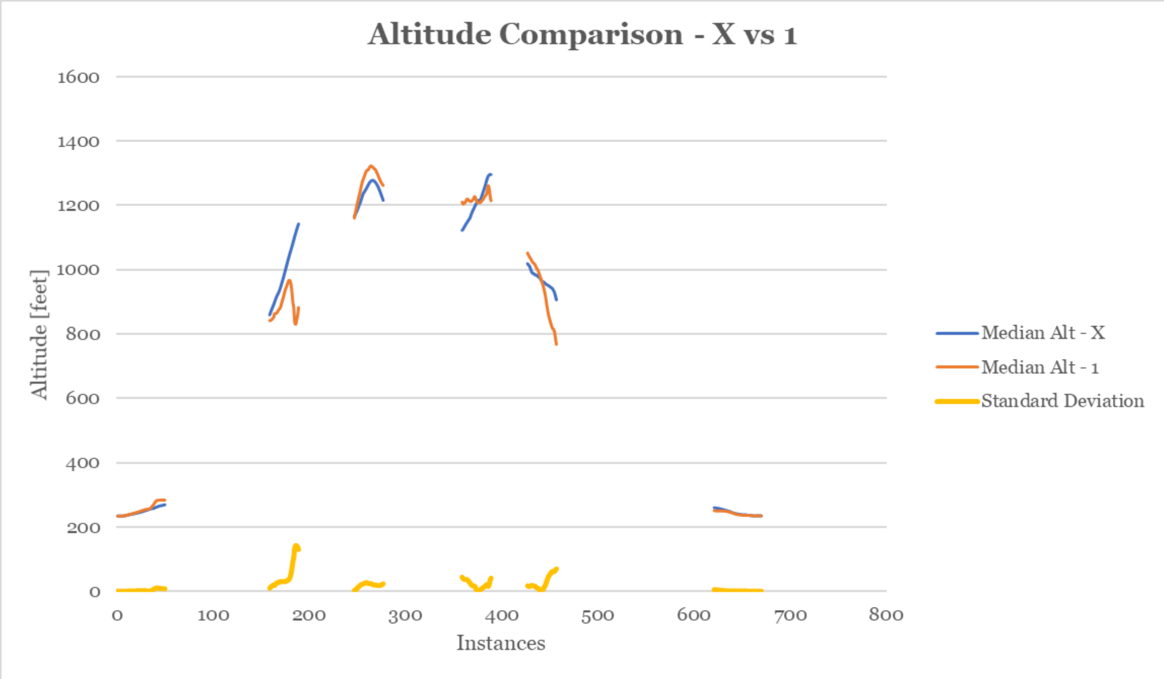


Figure 4.27 - Operator X vs Operator 1 missions comparison and standard deviation values of altitude per task

It is observed that during the interception of the gates 1, 2 and 3 (Figure 4.27), the Operator 1 altitude median, shows accentuated differences when compared with the median of the Operator X, thus in those instances, a larger standard deviation is seen. During both takeoff and landing, the medians show approximate values.

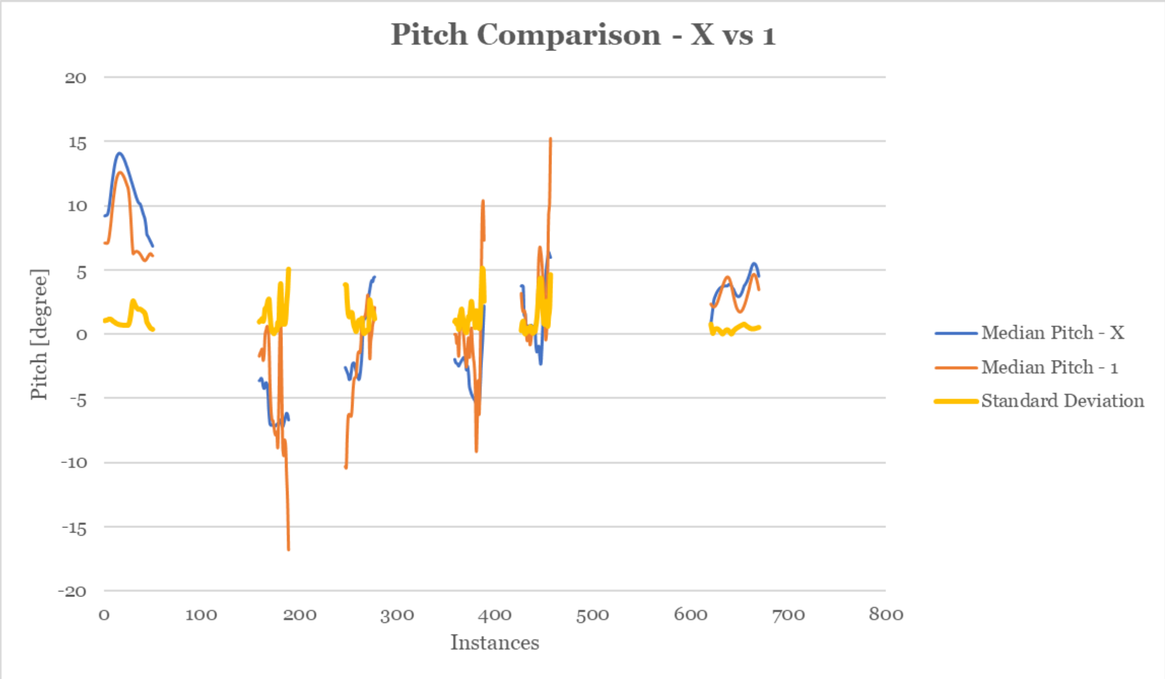


Figure 4.28 - Operator X vs Operator 1 missions comparison and standard deviation values of pitch angle per task

It is observed that during the interception of the gates (Figure 4.28), the Operator 1 pitch median shows accentuated differences when compared with the median of the Operator X, thus in those instances, a larger standard deviation is seen. During both takeoff and landing, the medians show approximate values.

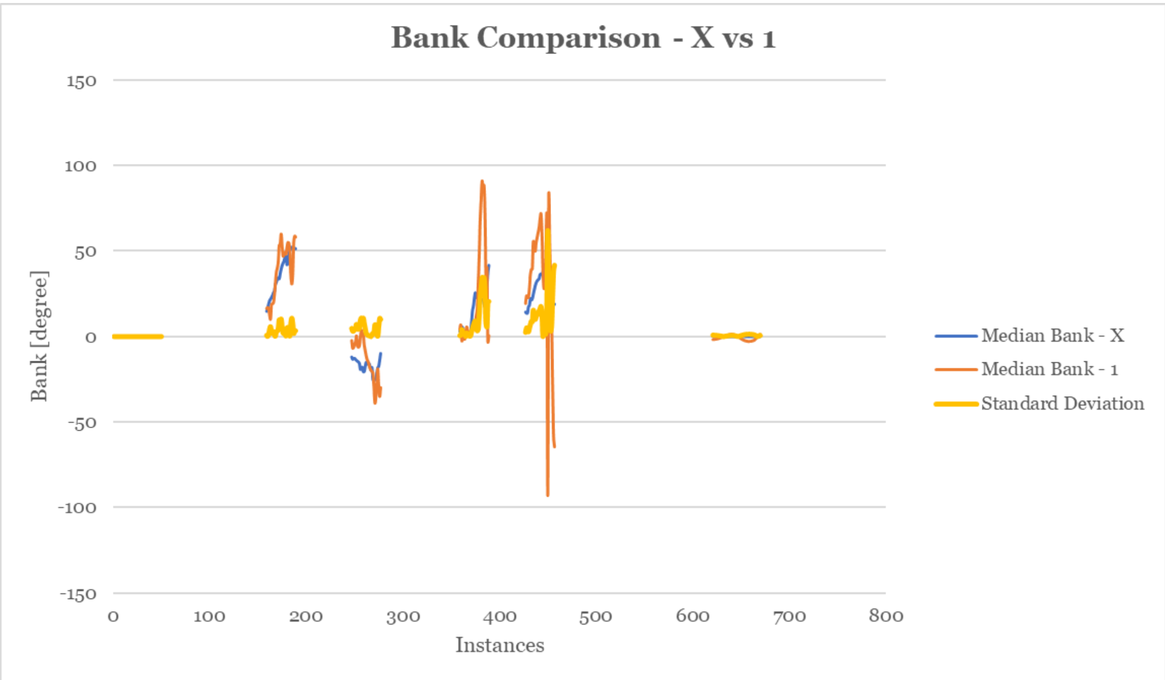


Figure 4.29 - Operator X vs Operator 1 missions comparison and standard deviation values of bank angle per task

It is seen that during the interception of the gates 3 and 4 (Figure 4.29), the Operator 1 bank median shows accentuated differences when compared with the median of the Operator X, therefore, a larger standard deviation is noticed. During both takeoff and landing, the medians show approximate values.

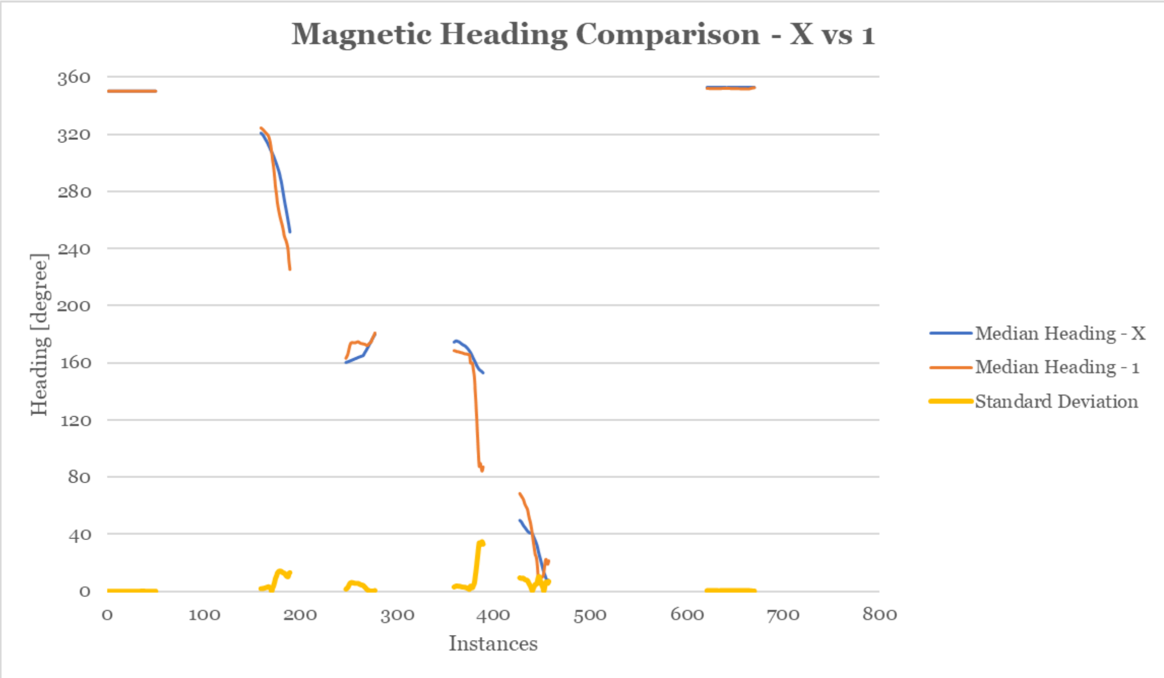


Figure 4.30 - Operator X vs Operator 1 missions comparison and standard deviation values of magnetic heading per task

It is observed that during the interception of the gates 3 and 4 (Figure 4.30), the Operator 1 bank median shows major differences when compared with the median of the Operator X, thus in those instances, a larger standard deviation is noted. When associated with Figure 4.29, is coherent and shows that the Operator 1 was turning while intercepting the gates. During both takeoff and landing, the medians show approximate values.

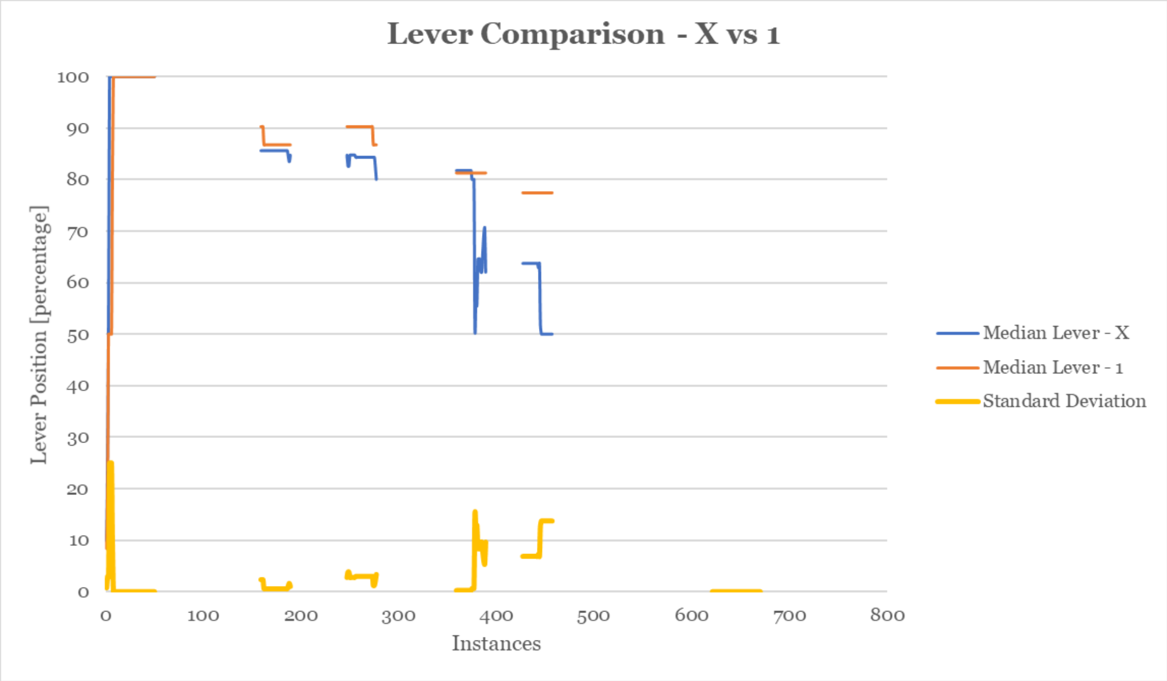


Figure 4.31 - Operator X vs Operator 1 missions comparison and standard deviation values of lever position per task

It is observed that during the interception of the gates the Operator 1 has higher values of lever position when compared with Operator X (Figure 4.31). This is connected to the indicated airspeed for those particular moments, which is according to Figure 4.26. During both takeoff and landing, the medians show approximate values.

From Figure 4.32 to Figure 4.38 it is possible to verify and compare the median for each Operator. Tasks were highlighted in the first figure for better understanding.

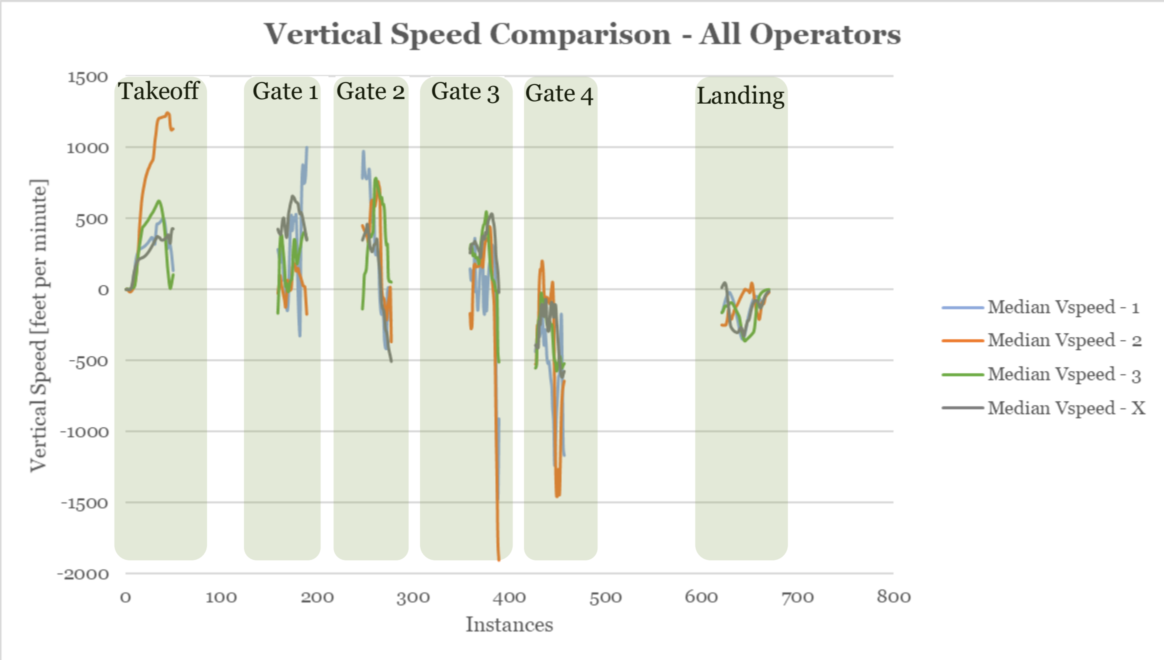


Figure 4.32 - Comparison of vertical speed median values for all Operators per task

It is observed that the Operator 1 and 2 perform differently from Operator X (Figure 4.32). Operator 1 performs the interception of gate 1 and 2 reaching high values of vertical speed. During the takeoff, the Operator 2 reaches accentuated positive values of vertical speed, and during the interception of gate 3 and 4, the Operator 2 has a great amplitude of values, reaching accentuated negative values. During the landing, the Operator 2 has an opposite median when compared with Operator X.

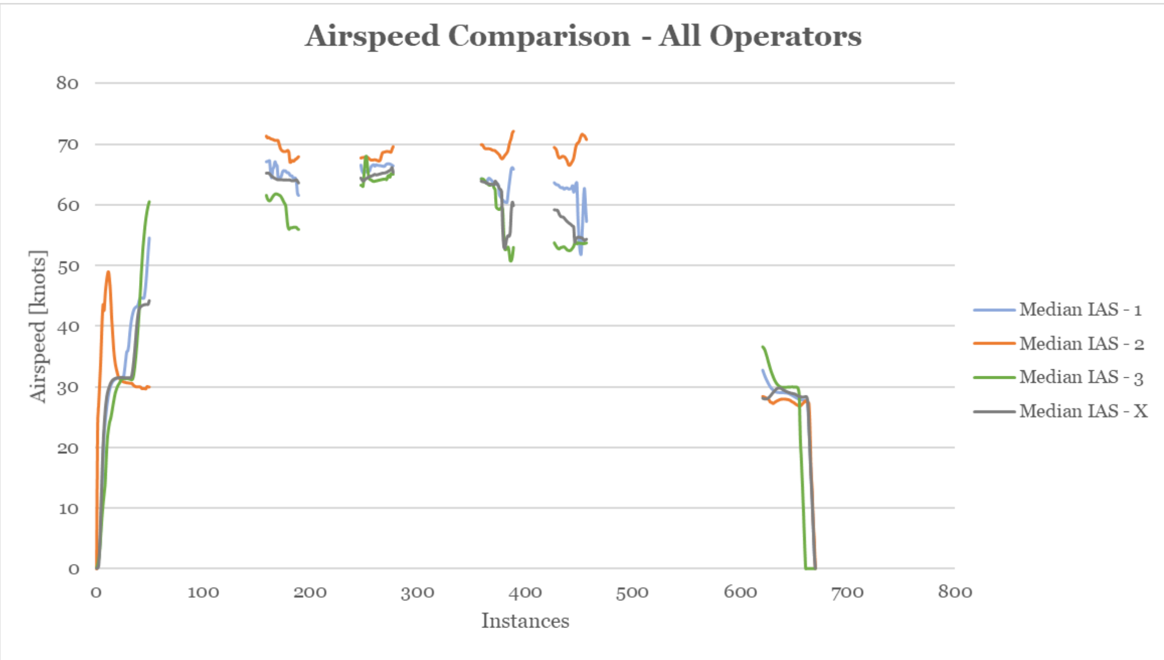


Figure 4.33 - Comparison of airspeed median values for all Operators per task

For the airspeed (Figure 4.33), it is possible to observe that in most tasks, Operators perform in similarity to Operator X. However, it is noticed that Operator 2, has airspeed variations during takeoff and during cruise, flies at a higher airspeed than the recommended airspeed for cruise flight.

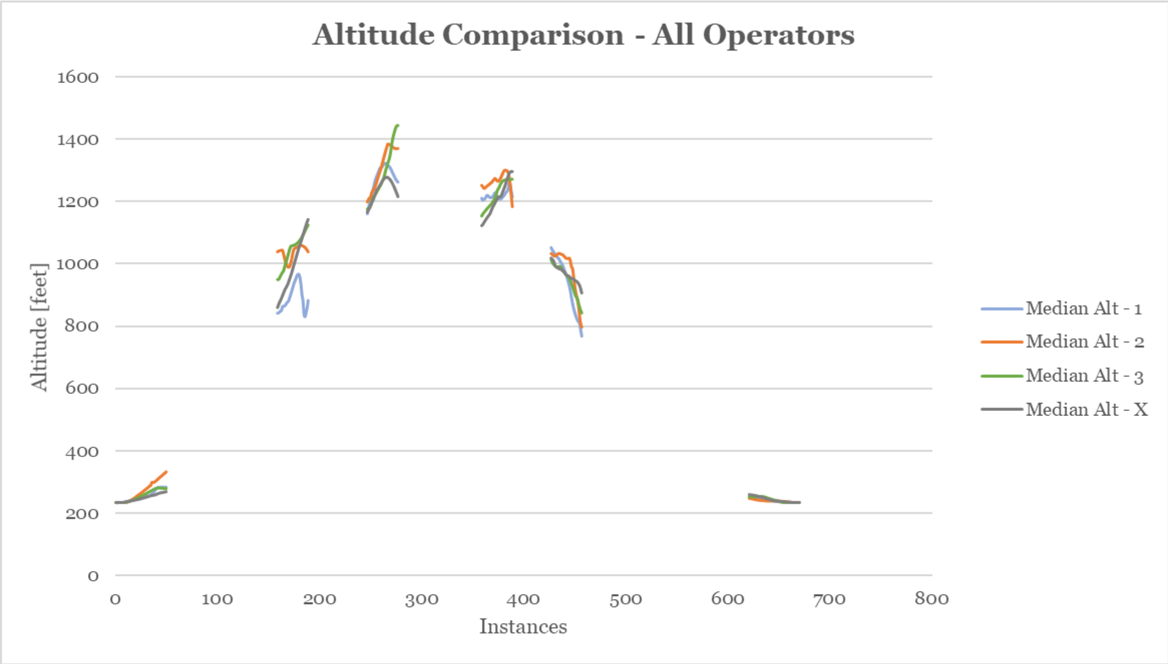


Figure 4.34 - Comparison of altitude median values for all Operators per task

Regarding altitude (Figure 4.34), it is possible to observe that Operators perform in similarity to Operator X.

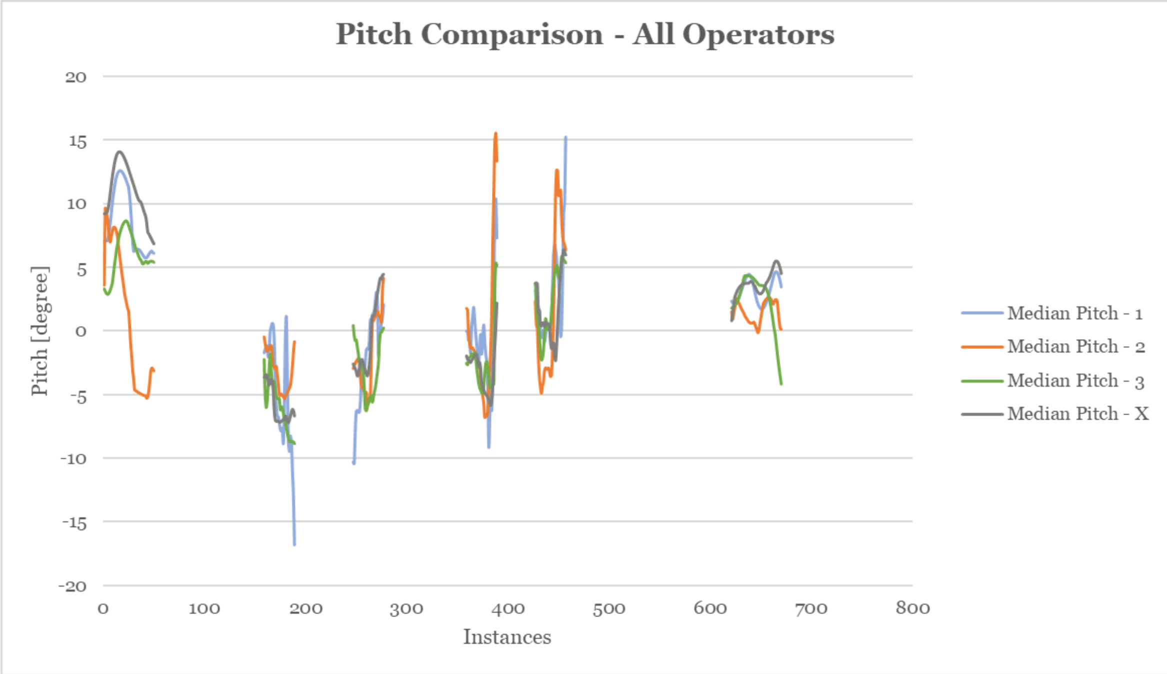


Figure 4.35 - Comparison of pitch angle median values for all Operators per task

In Figure 4.35, during Takeoff, Operator 2 has an opposite tendency compared to Operator X, reaching negative values of pitch. In similarity, Operator 3 also performs the landing phase with an opposite tendency. During cruise, Operators perform similar regarding the Operator X median.

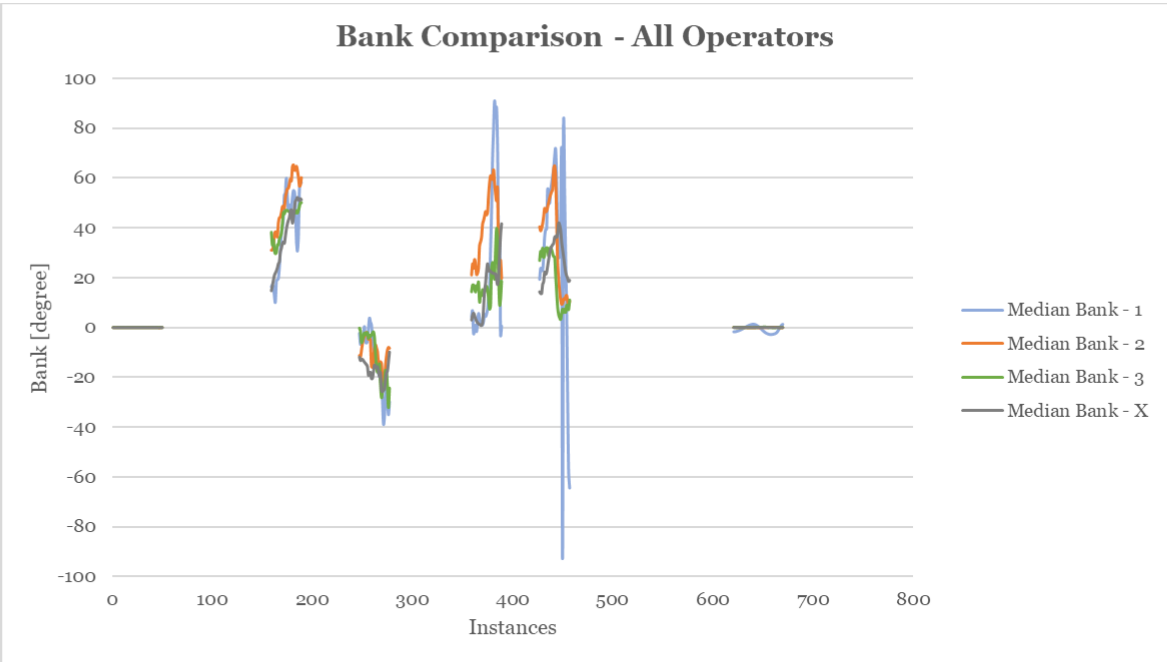


Figure 4.36 - Comparison of bank angle median values for all Operators per task

In Figure 4.36, Operator 1 performs the interception of gate 3 or gate 4 with a higher amplitude of values. Operator 2 also performs with such tendency on gate 1, 3 and 4, although reaching lower values in comparison. The remaining tasks are performed in great similarity of Operator X.

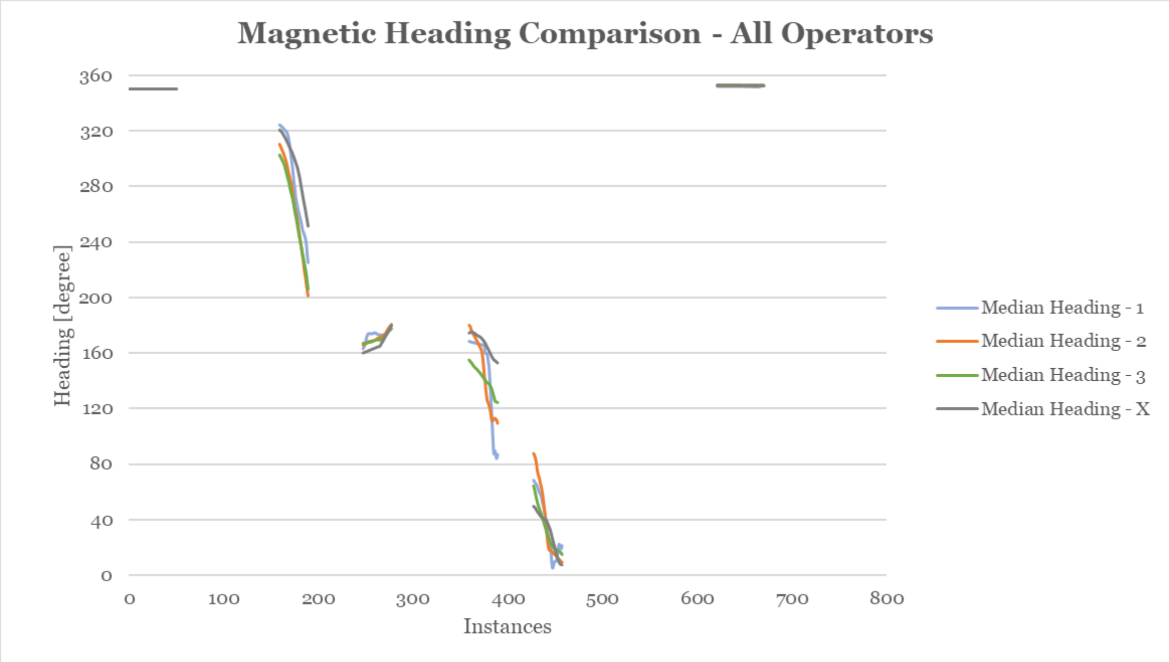


Figure 4.37 - Comparison of magnetic heading median values for all Operators per task

In Figure 4.37, that on the interception of gate 3, Operators accomplish the missions with broader variations of heading in comparison with Operator X. However, in all other tasks, they are in line with the Operator X median values.

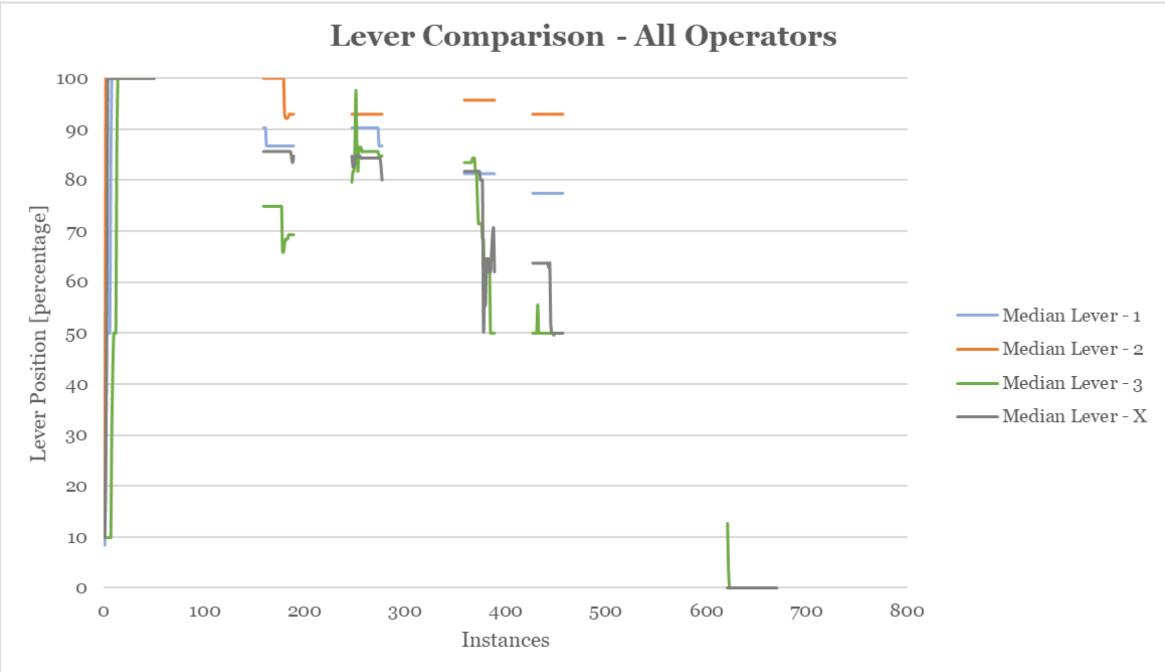


Figure 4.38 - Comparison of lever position median values for all Operators per task

On Figure 4.38, Operators share the same lever positions values during takeoff and landing, however, Operator 3 conducts lever changes during the landing. During gate interception, it is possible to observe that Operator 2 values are higher, which can be connected to the airspeed flown during cruise, as seen in Figure 4.33. Operator 3 has the closest values to Operator X, although, on the interception of gate 2, Operator 1 performs closer to Operator X median.

4.3.7 Results

From the data analysed on the Flight Comparison sub-category, a table translating the success of the mission and flight stabilization were defined, Table 4.11 and Table 4.12 respectively.

Table 4.11 - Mission Success per Operator and per Attempt

	Operator 1	**Operator 2**	**Operator 3**	**Operator X**
Mission Attempt 1	Failed	Successful	Successful	Successful
Mission Attempt 2	Failed	Successful	Successful	Successful
Mission Attempt 3	Successful	Successful	Successful	Successful

Table 4.12 - Flight Stabilization per Operator and per Attempt

	Operator 1	**Operator 2**	**Operator 3**	**Operator X**
Mission Attempt 1	Unstable	Stable	Stable	Stable
Mission Attempt 2	Unstable	Stable	Stable	Stable
Mission Attempt 3	Stable	Stable	Stable	Stable

By analysing the tables, together with the examination of the routes in every attempt, it was concluded that most Operators successfully performed the missions attempts according to the SOPs. Operator 1 was the one that experienced the most difficulties, with two unstable flights that lead to a crash. However, on the last mission attempt, Operator 1 successfully performs the mission, having a similar duration of the mission attempts of Operator X. Operator 2 tended to fly above the recommended cruise speed, although reducing the airspeed for approach in an earlier stage than the remaining Operators. The shorter duration of mission attempts of Operator 2 is thus justified by the higher airspeed during cruise flight.

Regarding the task comparison analysis of the data collected, by having in consideration the data shown on the several figures, together with the calculated medians and standard deviations, a maximum value of deviation was highlighted on Table 4.13.

Table 4.13 - Standard Deviation Maximum per Variable and per Operator in relation to Operator X

	Operator 1	**Operator 2**	**Operator 3**
Vertical Speed	795,133	950,451	373,559
Indicated Airspeed	5,1675	13,4755	14,177
Altitude	141,938	89,5965	114,28
Pitch	5,133	7,9545	4,342
Bank	62,04375	20,823	18,5745
Magnetic Heading	34,7355	25,1645	22,76
Lever Position	24,9985	36,371	45,0545

Here, it is possible to note that Operator 3 had the lower value of standard deviation in relation to the Operator X in most parameters, achieving the closest median values. Both Operator 2 and Operator 1 achieve extreme values when compared with both Operator 3 and Operator X.

4.4 Conclusions

Throughout this chapter, techniques for a training programme were explored, including verification and validation methods for the programme applicable to the synthetic environment designed on Chapter 3 - Case Study I: Development of the Synthetic Environment for URBLOG.

This verification and validation were supported by a Human In the Loop (HITL) study, conducted by three operators with different backgrounds. Operators followed an operating manual of the vehicle and were asked to conduct and repeat a mission developed in the flight simulator software were the URBLOG was implemented. This mission was composed by a flight, intercepting several gates composing a route. Flight parameters, route and duration were recorded for post-analysis.

Due to COVID19 contingencies, one of the operators was not able to perform the missions on the synthetic environment designed, therefore using alternative devices within the requirements defined.

Operators were asked to answer questionnaires regarding their background and specific questions regarding the mission completion.

Once the missions were performed, data was analysed, including recorded parameters per flight and task, originating 91 graphics. That data was compared with that of Operator X, representing the most optimum-relative values for a satisfactory comparison.

Having that in consideration, it is concluded that:

- The URBLOG Operating Manual was effective, providing enough information for the correct interpretation of the vehicle's characteristics and control, the synthetic device environment, including the hardware, instruments, and head tracking device, if applicable;
- As the devices used by Operator were not the same, the mission was performed with different hardware equipment sensibilities, providing small differences in the recorded parameters. That is visible on the Lever Position parameter analysed;
- The level of comfort appointed by the operators during the mission execution indicates that the synthetic environment designed was adequate for the vehicle;
- Only Operator 2 did not use the head tracking device for the control of the OTW of the vehicle. However, it did not negatively affect the accomplishment of the missions. Operators that used the device did not find it distracting;
- Operator 1 was the one with the most difficulties in performing the mission. Even so, the mission attempt 3 was performed according to the SOPs and within expected parameter amplitude. Tasks were correctly performed, and the duration of the flight was within the recorded durations of Operator X. It is then possible to assume that subjects with no flying experience, either real, virtual or from aero models, can, in a short period, adjust to the devices used and perform the mission's tasks, according to the operating manual of the vehicle. This can be enhanced with dedicated training for unexperienced subjects;
- Although Operator 2 real flight experience was shown on the approach technique, reducing the speed on an earlier stage, Operator 3, without any real flight experience but increased virtual experience, achieved better mission results. It is then seen in the sample of this study that subjects with more virtual experience can react better on such synthetic environment than real-life pilots;
- In terms of demographics, both male operators successfully performed all mission attempts, while the only inexperienced female subjects did not. As Operator X is also female, it is not possible to correlate the gender in terms of aptitude. The oldest subject was Operator 1, only successfully performing one mission attempt. The second oldest subject successfully performed all mission attempts. Again, it is not possible to correlate age with aptitude as only one element of each age range performed the study;
- As for recommendations and suggestions, all operators suggested improvements on the approach and landing phase, referring that the flap position should be visible on the instruments and inhibition of flap positions during certain flight phases should happen, especially during the landing phase.

The training programme developed within this case study provided successful results, therefore, verifying and validating both programme and the synthetic environment designed.

As the current instruments chosen for the virtual cockpit do not show the flaps position, a further study of the possible addition of new instruments in this virtual cockpit or different hardware interfaces integrating this function need to be considered. Changes to the aircraft configuration file need to be realised so flap position inhibition can occur. As these changes would be time-consuming and require a new HITL study to validate and verify their use, they are not included in this work.

Chapter 5 - Conclusions

5.1 Dissertation Synthesis

As technology evolves, new and better solutions appear in aviation. With a new interest in airships and their flight characteristics, they can be integrated in remote pilot aircraft systems (RPAS). For that reason, this work focused on these topics, interconnecting them with synthetic environments as flight training devices, remote pilot stations, training of remote operators and applicable human factors. After conducting a review of current aspects of those topics, two case studies were approached.

The first case study consisted of the development of a synthetic environment for an unmanned airship prototype, integrated in a mobility solution. This airship, the UBRLOG, had a small number of information available. To simulate its main characteristics and purpose, a model of the URBLOG was firstly designed on CAD software, which was followed by the analysis of several flight simulator software options, with their advantages and disadvantages taken in consideration. An option was chosen and the URBLOG was then implemented on Prepar3D® software, with certain limitations.

To allow the simulation of the operation of the vehicle, a virtual cockpit was studied, where several instruments were applied, together with the necessary hardware interfaces for its synthetic environment. This was developed considering the operator's point of view and the human factors considerations applicable to cockpit design and remote pilot stations (RPS). Two main types of instruments were chosen, and a HUD was adapted for better interpretation on an OTW view. The adapted HUD and the head-tracking device to control the OTW view were chosen to enhance the sensing of the operator. Both instruments and interfaces were defined to support one of the main principles of flying a RPA, which is Aviate. A layout was designed, taking into account its use as a flight training device (FTD) and as part of the remote control station (RPS) of the vehicle. It consists of a personal laptop computer with Prepar3D® installed, together with a HOTAS flight control system, a head tracking device, and an additional screen. It was then implemented as synthetic environment for further application.

On a second case study, a basic training programme was produced to train the unmanned vehicle operator of that station or device. It was elaborated to allow the appropriate operation of the synthetic environment and to enable the verification and validation of both programme and environment. A human in the loop (HITL) study was conducted with subjects from different backgrounds, which consisted of the completion of a virtual mission according to the operating manual of the vehicle elaborated. This manual included the characteristics and limitations of the URBLOG, the standard operational procedures (SOPs) for its correct operation as well as for instructions for the head tracking device configuration and virtual mission. This mission was developed on the flight simulator software where the URBLOG was implemented and it was repeated three times. It was composed by a flight, intercepting several gates composing a route. Due to Worldwide contingencies, only three test subjects were able to perform the study, one being performed with alternative hardware interfaces. Operators were asked to answer questionnaires regarding their background and specific questions regarding the mission completion. Flight parameters, route performed, and duration were recorded for post-analysis.

The post-analysis comprises the comparison of the recorded data with an optimum-relative reference from one external experienced operator. Standard deviations and medians of and between operators were calculated, originating 91 graphics for enhanced analysis. Conclusions were achieved regarding both training programme, the synthetic environment and possible background influence when choosing an operator for this system.

The training programme developed provided successful results, therefore, verifying and validating both programme and the synthetic environment designed. The URBLOG operating manual was effective, presenting enough information for the correct interpretation of the vehicle's characteristics and control on that synthetic environment. The level of comfort appointed by the operators during the execution of the mission also indicated that the synthetic environment designed was adequate for the vehicle. The results of the study suggest that subjects with more virtual experience can react better on such synthetic environment than real-life pilots, but subjects with no flight experience whatsoever can in a short period adapt and perform the tasks according to the SOPs.

As for recommendations and suggestions, all operators suggested improvements on the approach and landing phase, referring that the flap position should be visible on the instruments and inhibition of flap positions during certain flight phases should happen, especially during the landing phase. These enhancements are pertinent and might lead to an improvement in the controllability of the vehicle, but as these changes would be time-consuming as they require further research regarding interfaces and a new HITL study to validate and verify their use, they are not included in this dissertation.

5.2 Concluding Remarks

During this work, the unmanned URBLOG prototype of the Multifunctional Air Transport System was successfully developed on flight simulation training device that can also be used as part of the remote pilot station (RPS) of this Remotely Piloted Aircraft System (RPAS). This simulation on a synthetic environment was verified and validated in terms of the operator's point of view, having in consideration several human factors for these systems, by a training programme that was also validated for further use. The objectives of this dissertation were thus clearly achieved. However, due to the few information of the vehicle itself, a series of assumptions were made to be able to illustrate its concept in simulation. For that reason, certain software and processes were chosen but if more data were available, other paths could have been taken. This would not only impact the virtual and hardware interface of the synthetic environment itself, but also the vehicle operating procedures and limitations that were considered in the training programme. Certain aspects of the vehicle could not be implemented as the propulsion of the rotors installed on wings and the docking of the device, as it is only controllable above ground level (AGL).

The results achieved on the Human In The Loop (HITL) suggest interesting conclusions regarding the background experience required on an operator of this kind of system, although further studies on that matter shall be performed. It is also recognized the use of a sample of data of a single operator (Operator X) for the comparison of data is limited and might induce misleading results. Enhancements suggested by the test subjects are pertinent and might lead to an improvement in the controllability of the vehicle.

5.3 Prospects for Future Work

As mentioned at the beginning of this work, synthetic environments like flight training devices can be easily adequate for different types of virtual, physical, or procedural changes, when compared with real implementation on the vehicle or system. Being so, future developments of this work can be focused on the following items:

- Implement the proposed suggestions of the HITL study conducted;
- Improve the URBLOG's model in order to simulate propulsion from the rotors in all phases of flight, allowing stationary flight for enhanced vertical takeoff and landing. Include both rudder and trim control to the model;
- Develop a landing gear system or landing struts within this design prototype to allow the docking of the vehicle;

- Implement this synthetic environment on a desktop computer, with further graphic possibilities to include additional screens for OTW view, preferably allowing a 180º view. For this, it is recommended that the HUD stays in a fixed position instead of moving with the view of the operator;
- Gather data from proficient RPAS pilots on this synthetic environment and introduce it on the HITL flight data comparisons, including a higher number of test subjects as well;
- Implement the URBLOG in other flight simulator software once more data is available and compare results, using the same RPS and training programme, with adequate operational changes;
- Further study of the impact of the head tracking device and touch screens in this environment;
- Inclusion of other functionalities for automated flight, as the auto-pilot, analysing its effect on the operator monitoring skills; and implement navigation-related requirements;
- Applicate the conceptions achieved on a real-life URBLOG RPAS system.

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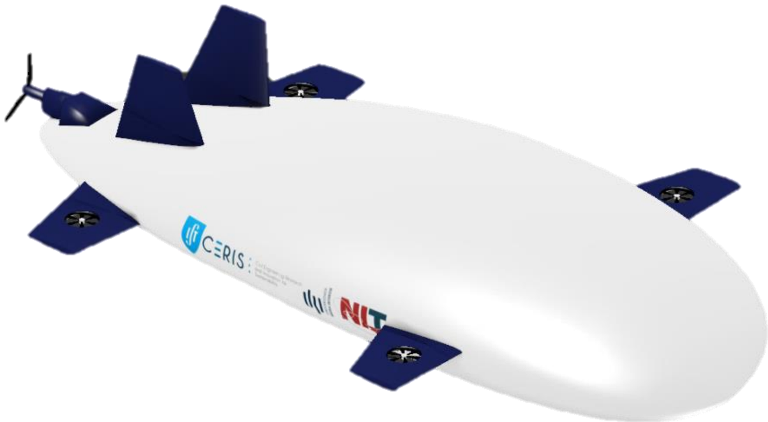
Appendix A - URBLOG OPERATING MANUAL Version 1.0



URBLOG

OPERATING MANUAL

Version 1.0

For the model implemented in the MSc dissertation:

Development of a Flight Simulation Training Device and Remote Pilot Station: The URBLOG Unmanned Hybrid Airship Vehicle Case

Universidade da Beira Interior

Integrated MSc in Aeronautical Engineering

Laura Sofia Nobre Martins

Under Supervision of: Jorge Miguel dos Reis Silva

April 2020

Contents

1. Introduction

The purpose of the operating manual is to support documentation for the Operator of the URBLOG. It provides all necessary operating procedures and limitations, including supporting procedures as basic piloting skills and setup related requirements.

The URBLOG is an unmanned aerial vehicle (UAV), characterized by being an airship designed to have its cruise flight achieved by the deflection of 4 main surfaces (wings) and vertical stabilizers, propelled by an engine of large diameter on the rear of the aircraft. Its static control is achieved by using 4 rotors located on the wings, plus the deflection of the rear engine. This concept combines the traditional airfoil and rotorcraft technology applied in its control surfaces, becoming a hybrid system that can perform hovering and vertical takeoff and landing (VTOL) operations.

This vehicle was adapted for flight simulation software to demonstrate its functionalities, and enable the study of an Operator training programme, in which this operating manual is included. The flight simulation software where this vehicle is simulated is the Lockheed Martin Prepar3D® (P3D) V4.

The structure of this manual was based on the Airbus Flight Crew Techniques Manual (FCTM), the Airbus Flight Crew Operation Manual (FCOM) and the guide for a simulated RQ-4A Global Hawk, "Guía de Simulador de RQ-4A Global Hawk – Flight Simulator Version 1.0" developed within a dissertation.

References of these documents are provided in the MSc dissertation related to this URBLOG simulation and are [58], [64] and [65].

In this manual, it is also included the Head Tracking Configuration on Appendix A.1 and instructions for the particular mission developed for URBLOG studies in Appendix A.2.

2. Aircraft Specifications

The current version of URBLOG implemented on P3D has the specifications defined in Table A.1.

Table A.1 - URBLOG Specifications

Main Dimensions	
Length	8.5 meters
Wingspan	5.4 meters
Height	2.4 meters

Weight	
Empty Weight	68 kg
Maximum Weight	122.5 kg

Fuel	
Fuel Capacity	75 l

Performance	
Vne (never exceed speed)	73 KIAS
Vno (max. cruising speed)	70 KIAS
Vfe (max. flap speed)	65 KIAS
Vsi (clean stall speed)	20 KIAS
Vso (stall speed with flaps)	10 KIAS
Maximum Operating Altitude	5000 feet

3. Installation

To install this URBLOG version in P3D software:

1. *Extract NIT_UrbLog_UAV to a folder;*
2. *Copy the whole folder to the Airplanes folder, in the SimObjects P3D directory. The standard location of this folder is Program Files\Lockheed Martin\Prepar3D v4\SimObjects\Airplanes.*

To access this aircraft in P3D:

1. *Click on "Vehicles" in the menu bar;*
2. *Type "Urblog" into the search bar;*
3. *Select the aircraft and click "OK".*

To uninstall this URBLOG version, simply erase the "*NIT_UrbLog_UAV*", placed on the Airplanes folder.

4. Systems Guide

4.1. Airframe

The URBLOG is a hybrid airship, equipped with a set of controlled surfaces: two pair of wings with variable angle, equipped with propulsive rotors. The front pair of wings act as aileron and the aft wings, as elevator. The tail is composed of two vertical stabilizers, both with rudder deflecting surfaces.

It has a controllable buoyancy system that can provide aerodynamic force for VTOL operations.

All surfaces contain trim tab actuators, nevertheless, controls are not considered in this simulation.

4.2. Avionics

Representing the URBLOG's avionics, there are four panels available on the URBLOG as in Figure A.1:

- Primary Flight Display (PFD)
- Multi-Function Display (MFD)
- Head-Up Display (HUD)
- Secondary PFD & HUD Activation

Figure A.1 - Panels

To access the panels, press the following keys:

PFD	**SHIFT+1**
MFD	**SHIFT+2**
SECONDARY PFD & HUD ACTIVATION	**SHIFT+3**
HUD	**SHIFT+4**

To close the panel, press the same key combination. In order to move the panel, undock the window. This will enable its movement on the screen, the change of its size and the possibility of showing an external monitor if installed. Nevertheless, several panels can be open at the same time.

The avionic system represented in this URBLOG simulation is the Garmin 1000. The main flight information is in two displays, instead of traditional gauges. The main flying information is shown on a Primary Flight Display (PFD). The airspeed and altitude indicators, including the vertical speed indicator, with the rate of climb or descent, are represented on tape; a large attitude indicator shows the attitude of the aircraft regarding its pitch and roll, and the horizontal situation indicator (HSI) the heading. Other information, as engine data, location and weather are shown on the Multi-Function Display (MFD). Each display has a set of knobs, buttons and softkeys, identically positioned on both PFD and MFD, as seen in Figure A.2. It also includes autopilot functionalities, the radio set and navigation configurations.

Figure A.2 - URBLOG's PFD and MFD

The G1000 has many functionalities which can be explored in detail by reading the Garmin G1000 Integrated Flight Deck Pilot's Guide - Cessna Nav III. Nevertheless, for the present version of URBLOG, the objective is only to use the PFD to read the presented flight information. For that purpose, extracted information from the G1000 guide[1] is shown below:

[1] Information extracted from pages 48, 52, 53, 55, 57, 60 and 71 from the Garmin G1000 Integrated Flight Deck Pilot's Guide - Cessna Nav III

1. NAV Frequency Box
2. Airspeed Indicator
3. True Airspeed
4. Current Heading
5. Turn Rate Indicator
6. Heading Bug
7. Outside Air Temperature (OAT)
8. Softkeys
9. System Time
10. Transponder Data Box
11. Horizontal Situation Indicator (HSI)
12. Barometric Altimeter Setting
13. Vertical Speed Indicator (VSI)
14. Reference Altitude Bug
15. Altimeter
16. Reference Altitude
17. COM Frequency Box
18. Navigation Status Box
19. Slip/Skid Indicator
20. Attitude Indicator

ATTITUDE INDICATOR

Attitude information is displayed over a virtual blue sky and brown ground with a white horizon line. The Attitude Indicator displays the pitch, roll, and slip/skid information.

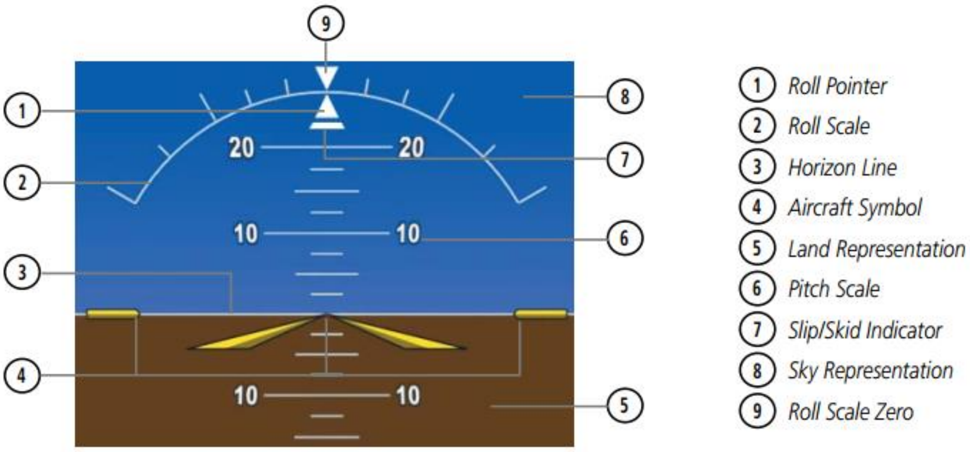


Figure 2-6 Attitude Indicator

The horizon line is part of the pitch scale. Above and below the horizon line, major pitch marks and numeric labels are shown for every 10°, up to 80°. Minor pitch marks are shown for intervening 5° increments, up to 25° below and 45° above the horizon line. Between 20° below to 20° above the horizon line, minor pitch marks occur every 2.5°. If the Synthetic Vision System (optional) is activated, the pitch scale is reduced to 10° up and 7.5° down; refer to the Additional Features section.

The inverted white triangle indicates zero on the roll scale. Major tick marks at 30° and 60° and minor tick marks at 10°, 20°, and 45° are shown to the left and right of the zero. Angle of bank is indicated by the position of the pointer on the roll scale.

The Slip/Skid Indicator is the bar beneath the roll pointer. One bar displacement is equal to one ball displacement on a traditional inclinometer. The indicator bar moves with the roll pointer and moves laterally away from the pointer to indicate uncoordinated flight. Slip (inside the turn) or skid (outside the turn) is indicated by the location of the bar relative to the pointer.

Figure 2-7 Slip/Skid Indication

ALTIMETER

The Altimeter displays 600 feet of barometric altitude values at a time on a moving tape rolling number gauge. Numeric labels and major tick marks are shown at intervals of 100 feet. Minor tick marks are at intervals of 20 feet. The indicated altitude is displayed inside the black pointer.

The barometric pressure setting is displayed below the Altimeter in inches of mercury (in Hg) or hectopascals (hPa) when metric units are selected. Adjusting the altimeter barometric pressure setting creates discontinuities in VNV vertical navigation, moving the descent path. For large adjustments, it may take several minutes for the aircraft to re-establish on the descent patch. If the change is made while nearing a waypoint with a VNV Target Altitude, the aircraft may not re-establish on the descent path in time to meet the vertical constraint.

Selecting the altimeter barometric pressure setting:

Turn the **BARO** Knob to select the desired setting.

VERTICAL SPEED INDICATOR (VSI)

The Vertical Speed Indicator (VSI) displays the aircraft vertical speed on a fixed scale with labels at 1000 and 2000 fpm and minor tick marks every 500 fpm (Figure 2-11). Digits appear in the pointer when the climb or descent rate is greater than 100 fpm. If the rate of ascent/descent exceeds 2000 fpm, the pointer appears at the edge of the tape and the rate appears inside the pointer.

HORIZONTAL SITUATION INDICATOR (HSI)

The Horizontal Situation Indicator (HSI) displays a rotating compass card in a heading-up orientation. Letters indicate the cardinal points with numeric labels every 30°. Major tick marks are at 10° intervals and minor tick marks are at 5° intervals. A digital reading of the current heading appears on top of the HSI, and the current track is represented on the HSI by a magenta diamond. The HSI also presents turn rate, course deviation, bearing, and navigation source information. The HSI is available in two formats, a 360° compass rose and a 140° arc.

TURN RATE INDICATOR

The Turn Rate Indicator is located directly above the rotating compass card. Tick marks to the left and right of the lubber line denote half-standard and standard turn rates. A magenta Turn Rate Trend Vector shows the current turn rate. The end of the trend vector gives the heading predicted in 6 seconds, based on the present turn rate. A standard-rate turn is shown on the indicator by the trend vector stopping at the standard turn rate tick mark, corresponding to a predicted heading of 18° from the current heading. At rates greater than 4 deg/sec, an arrowhead appears at the end of the magenta trend vector and the prediction is no longer valid.

Figure 2-17 Turn Rate Indicator and Trend Vector

WIND DATA

Wind direction and speed in knots can be displayed relative to the aircraft in a window to the upper left of the HSI. When the window is selected for display, but wind information is invalid or unavailable, the window displays NO WIND DATA. Wind data can be displayed in three different ways.

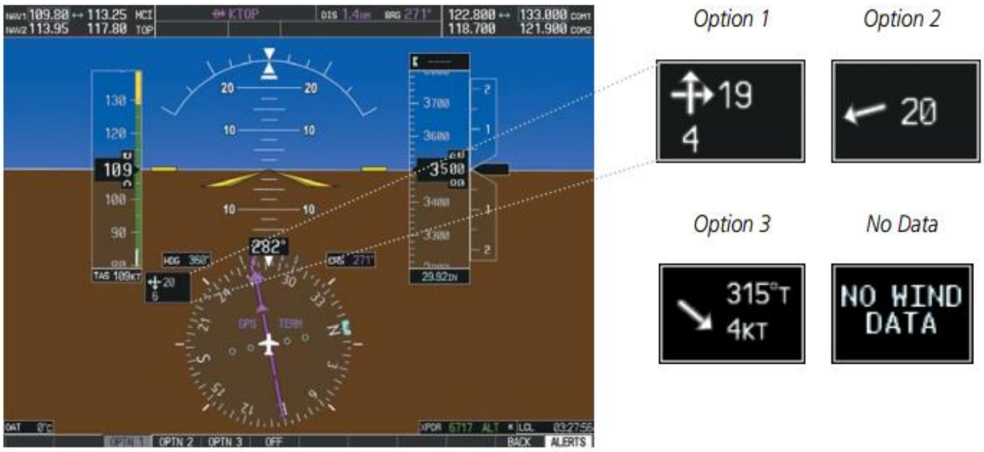


Figure 2-30 Wind Data

Displaying wind data:

1) Press the **PFD** Softkey.
2) Press the **WIND** Softkey to display wind data below the selected heading.
3) Press one of the **OPTN** softkeys to change how wind data is displayed:
   - **OPTN 1**: Wind direction arrows with headwind/tailwind and crosswind components
   - **OPTN 2**: Wind direction arrow and numeric speed
   - **OPTN 3**: Wind direction arrow with numeric True direction and numeric speed
4) To remove the window, press the **OFF** Softkey.

Complementing the PFD, a heads-up display (HUD) was integrated into this simulation, providing key information to the pilot, as seen in Figure A.3.

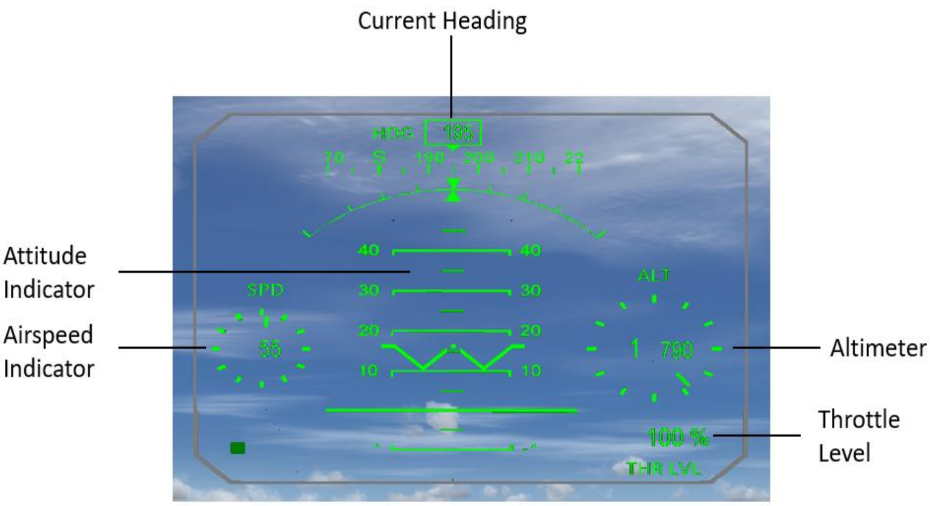


Figure A.3 - URBLOG's HUD

The vector bars for airspeed and altitude turn clockwise when airspeed or altitude is increasing, and counter-clockwise when decreasing. The speed of rotation suggests the magnitude of change.

When wind is present and it exceeds 5 knots, the wind information will appear near the upper right corner.

To activate or deactivate the HUD, it is necessary to click on the HUD button present on the secondary PFD & HUD activation, according to Figure A.4. Once the HUD button is active, the HUD will be available in the HUD panel.

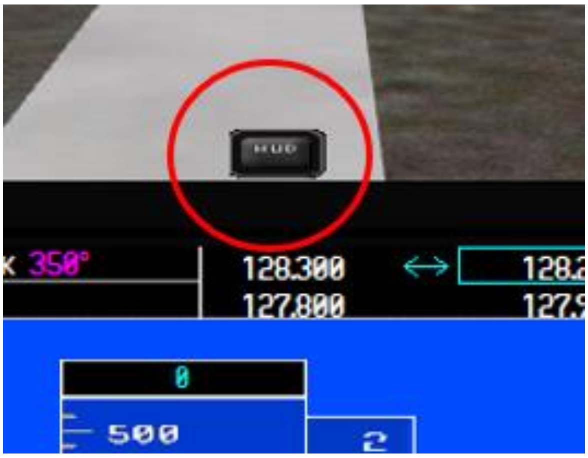


Figure A.4 - HUD Activation Button

4.3. Engine

The engine controls of URBLOG consists of a single throttle control and it will adjust the engine RPM. The full forward position sets the engine to fully open, and the full aft position to fully closed. This model initiates with the engine already started.

4.4. Flap System

This version of URBLOG has 9 levels of flaps available. During vertical Takeoff, it is necessary for the phased retraction of flaps. During approach and vertical landing, a phased extension is recommended, but the maximum extension of flaps that shall be applied is until level 6. This is reflected in the normal procedures checklist.

4.5. Controls

The minimum required setup to control this URBLOG simulation consists of a laptop or desktop, connected to a joystick. A hands-on throttle-and-stick (HOTAS) is recommended, to provide better control of both throttle and joystick inputs.

To see both out-the-window (OTW) view and the instruments, an additional display and a head tracking device are also recommended to enhance the viewing control.

The recommended setup and devices are shown below in Figure A.5.

Figure A.5 - Setup

The joystick controls the attitude of the URBLOG. The throttle controls the airspeed. These inputs are represented in Figure A.6.

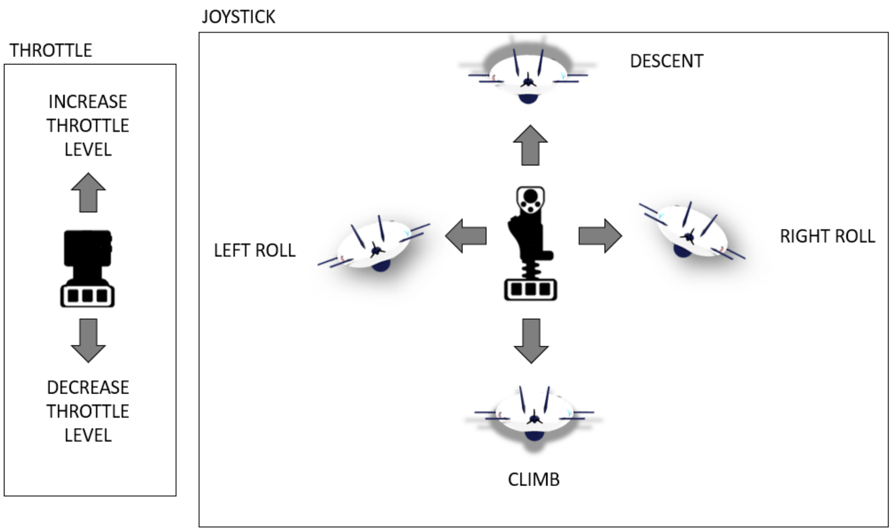


Figure A.6 - Joystick and Throttle Inputs

The URBLOG requires that for a certain attitude to be followed, continuous input shall be given on the joystick. As an example, for the right roll to be performed, it is necessary to maintain a continuous right input on the joystick.

A head tracking device enables that Operator's head is recognized in the different axis by its optical tracking system. These possibilities the change of direction of the out-the-window (OTW) view without any physical input. By tilting the head, the view changes towards that direction. If not used, the OTW view can be changed by pressing the hat switch towards the pretended direction. Both inputs are represented below in Figure A.7.

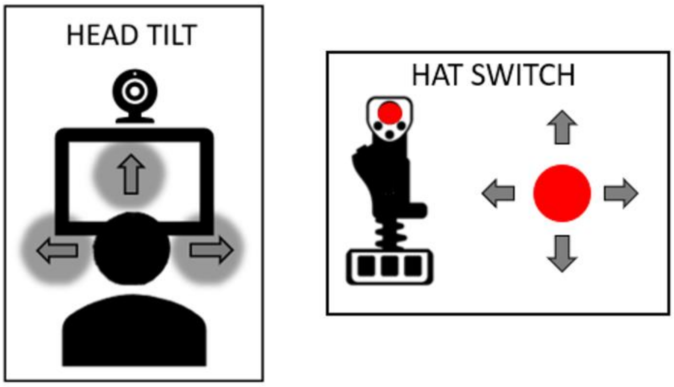


Figure A.7 - OTW View Inputs

Before using the head tracking for the OTW view, it is necessary to configure the FaceTrackNoIR software according to the Operator. How to conduct these configurations can be found in Appendix A.1.

When using the head tracking device, the HUD display follows the OTW view, which can reduce situational awareness if not properly anticipated by the Operator. Nevertheless, the PFD is not affected by any OTW view inputs.

5. Normal Procedures Checklist

The procedures contained in this chapter in Table A.2 are presented as the best way to proceed, from a technical and operational standpoint. However, they are continually updated based on experience and by any revision of the simulated model.

All items of a given procedure are listed in a sequence that follows a standardized scan of the panels and implemented functions of the URBLOG, assuring that all actions are conducted most efficiently.

Buttons can be assigned differently. The standard P3D button configuration is considered in these procedures.

These procedures assume that all systems are operating normally.

The altitudes expressed are above ground level (AGL) and speed in knots-indicated airspeed (KIAS).

Table A.2 - Normal Procedures

BEFORE TAKEOFF	
[ ] Parking Brake	**VERIFY IF SET** (press **CTRL+PERIOD**)
[ ] Flaps	**FULL EXTENSION TO FLAPS 9** (press **F8)**
[ ] PFD	**SET** (press **SHIFT+1**)
[ ] HUD	**ACTIVATE** (press **HUD button**)
[ ] Flight Controls	FREE AND CORRECT

VERTICAL TAKEOFF	
[ ] Parking Brake	**RELEASE** (press **PERIOD** key)
[ ] Throttle	**FULL** (press **F4**)
[ ] Liftoff Speed	30 KIAS
[ ] First Flap Retraction Altitude	ABOVE 20 FEET AGL
[ ] Flaps	**RETRACT TO FLAPS 8** (press **F6**)

[ ] Speed	43 KIAS
[ ] Second Flap Retraction Altitude	ABOVE 40 FEET AGL
[ ] Vertical Speed Trend	NEUTRAL OR POSITIVE
[ ] Flaps	**RETRACT TO FLAPS 7** (press **F6**)
[ ] Speed	61 KIAS
[ ] Vertical Speed Trend	NEUTRAL OR POSITIVE
[ ] Third Flap Retraction Altitude	ABOVE 60 FEET AGL
[ ] Flaps	**RETRACT TO FLAPS 6** (press **F6**)

HORIZONTAL CLIMB	
[ ] Flaps	**FULL RETRACTION TO FLAPS 0** (press **F5**)
[ ] Throttle	**AS DESIRED** (press **F2** to decrease and **F3** to increase)
[ ] Pitch Attitude	**POSITIVE**

CRUISE	
[ ] Recommended Cruise Airspeed	65 KIAS
[ ] Throttle	**AS DESIRED** (press **F2** to decrease and **F3** to increase)

DESCENT	
[ ] Pitch Attitude	**NEGATIVE**
[ ] Throttle	**REDUCE FROM CRUISE** (press **F2**)
[ ] Airspeed	**AS DESIRED**

APPROACH FOR VERTICAL LANDING	
[ ] Throttle	**REDUCE TO MINIMUM** (press **F1**)
[ ] Flaps	**EXTEND TO FLAPS 2** (press **F7 TWICE**)
[ ] Second Flap Retraction Altitude	BELOW 40 FEET AGL
[ ] Flaps	**EXTEND TO FLAPS 4** (press **F7 TWICE**)
[ ] Third Flap Retraction Altitude	BELOW 20 FEET AGL
[ ] Flaps	**EXTEND TO FLAPS 6** (press **F7 TWICE**)

SHORT/VERTICAL LANDING	
[ ] Airspeed	30 KIAS
[ ] Landing Attitude	**LOWER NOSE GENTLY**

[ ] Brakes	**APPLY SHORT BEFORE TOUCHDOWN** (press **PERIOD** key)

TOUCHDOWN	
[ ] Parking Brake	**SET** (press **CTRL+PERIOD**)

6. Limitations

At this point, URBLOG simulation will not permit the docking of the device.

Any simulation must be done above ground level (AGL), with the vehicle powered up.

The electrical propulsion given by the rotors installed on the wings is not simulated in this version. The rear propulsion system is the only source of thrust.

Even in simulation, the URBLOG Operator should fly according to the golden rule of Fly, Navigate and Communicate. It is always essential to maintain situational awareness, by precepting the actual flight conditions, as well as to predict its future status. It evolves the perception of the flight information, together with its systems, weather, air traffic control clearances (when present) and other pertinent elements, while flying the aircraft.

Appendix A.1 - Head Tracking Configuration

To use the head tracking device for head tilt control within the flight, it is necessary to configure its settings on the FaceTrackNoIR software. It is of major importance the definition of the neutral zone, where movements are not desired and the sensibility of each tilt, as an input. It can depend on the distance between the Operator and the camera; the light present on the site; the height of the Operator and its relation to the camera; and the objectives of the flight. This configuration of the tracking curves in Figure A.8 can be performed on the Curves button

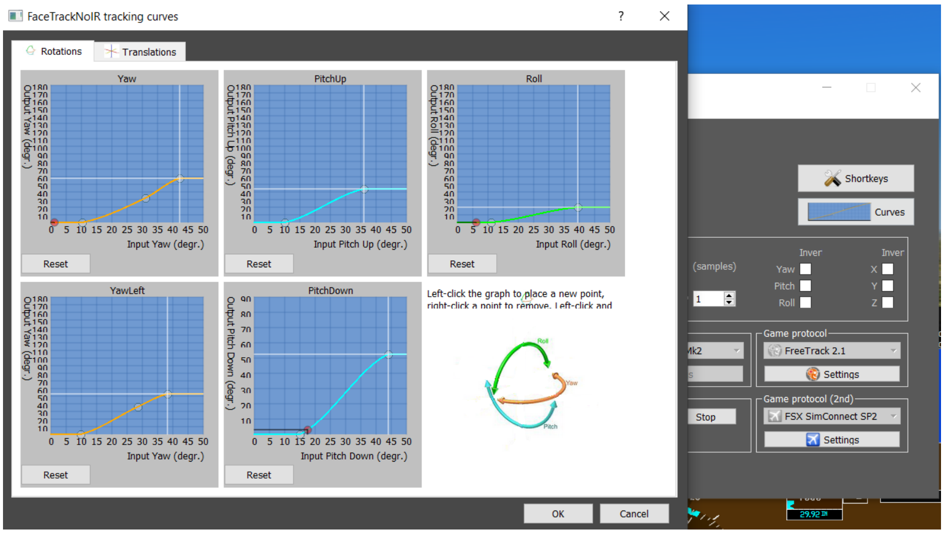


Figure A.8 - Tracking Curves Configuration

After being defined accordingly, the profile shall be saved, and choose the following settings:

- Tracker Source: faceAPI V3.2.6 (on the settings, it is possible to verify the head tracking by selecting show videowidget)
- Filter: Accela Filter Mk2
- Game Protocol: FreeTrack 2.1
- Game Protocol (2nd): FSX SimConnect SP2

Shortkeys can also be defined, for instance, to reset the present view. Changes can be made on the ShortKeys button and saved on the same profile.

Once ready, click on START under the GO! tab. The head tilt function is now active.

To deactivate, click on STOP.

Appendix A.2 - URBLOG Mission

A mission was developed to include several tasks that simulate the objectives of URBLOG during air surveillance. It has an approximate duration of 8 minutes and the Operator is asked to perform it three times.

The mission consists of a short visual flight rules (VFR) flight, where the Operator shall follow a nearby road to the airport, by complying with the gates implemented, like the one on Figure A.9.

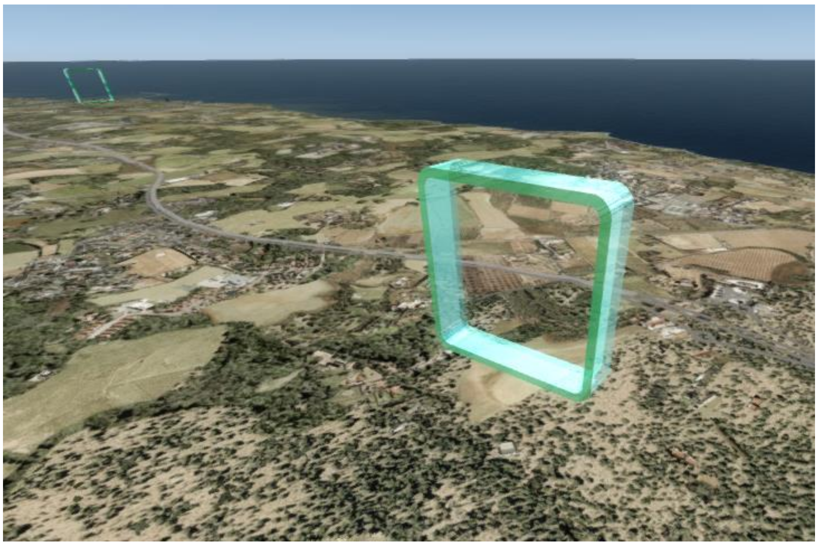


Figure A.9 - Green Square as Mission Gate

These gates will define the flight path required for this mission, and their altitude was defined according to above ground level (AGL). Information regarding the next gate is provided on the left upper corner of the screen, as below in Figure A.10.

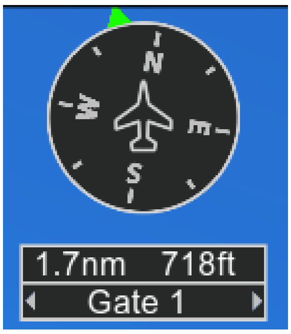


Figure A.10 - Position of the Next Gate

The flight includes a departure and arrival at a civil airport available on the flight simulator software, in this case, Oporto airport (ICAO: LPPR) in Portugal.

Initial flight parameters are equal in all mission attempts. These parameters include weather conditions, geographic location, altitude, heading, power setting and speed. The initial weather conditions are clear skies with no wind. No Air Traffic Control (ATC) instructions are simulated in this mission.

The accomplishment of the mission translates that all the SOPs were followed, a stable flight is conducted, and that the Operator was able to comply with all the tasks within the time defined. The SOPs deviations and unstable situations as crash, stall or failure to land will lead to a negative assessment and the consequent failure of the mission.

On-going textual messages provide instructions to comply with main tasks and the flight path according to Table A.3:

Table A.3 - Mission Outline

URBLOG Mission	
1	Vertical Takeoff from runway 35 LPPR
2	Transition from vertical flight to horizontal flight
3	Climb for 1st gate interception
4	Climb for 2nd gate interception
5	Cruise flight for 3rd gate interception, visually following the road
6	Descend for 4th gate interception
7	Visual approach to runway 35 LPPR
8	Transition from horizontal flight to vertical flight
9	Short landing on runway 35 LPPR

The mission scenario resembles a traffic pattern, although with deviations to simulate the air surveillance over a main road. The route is shown in Figure A.11.

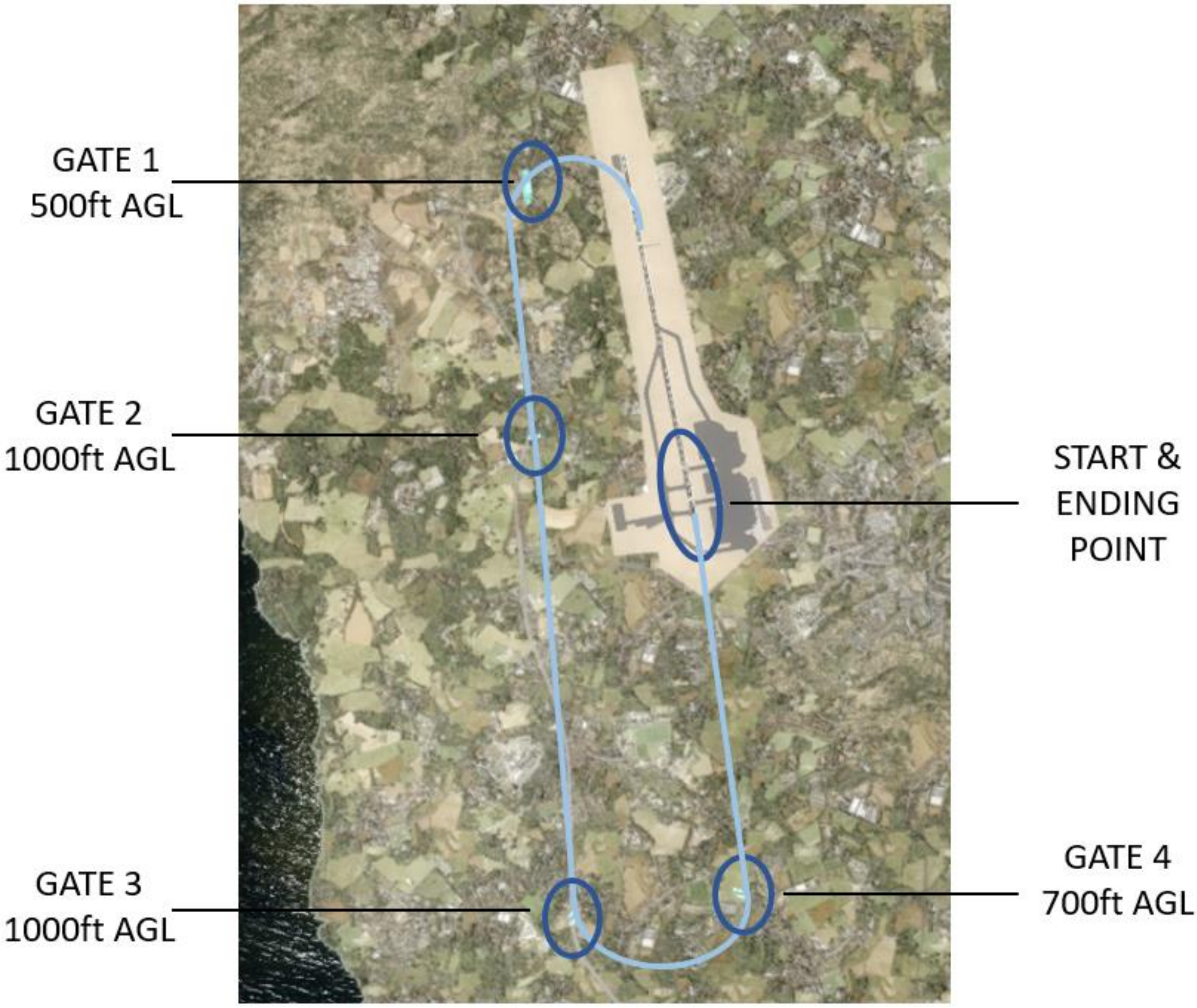


Figure A.11 - Mission Route

Appendix B - Flight Comparison Data

From Figure B.1 to Figure B.21 it is possible to verify the Operator 2, 3 and X data per mission, that originated a calculated median value.

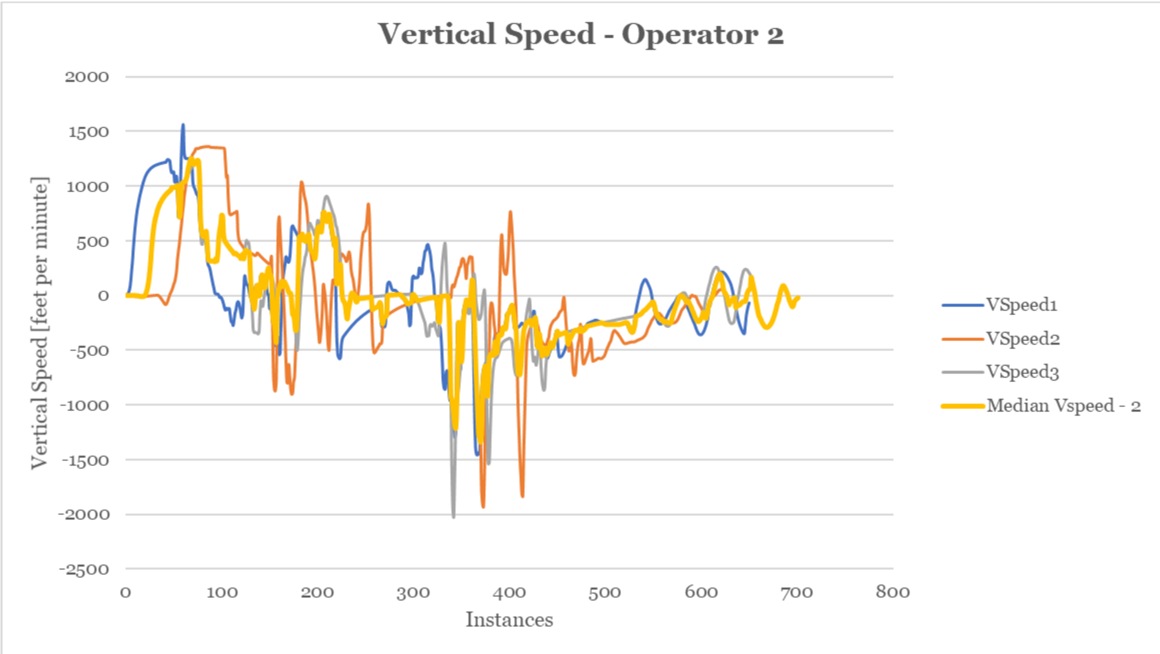


Figure B.1- Operator 2 missions comparison and median values of vertical speed

Operator 2 had a similar amplitude of vertical speed values during each mission (Figure B.1), however, on mission attempt 2, there were peak values between -2000 and 1000 feet per minute.

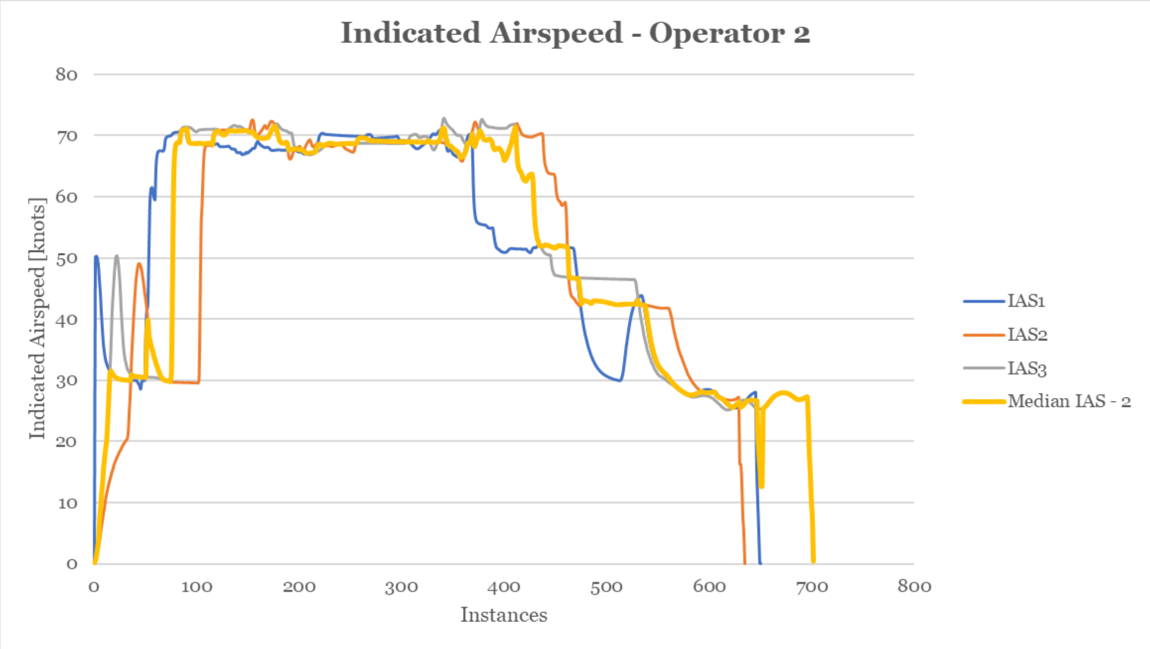


Figure B.2 - Operator 2 missions comparison and median values of indicated airspeed

During the 1st and 2nd mission attempt (Figure B.2), Operator 2 conducts more speed changes in relation to the 3rd mission attempt. Operator 2 mainly flies the cruise above the recommended airspeed (65 KIAS).

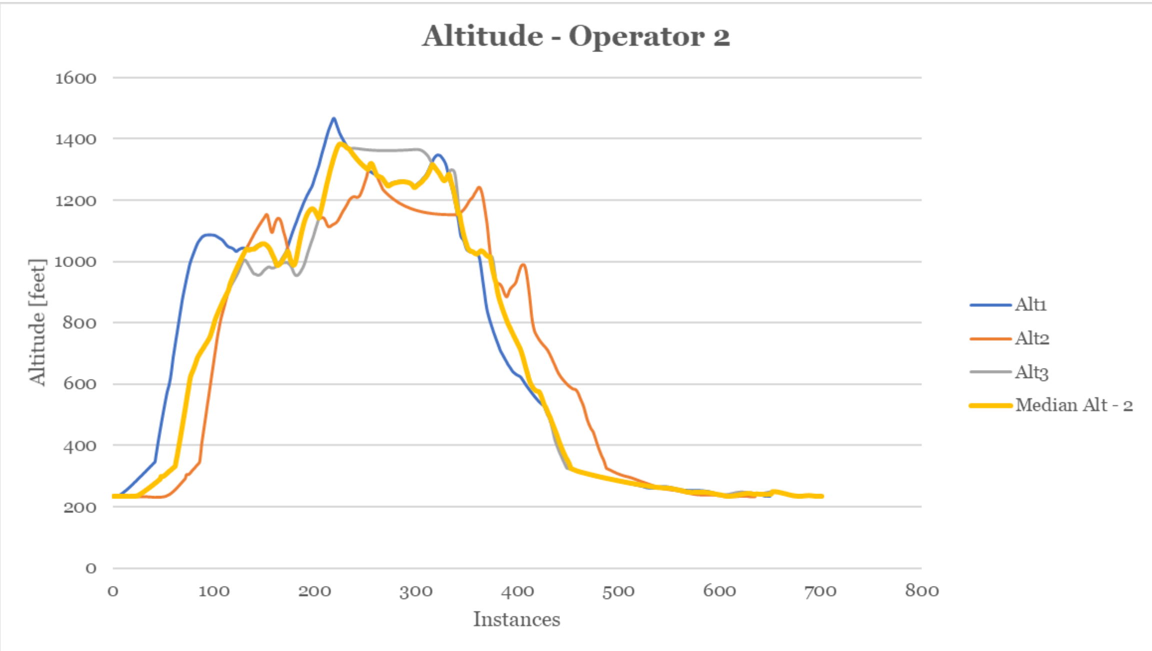


Figure B.3 - Operator 2 missions comparison and median values of altitude

Operator 2 during the 1st and 2nd attempts performs more accentuated climbs followed by immediate descents (Figure B.3), which is according to the Vertical Speed analysis on Figure

B.1. On attempt 3, Operator 2 conducts smoother altitude changes, especially during descent and final approach.

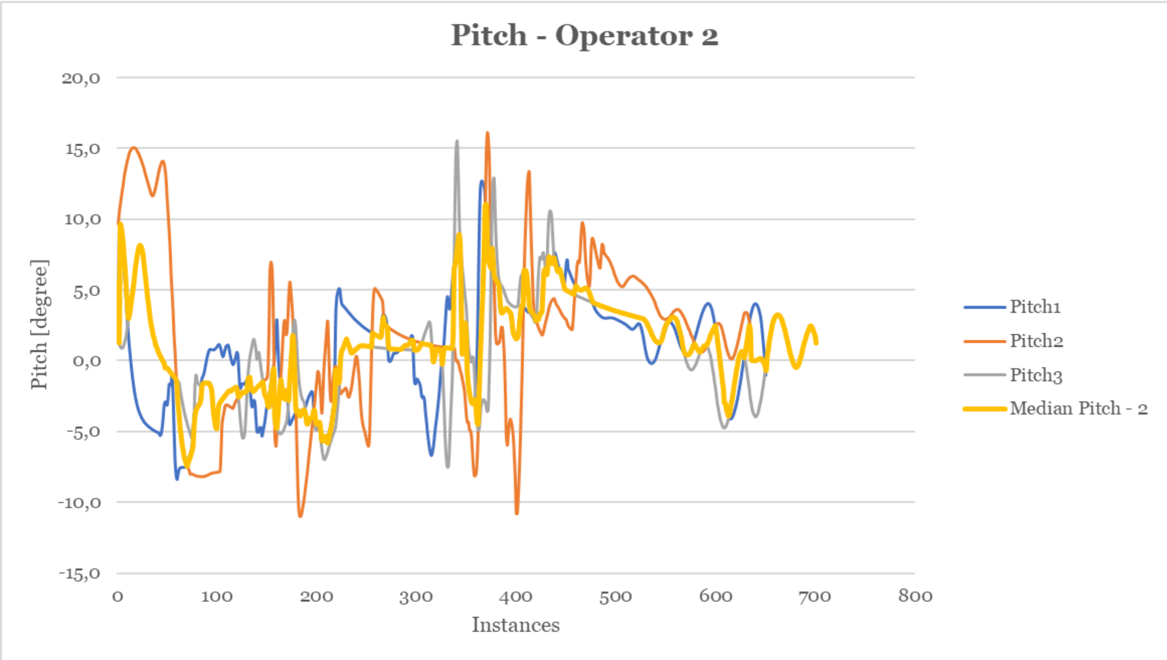


Figure B.4 - Operator 2 missions comparison and median values of pitch angle

Operator 2 during the 2nd and 3rd attempts performs more accentuated pitch inputs (Figure B.4), reflected in the pitch attitude, which is according to the Vertical Speed analysis on Figure B.1 and the Altitude analysis on Figure B.3. On attempt 3, Operator 2 executes smoother pitch changes.

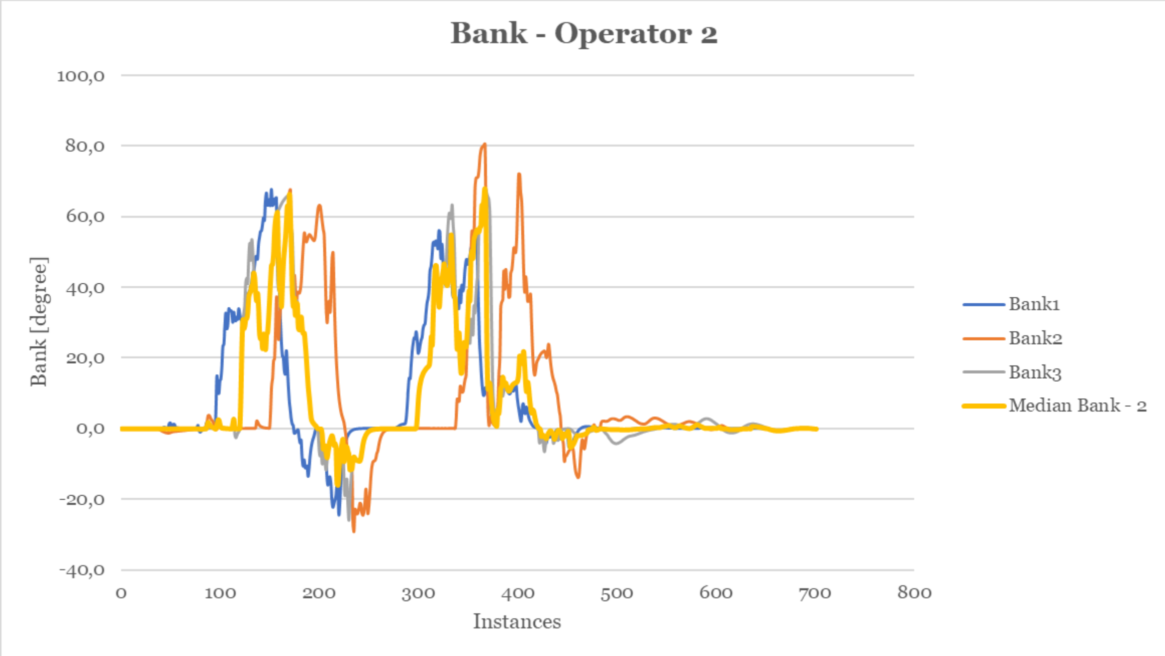


Figure B.5 - Operator 2 missions comparison and median values of bank angle

Operator 2 reached similar banks levels for all attempts (Figure B.5). Most of the banks were performed to the left (positive values), as it represents, in fact, the mission trajectory. Maximum values were reached when turning left on base to initiate final approach.

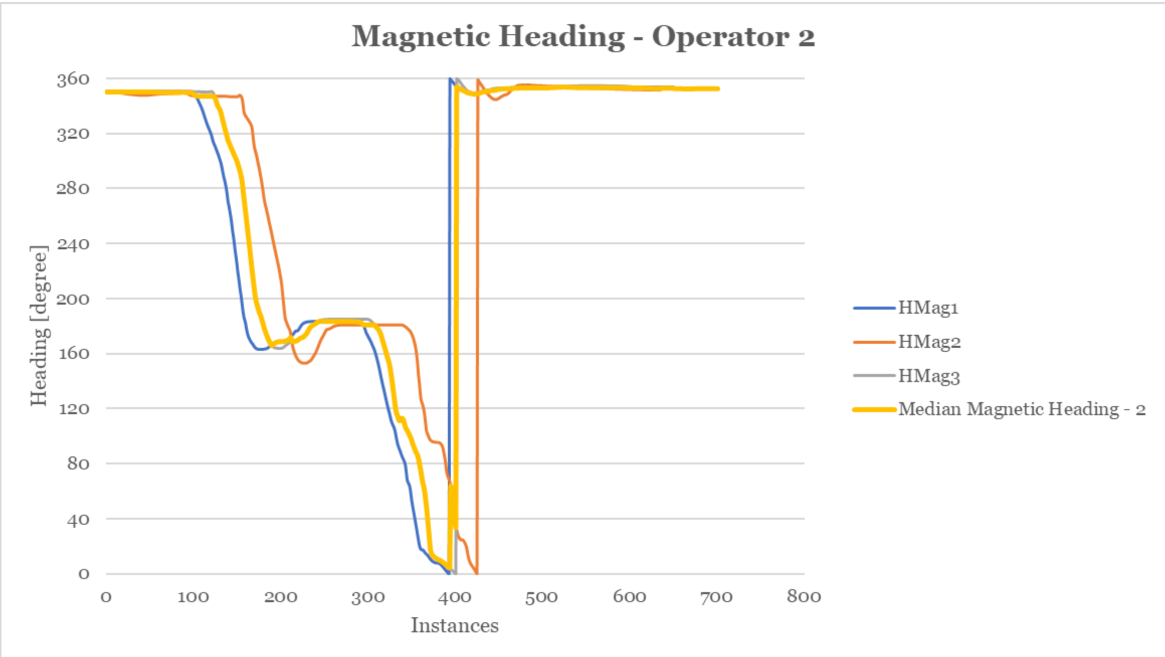


Figure B.6 - Operator 2 missions comparison and median values of magnetic heading

Operator 2 reached similar heading values accordingly to the mission route for all attempts (Figure B.6).

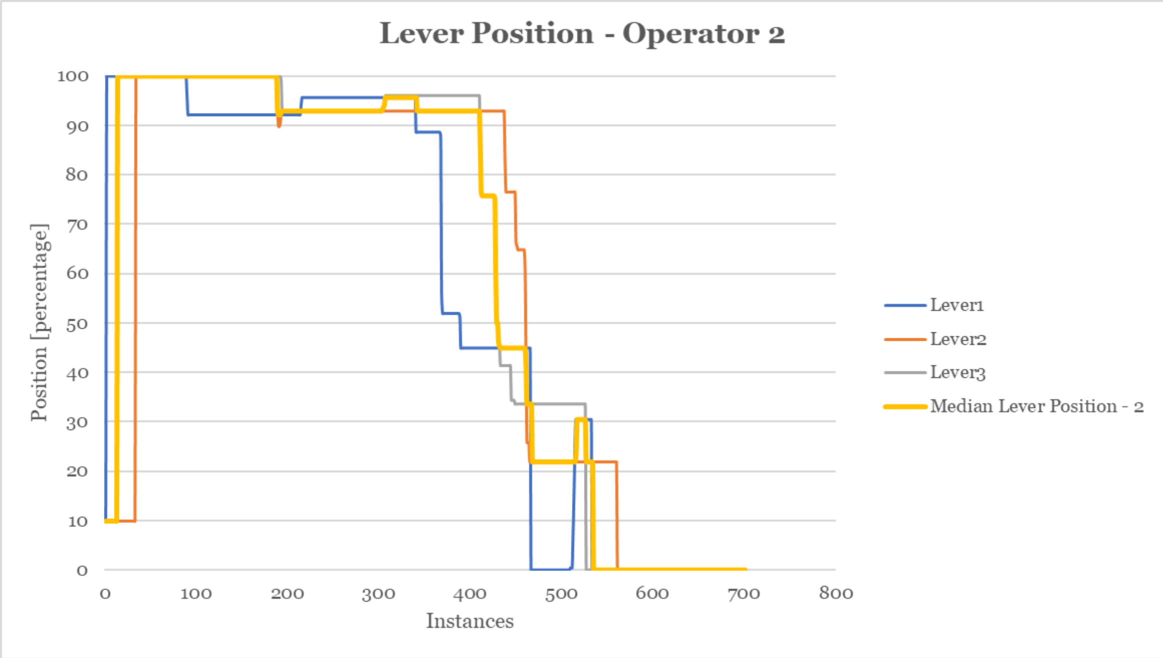


Figure B.7 - Operator 2 missions comparison and median values of lever position

Operator 2 performs a stable and similar lever position adjustments for all attempts (Figure B.7). In every attempt, the lever position for takeoff is correct.

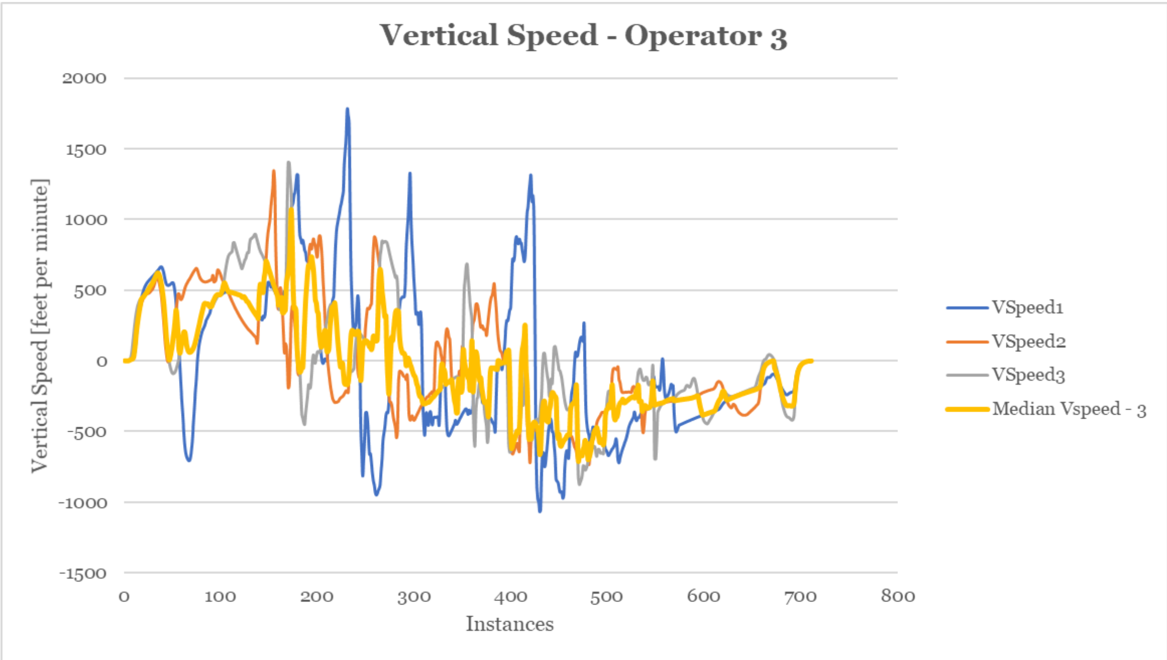


Figure B.8 - Operator 3 missions comparison and median values of vertical speed

Operator 3 had a similar amplitude of vertical speed values during missions 2 and 3 (Figure B.8). However, on attempt 1, peak values between -1000 and 1500 feet per minute were reached, in disparity of missions 2 and 3.

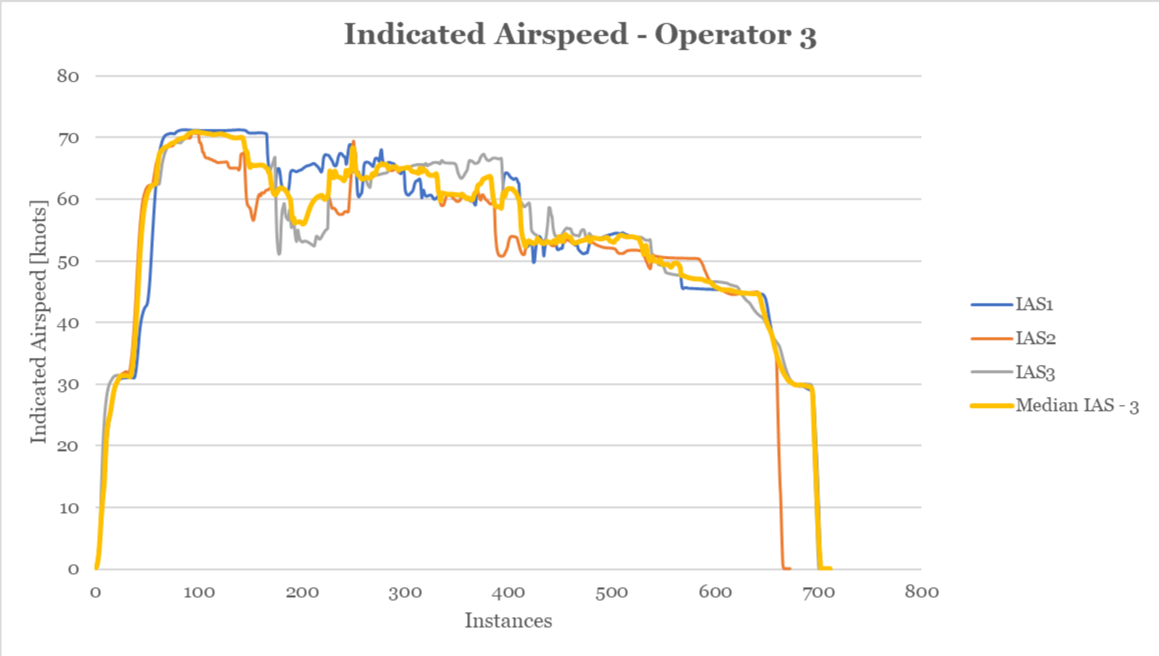


Figure B.9 - Operator 3 missions comparison and median values of indicated airspeed

Operator 3 conducts similar speed changes for all attempts (Figure B.9). The cruise speed was around the recommended airspeed (65 KIAS). On all cases, the Operator decided to keep around 45 knots on final approach and then decreased it from 45 knots until final landing speed.

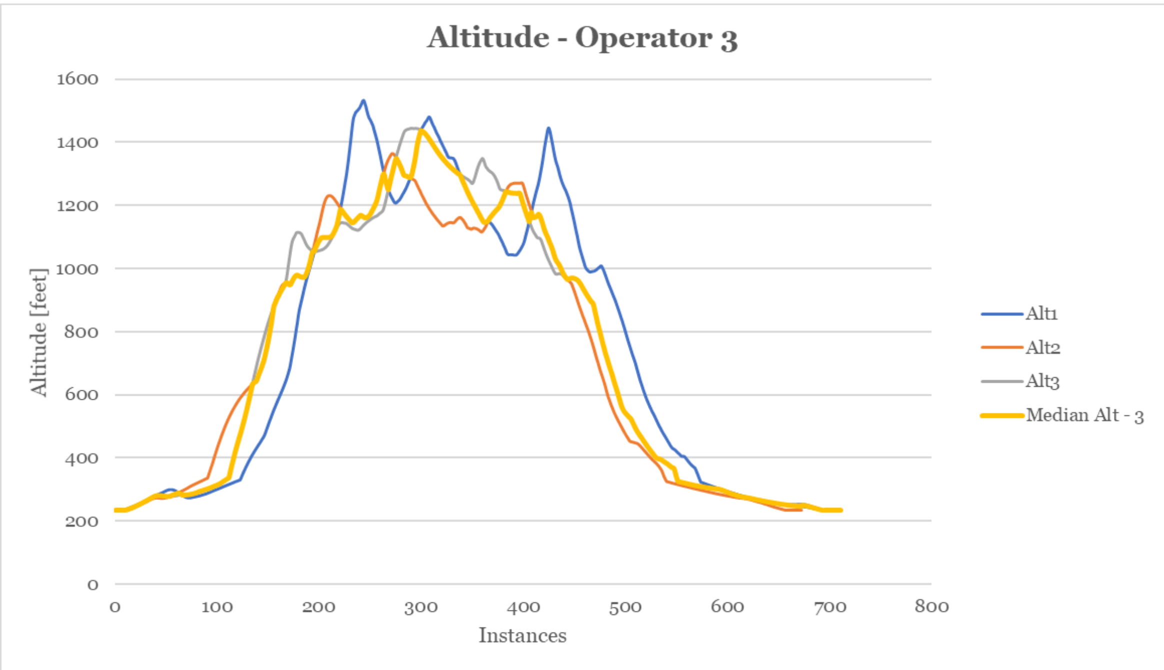


Figure B.10 - Operator 3 missions comparison and median values of altitude

Operator 3 during the 1st and 2nd attempt performed more accentuated climbs followed by immediate descents (Figure B.10), which is according to the Vertical Speed analysis on Figure B.8. On attempt 3, Operator 3 conducts smoother altitude changes, especially during the cruise phase.

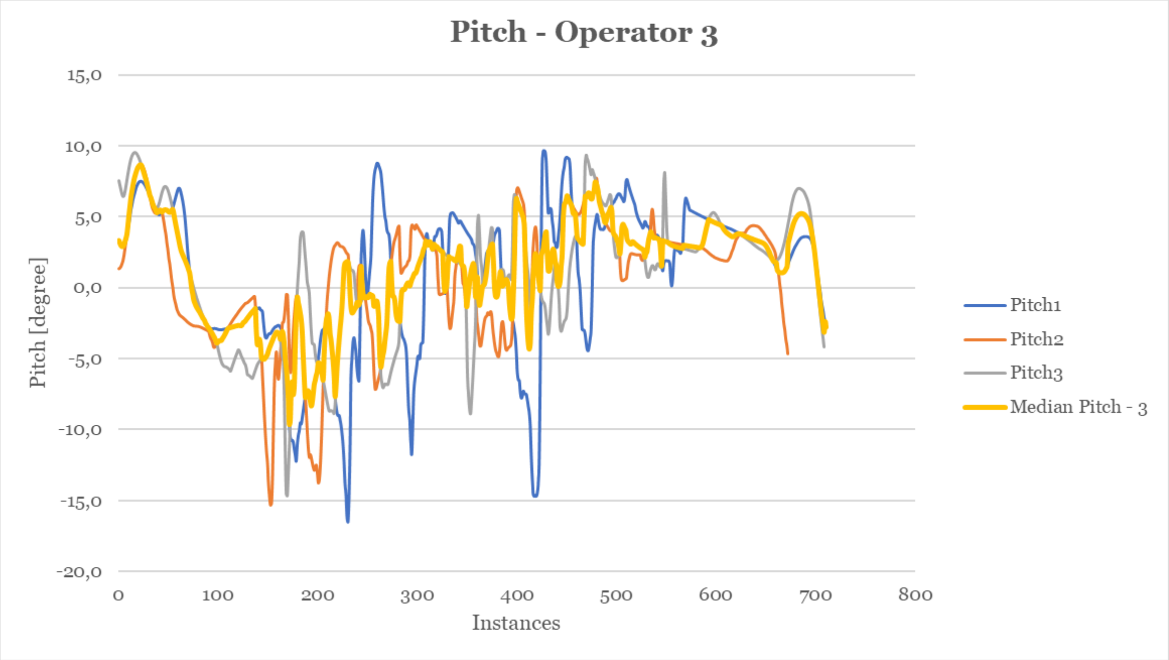


Figure B.11 - Operator 3 missions comparison and median values of pitch angle

Operator 3 during the 1st and 2nd attempts performs more accentuated pitch inputs (Figure B.11), reflected in the pitch attitude, which is according to the Vertical Speed analysis on Figure B.8 and the Altitude analysis on Figure B.10. On attempt 3, Operator 3 performs smoother pitch changes.

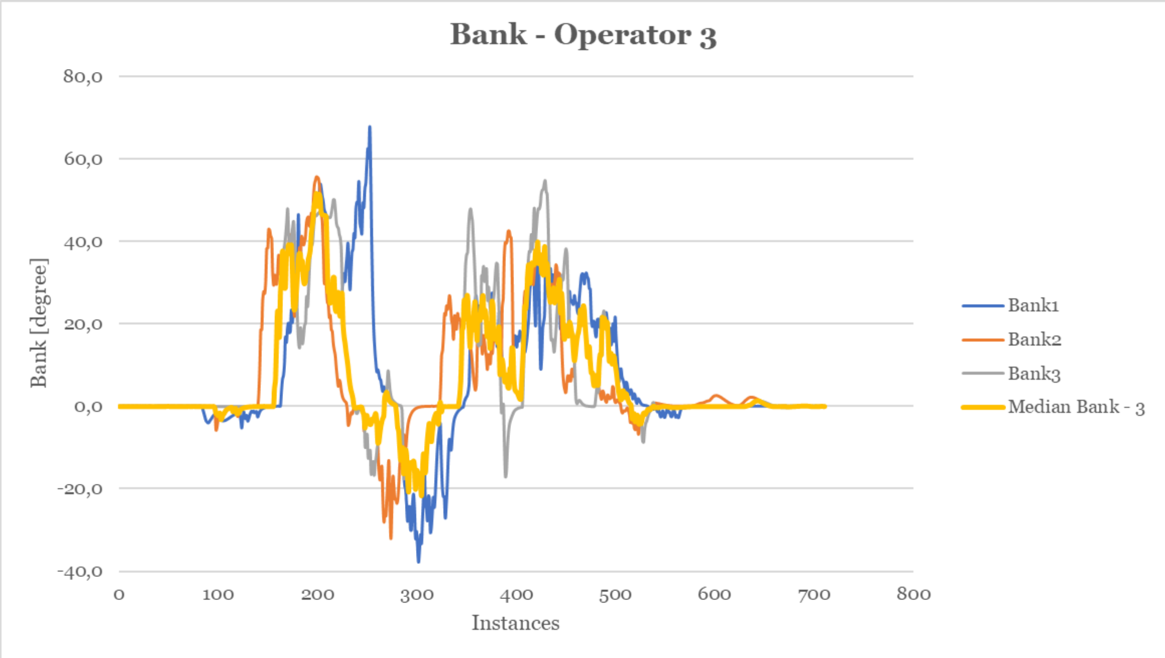


Figure B.12 - Operator 3 missions comparison and median values of bank angle

Operator 3 reached similar banks levels for all attempts (Figure B.12). The maximum value was reached on mission 1.

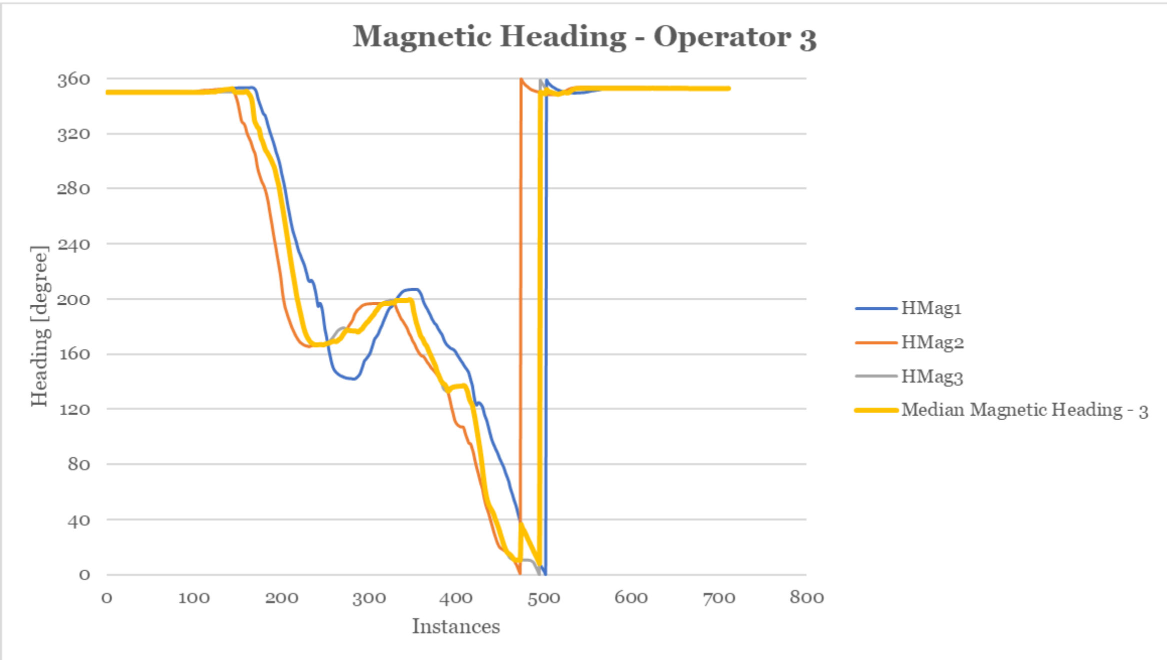


Figure B.13 - Operator 3 missions comparison and median values of magnetic heading

Operator 3 reached similar heading values accordingly to the mission route for all attempts (Figure B.13).

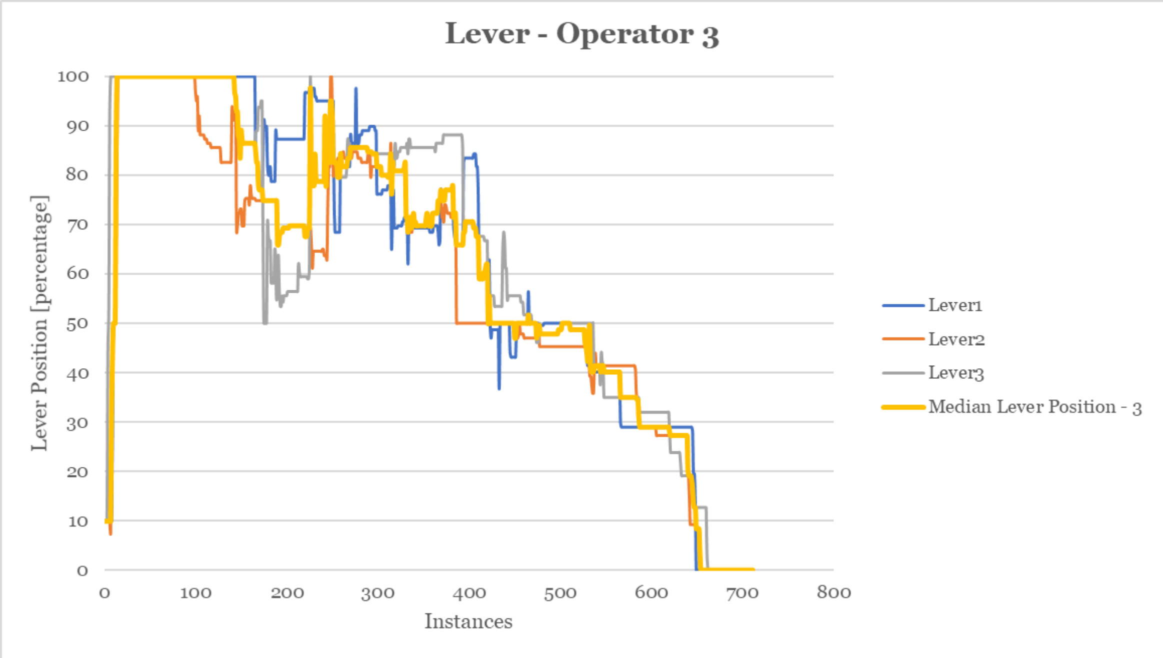


Figure B.14 - Operator 3 missions comparison and median values of lever position

Operator 3 performs several lever position adjustments during cruise flight but mainly precedent to the route turns (Figure B.14). Inputs are in line with the SOPs defined and in every attempt the lever position for takeoff is correct.

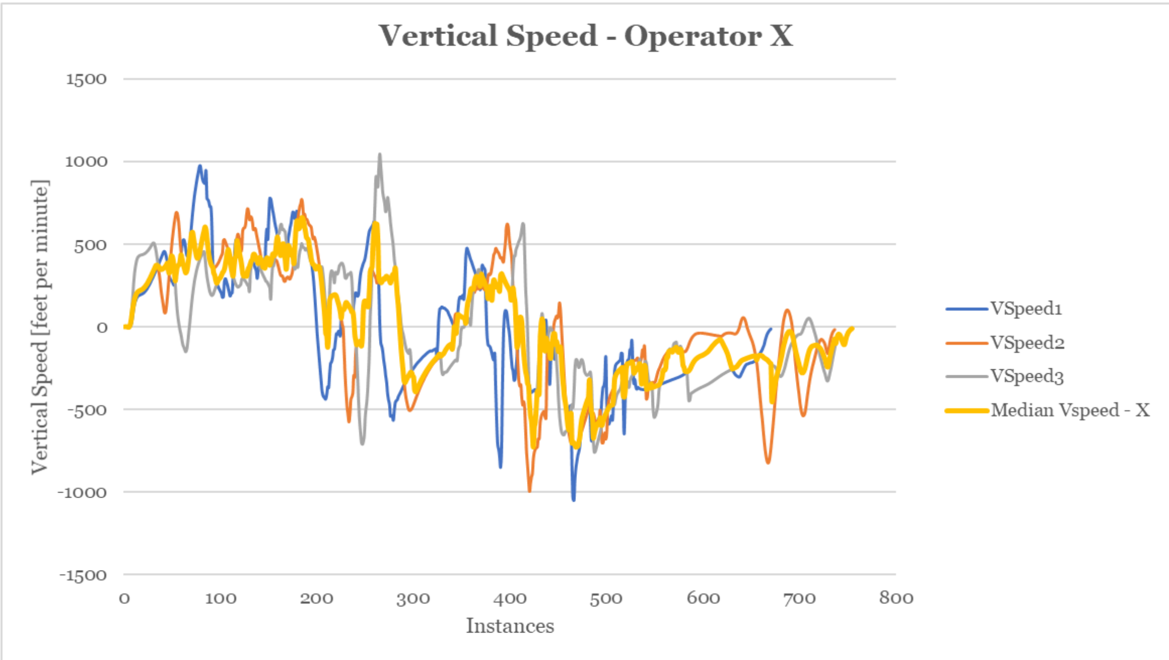


Figure B.15 - Operator X missions comparison and median values of vertical speed

Operator X had a similar amplitude of vertical speed values during all missions (Figure B.15). On attempt 3, there was a peak value around 1000 feet per minute.

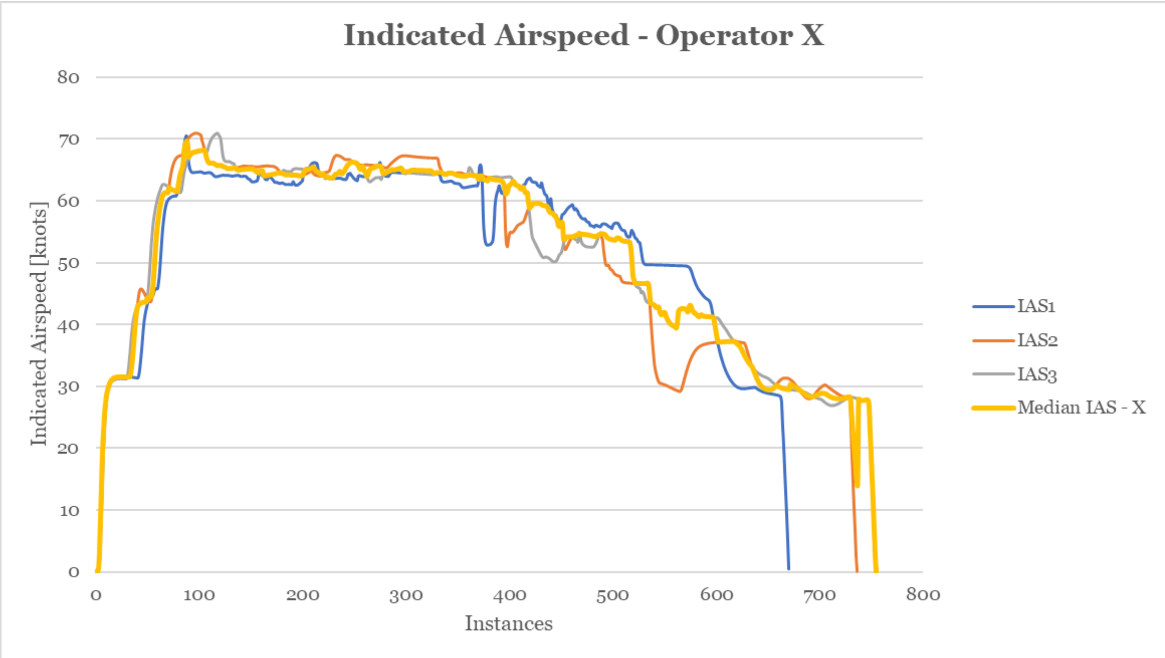


Figure B.16 - Operator X missions comparison and median values of indicated airspeed

Operator X conducts similar speed changes for all attempts (Figure B.16). The cruise speed was around the recommended airspeed (65 knots).

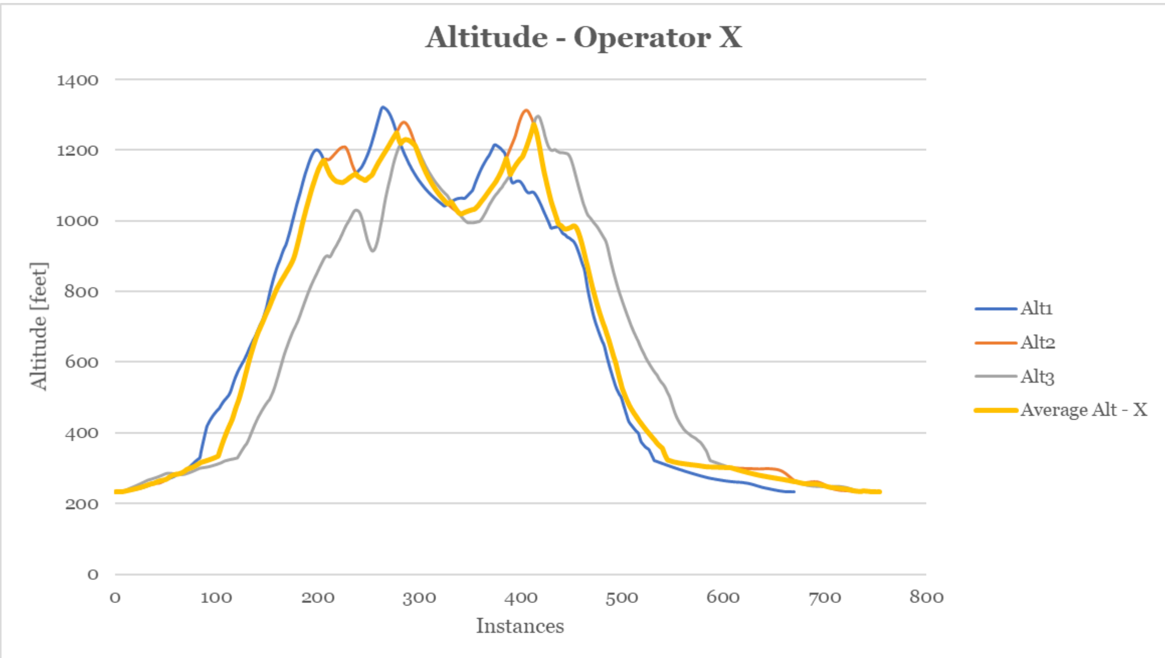


Figure B.17 - Operator X missions comparison and median values of altitude

Operator X conducts similar and smooth altitude changes for all attempts (Figure B.17).

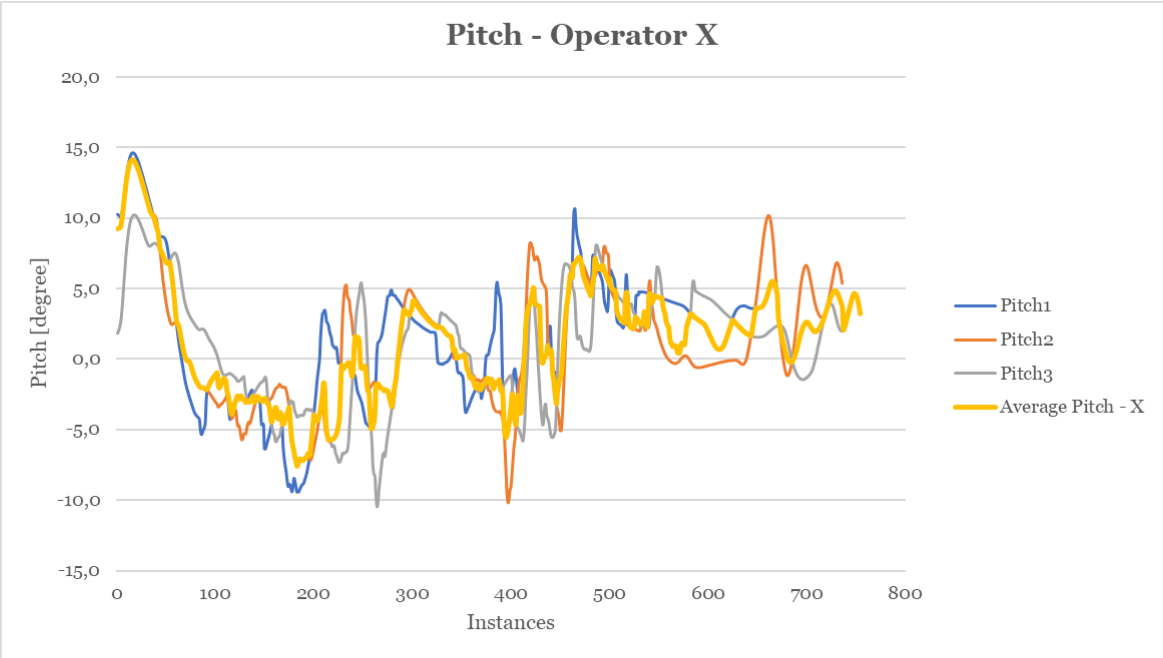


Figure B.18 - Operator X missions comparison and median values of pitch angle

Operator X reaches higher values on the 1st and 2nd attempts when compared with the 3rd attempts (Figure B.18).

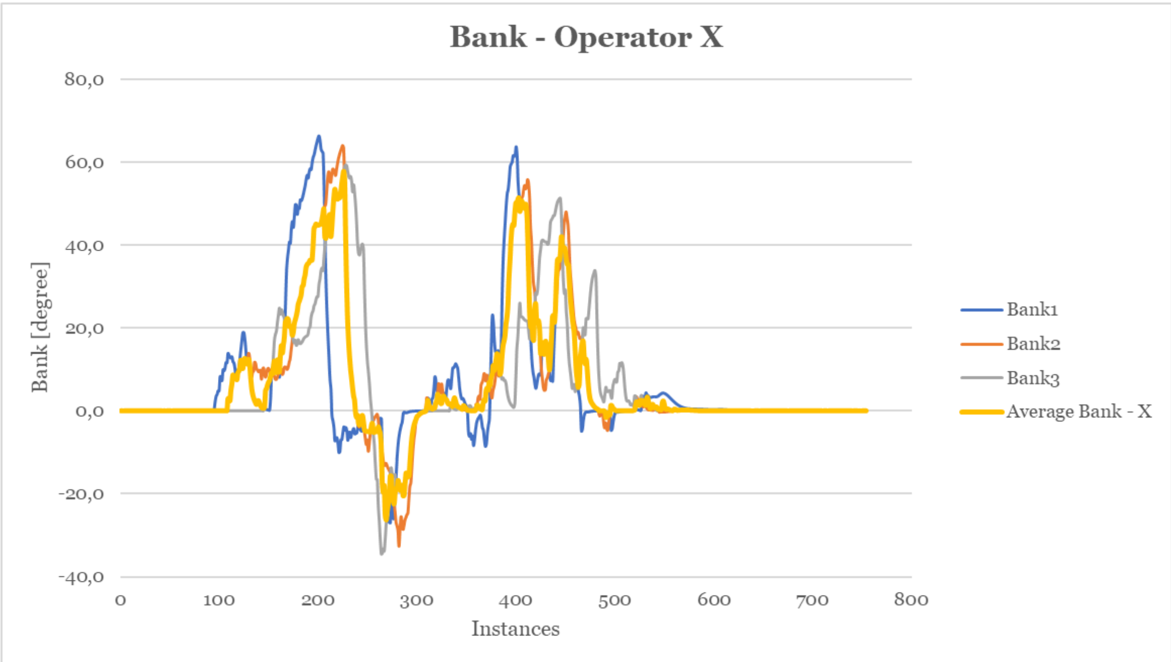


Figure B.19 - Operator X missions comparison and median values of bank angle

Operator X reached similar banks levels for all attempts (Figure B.19). Maximum values were reached on the first attempt.

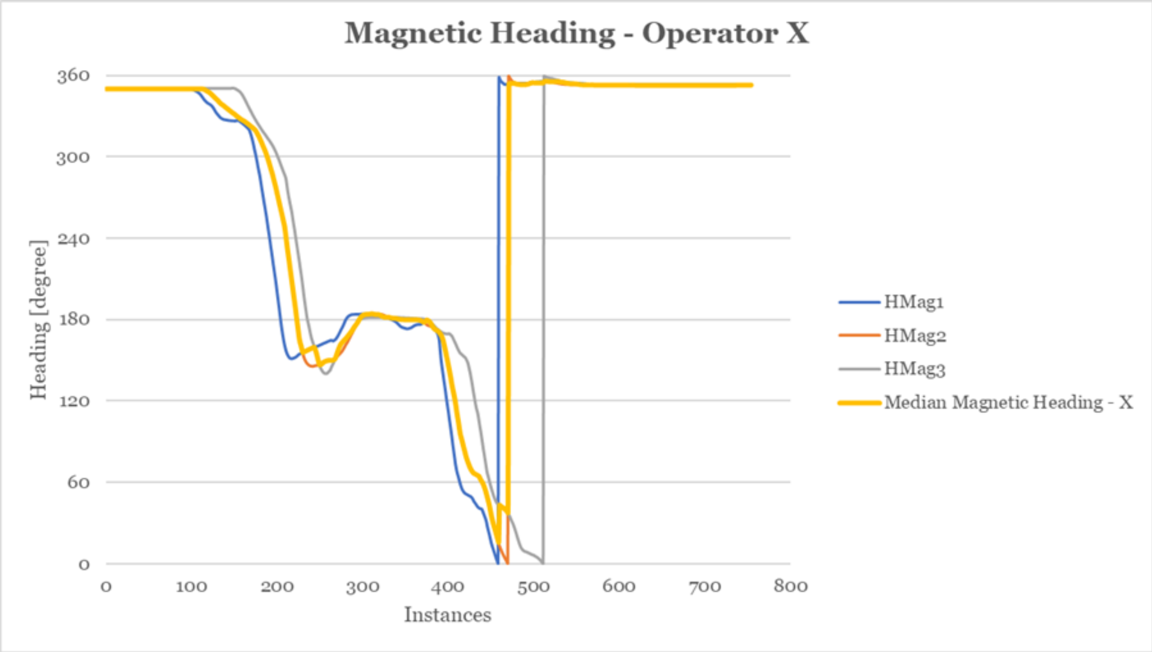


Figure B.20 - Operator X missions comparison and median values of magnetic heading

Operator X reached similar heading values accordingly to the mission route for all attempts (Figure B.20).

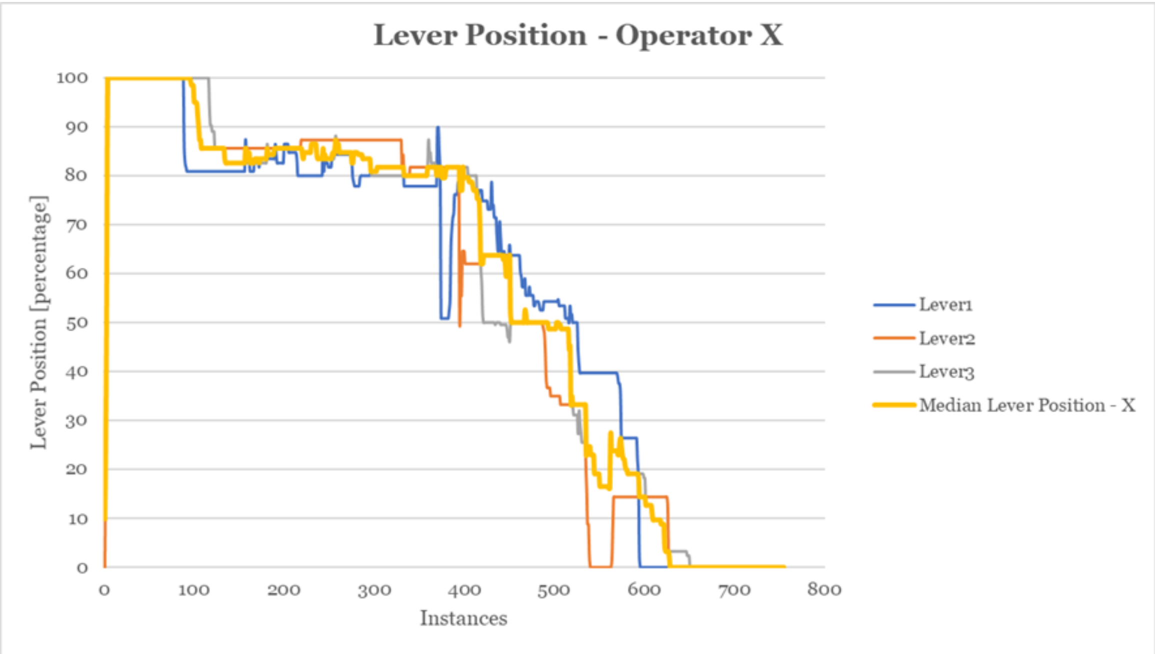


Figure B.21 - Operator X missions comparison and median values of lever position

Operator X performs smooth and similar lever adjustments in the first half of the mission (Figure B.21). However, several lever position adjustments were done on the second half of the mission.

Appendix C - Task Comparison Data

From Figure C.1 to Figure C.21 it is possible to verify the Operator 2 and 3 data per mission task, that originated a calculated median value.

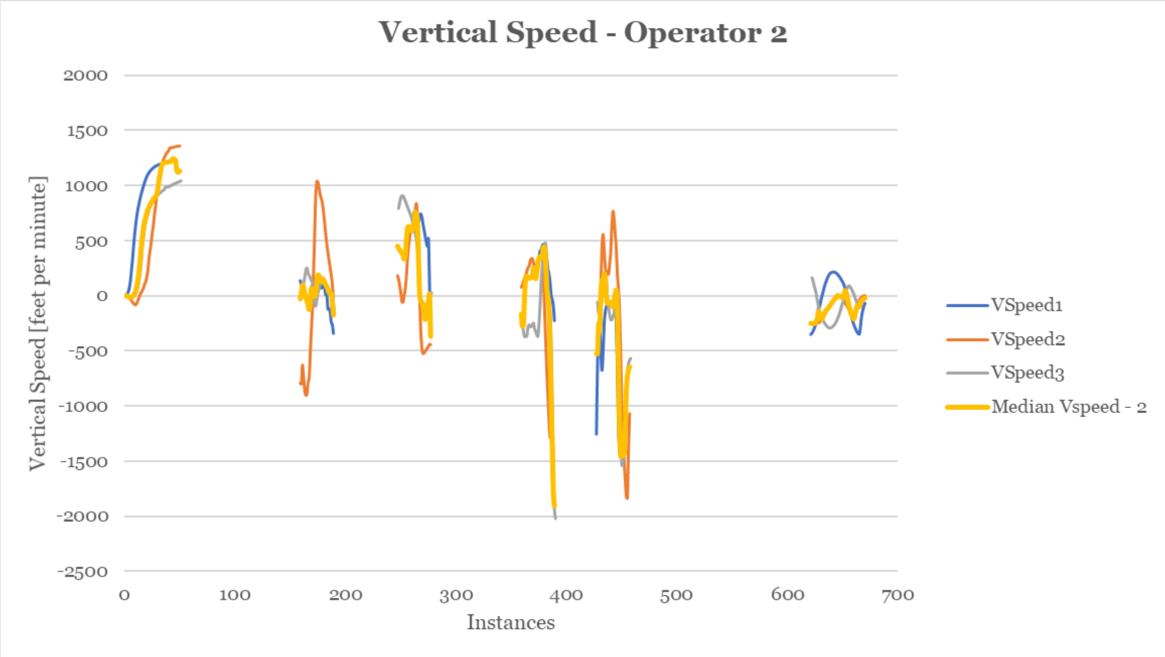


Figure C.1 - Operator 2 missions comparison and median values of vertical speed per task

Operator 2 had a similar amplitude of vertical speed values during each mission (Figure C.1), however, on mission attempt 2, peaks were reached on gate 1 and 4.

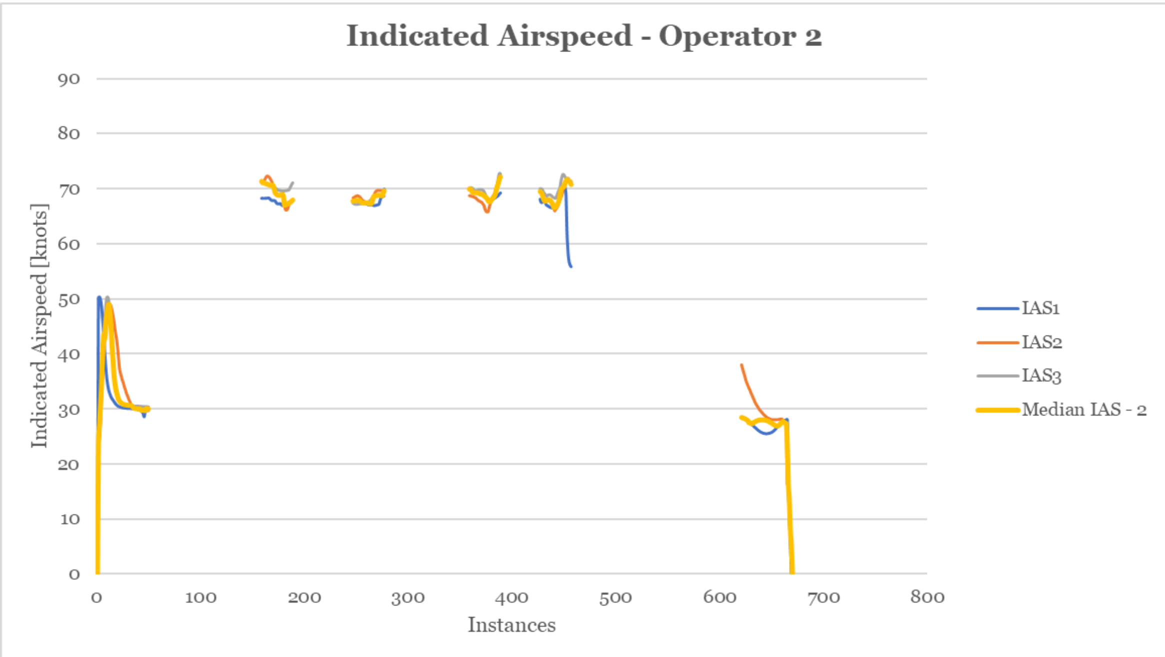


Figure C.2 - Operator 2 missions comparison and median values of indicated airspeed per task

During the takeoff phase on all missions (Figure C.2), the airspeed value increases and then immediately decreases due to high pitch values as indicated in Figure C.4. The main differences are noted on the last gate of mission 1, with some decrease in speed value, and on approach phase of mission 2, which was made from high-speed values when compared with mission 1 and 3.

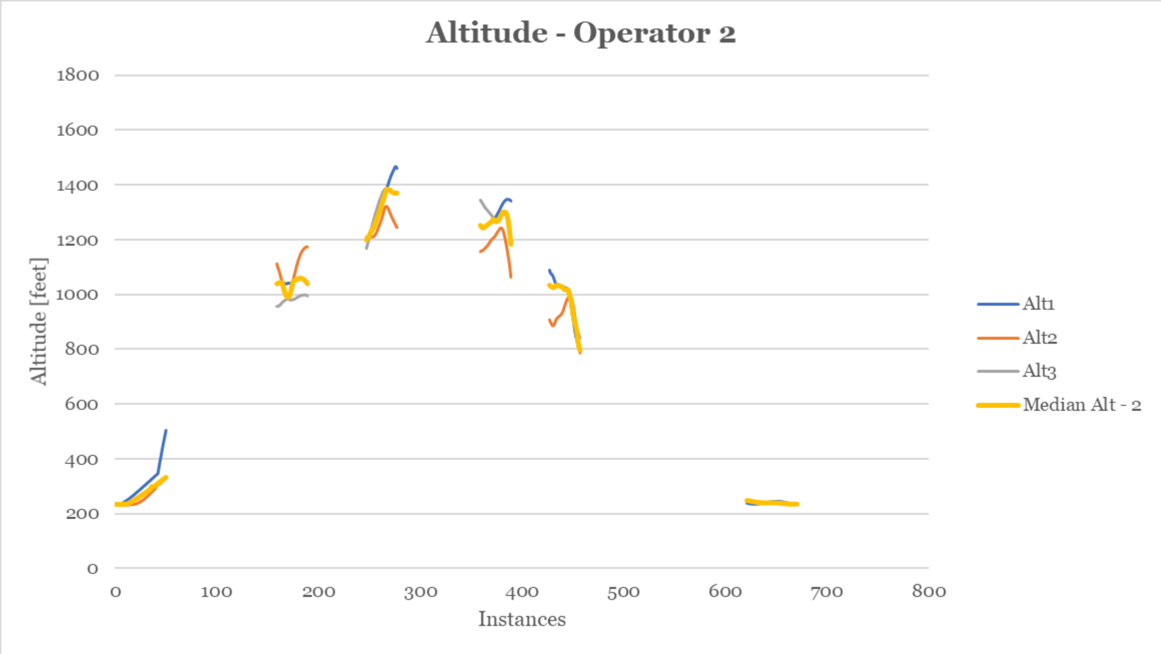


Figure C.3 - Operator 2 missions comparison and median values of altitude per task

On all missions, altitude values by Operator 2 are similar in all phases (Figure C.3).

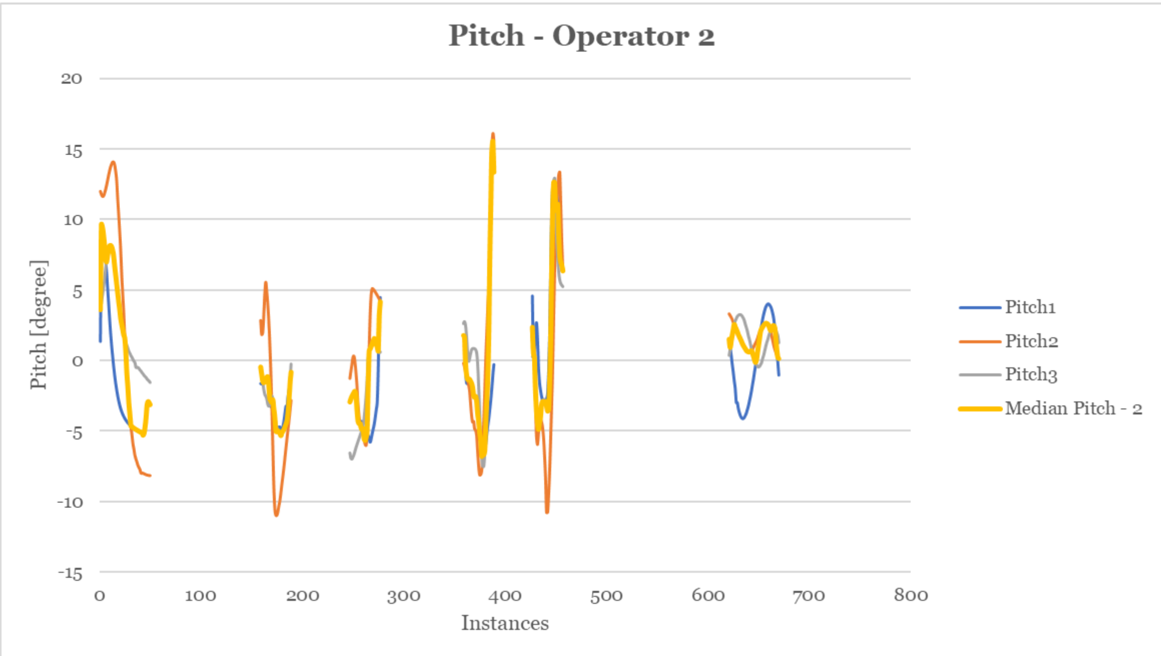


Figure C.4 - Operator 2 missions comparison and median values of pitch angle per task

On the mission attempt 1 and 2, is observed a greater range of values when compared with attempt 3, with accentuated peaks (Figure C.4).

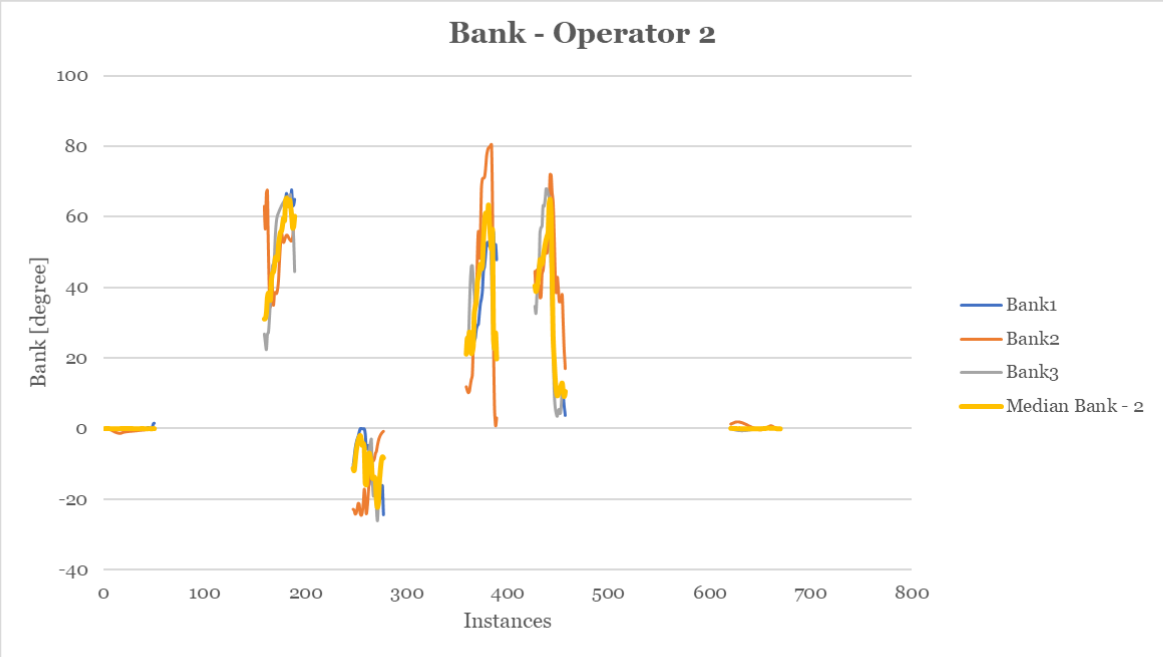


Figure C.5 - Operator 2 missions comparison and median values of bank angle per task

On all missions, bank values by Operator 2 are very similar in all phases (Figure C.5). Only on gate 2 in attempt 2, a bigger variation is verified.

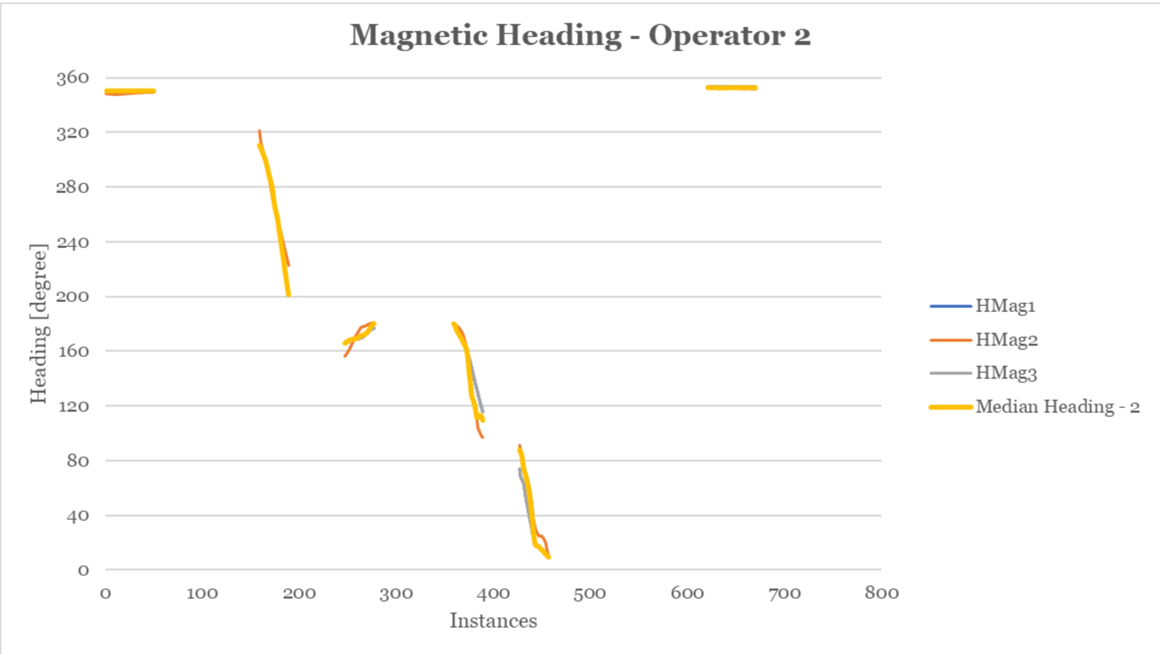


Figure C.6 - Operator 2 missions comparison and median values of magnetic heading per task

On all missions, heading values by Operator 2 are very similar on all phases (Figure C.6).

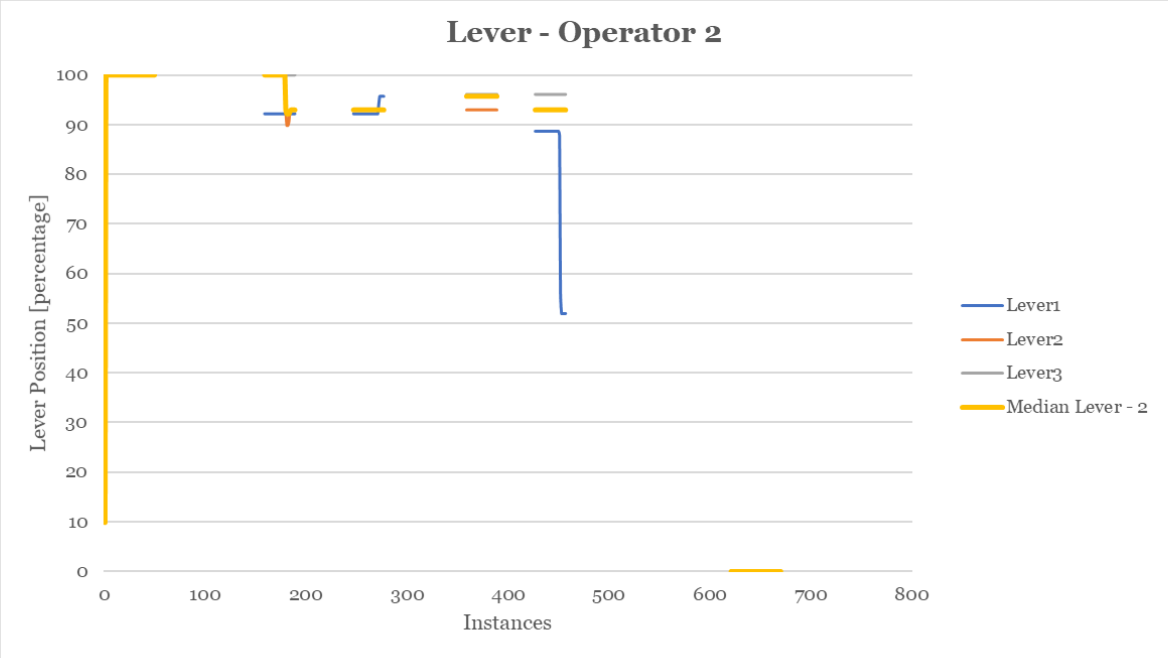


Figure C.7 - Operator 2 missions comparison and median values of lever position per task

Lever positions on Operator 2 missions are all very similar (Figure C.7). However, on the interception of gate 3, the values of the 1st attempt vary abruptly. On takeoff, the level position set is according to the SOPs in all attempts.

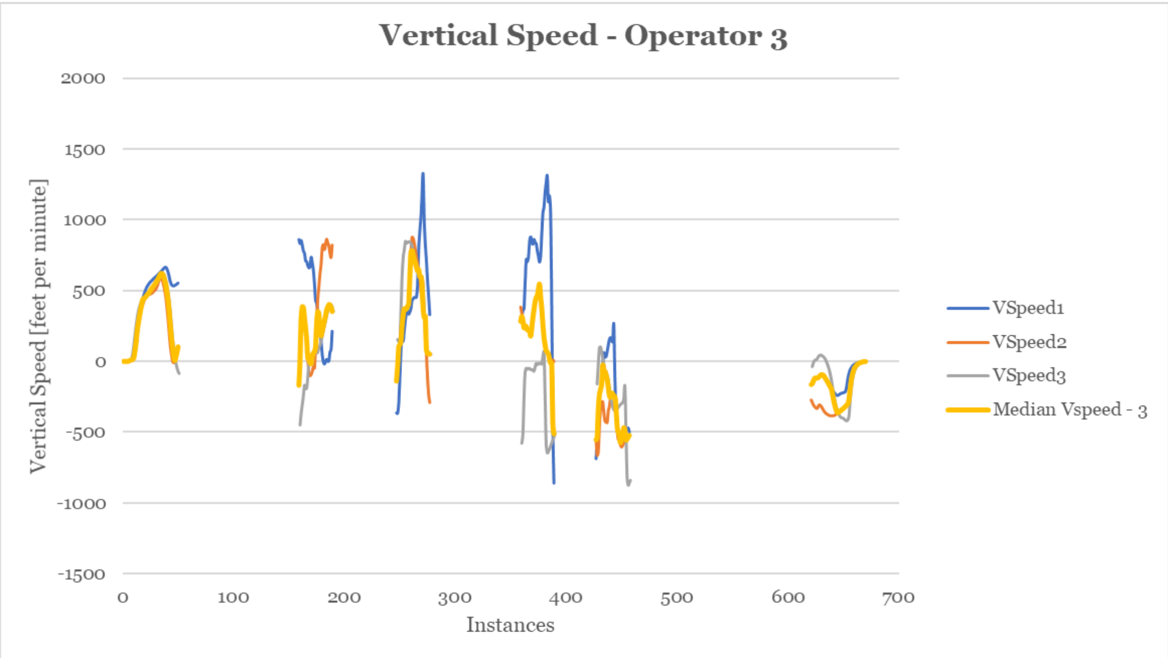


Figure C.8 - Operator 3 missions comparison and median values of vertical speed per task

Operator 3 had a similar amplitude of vertical speed values during each mission (Figure C.8), however, on mission attempt 1, peaks were reached on gate 2 and 3.

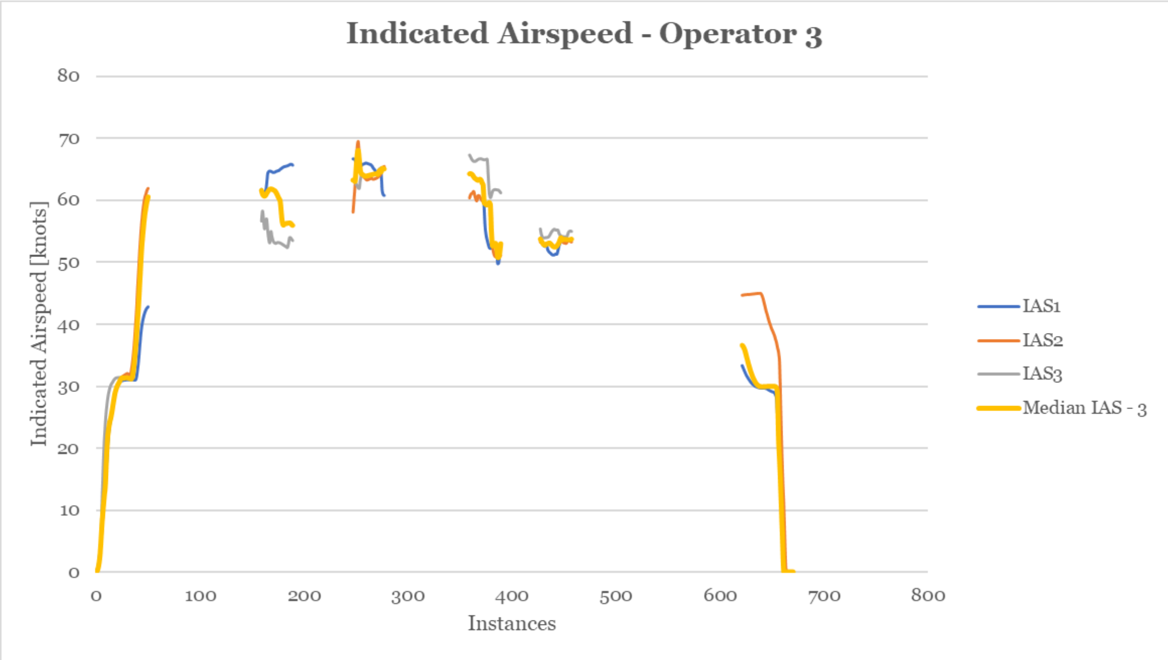


Figure C.9 - Operator 3 missions comparison and median values of indicated airspeed per task

On all missions, indicated airspeed values of Operator 3 are very similar on all phases (Figure C.9).

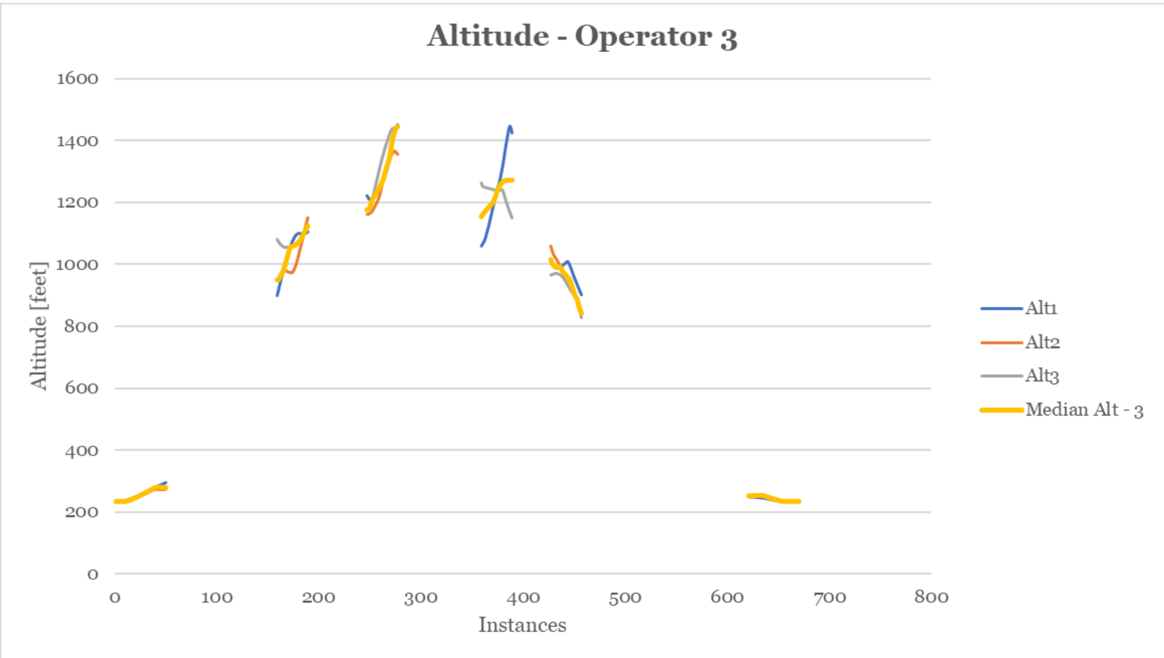


Figure C.10 - Operator 3 missions comparison and median values of altitude per task

On all missions, altitude values of Operator 3 are very similar in all phases (Figure C.10).

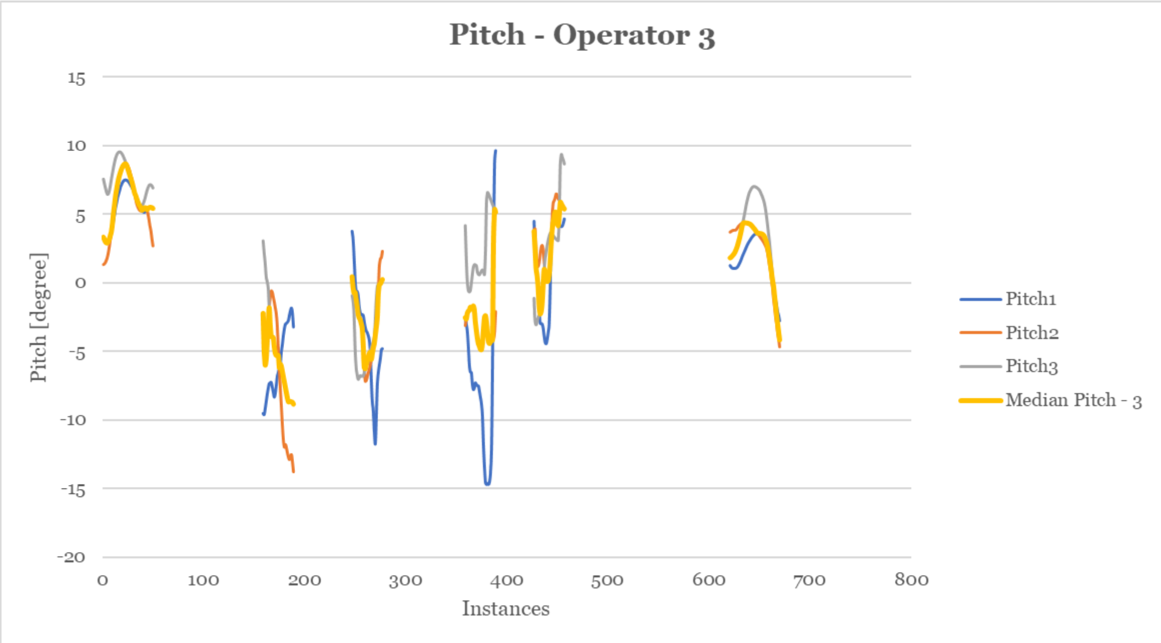


Figure C.11 - Operator 3 missions comparison and median values of pitch angle per task

On the mission attempt 1 (Figure C.11), is observed a greater range of values with accentuated peaks mainly on gates 2 and 3 when compared with attempt 2 and 3. For missions 2 and 3, pitch values of Operator 3 are very similar on all phases.

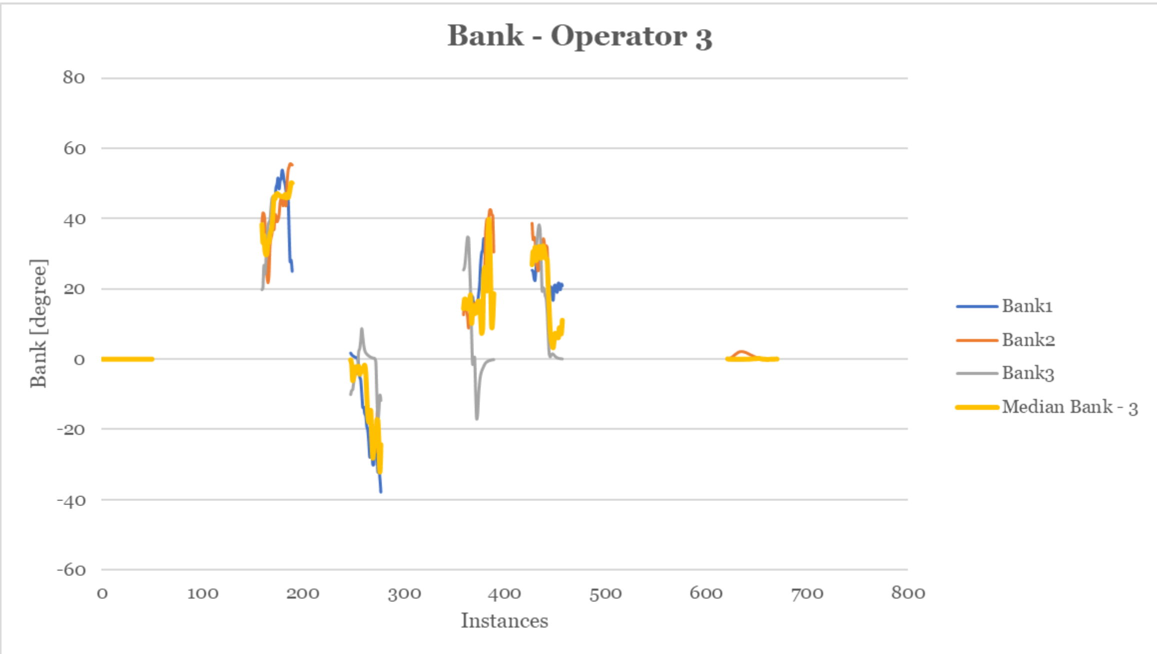


Figure C.12 - Operator 3 missions comparison and median values of bank angle per task

On all missions, bank values by Operator 3 are very similar in all phases (Figure C.12).

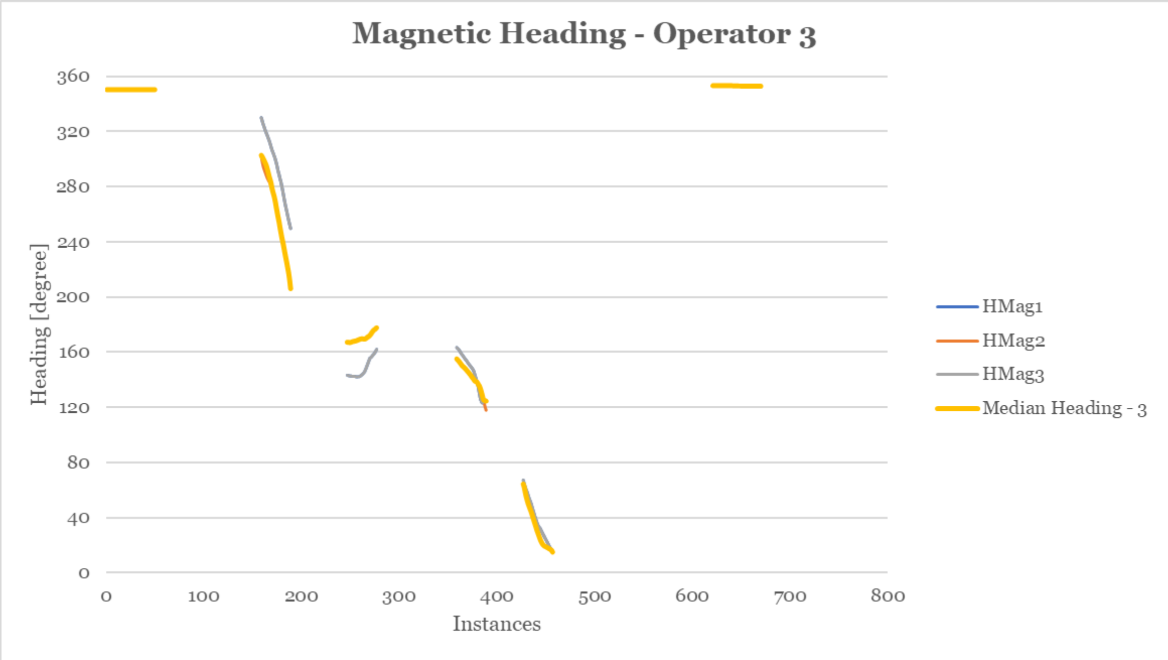


Figure C.13 - Operator 3 missions comparison and median values of magnetic heading per task

On all missions, heading values by Operator 3 are very similar on all phases (Figure C.13).

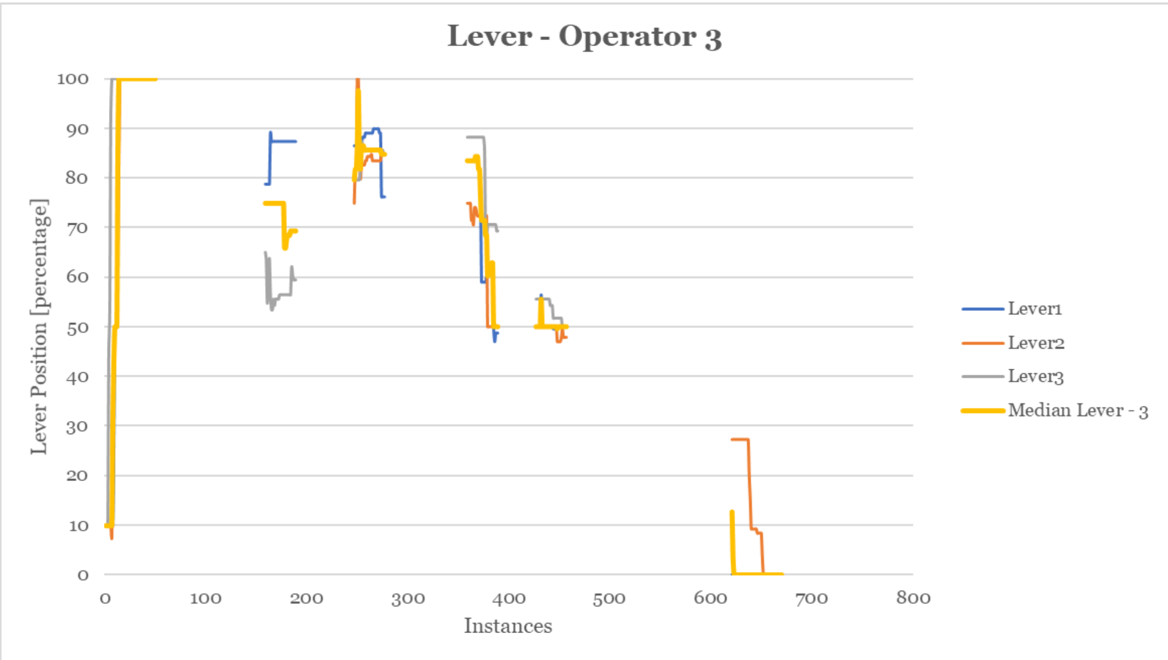


Figure C.14 - Operator 3 missions comparison and median values of lever position per task

On all missions, lever values by Operator 3 are very similar in all phases (Figure C.14). Only on gate 1, we verify some differences on this value between missions 1 and 3.

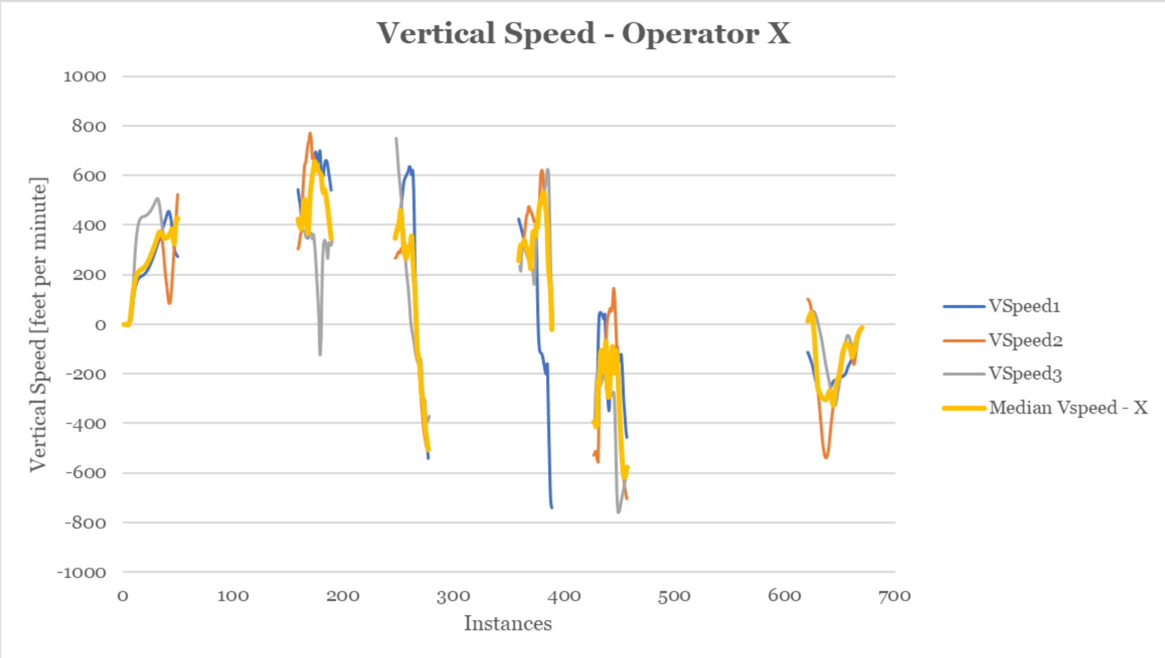


Figure C.15 - Operator X missions comparison and median values of vertical speed per task

Operator X had a similar amplitude of vertical speed values during each mission (Figure C.15), however, on mission attempt 3 a peak was reached on gate 1, and on mission 1 on gate 3.

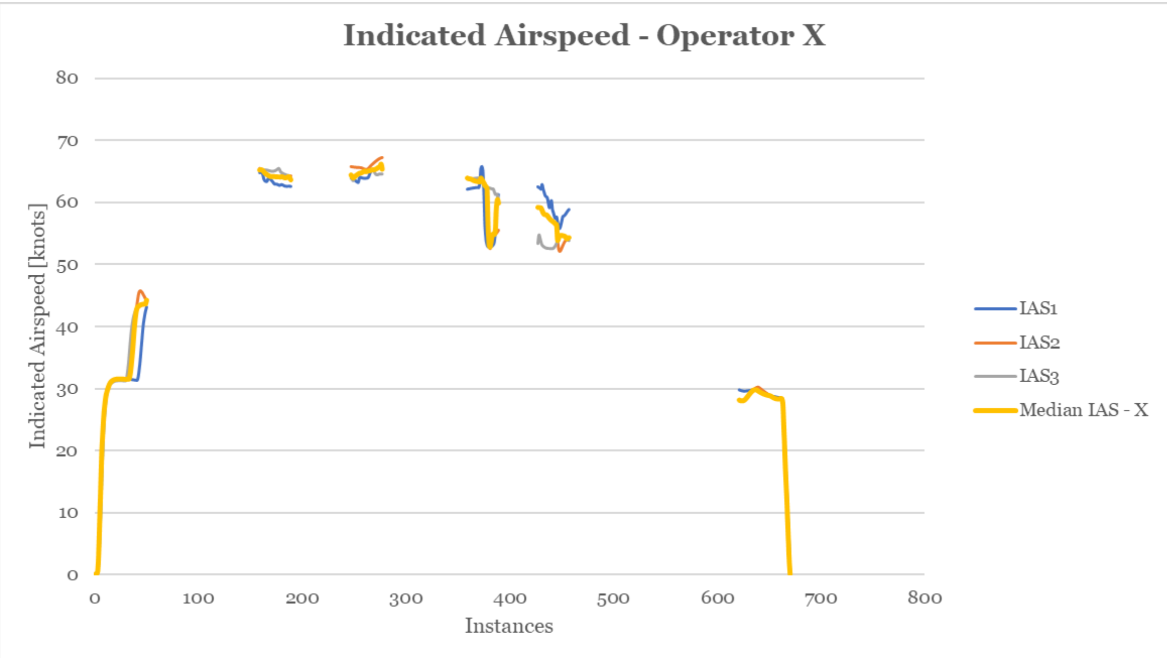


Figure C.16 - Operator X missions comparison and median values of indicated airspeed per task

On all missions and phases, the indicated airspeed values of Operator X are very similar (Figure C.16).

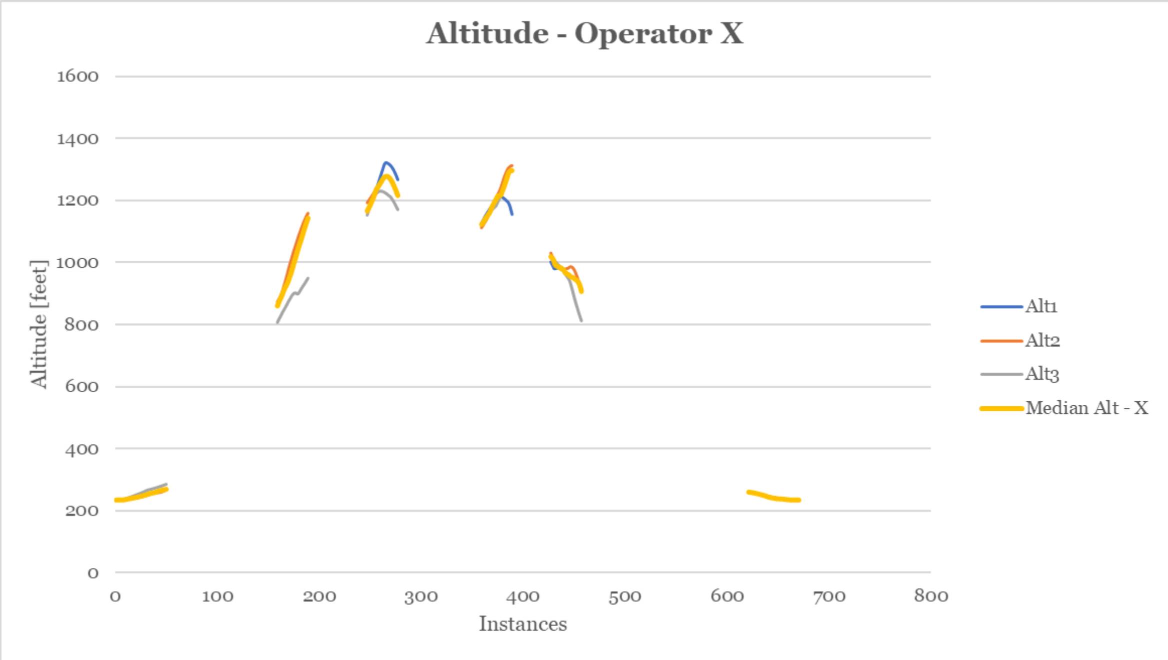


Figure C.17 - Operator X missions comparison and median values of altitude per task

On all missions, altitude values of Operator X are very similar in all phases (Figure C.17).

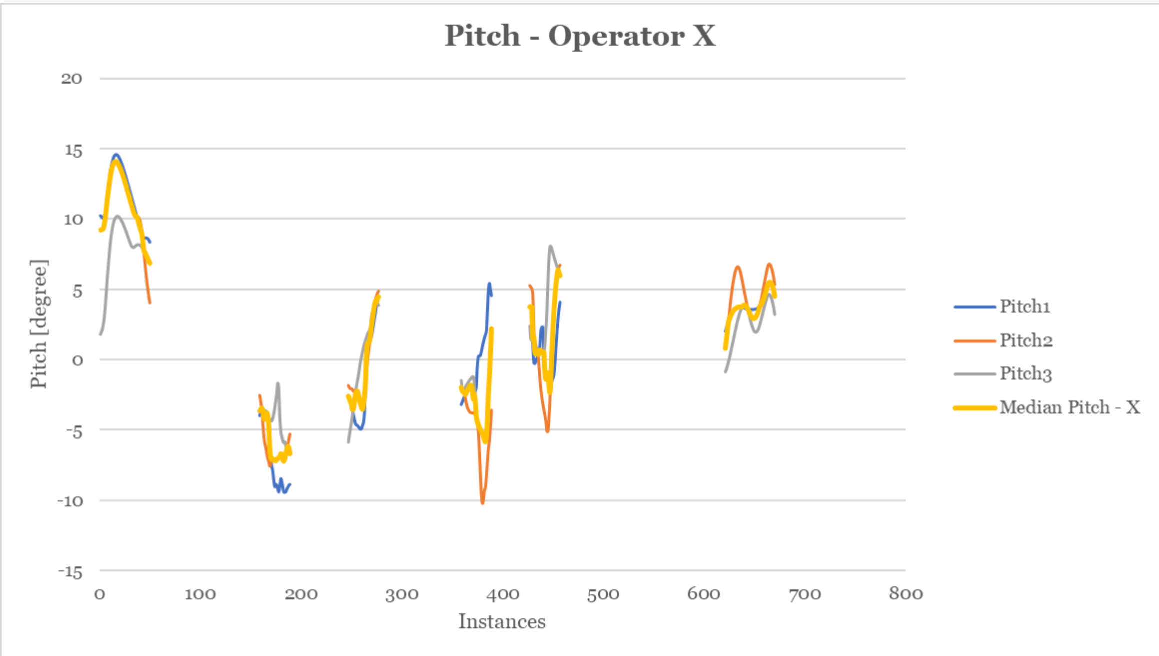


Figure C.18 - Operator X missions comparison and median values of pitch angle per task

On all missions, the pitch values of Operator X are very similar in all phases (Figure C.18). Only on gate 3, there are bigger differences in the verified values between missions 1 and 2.

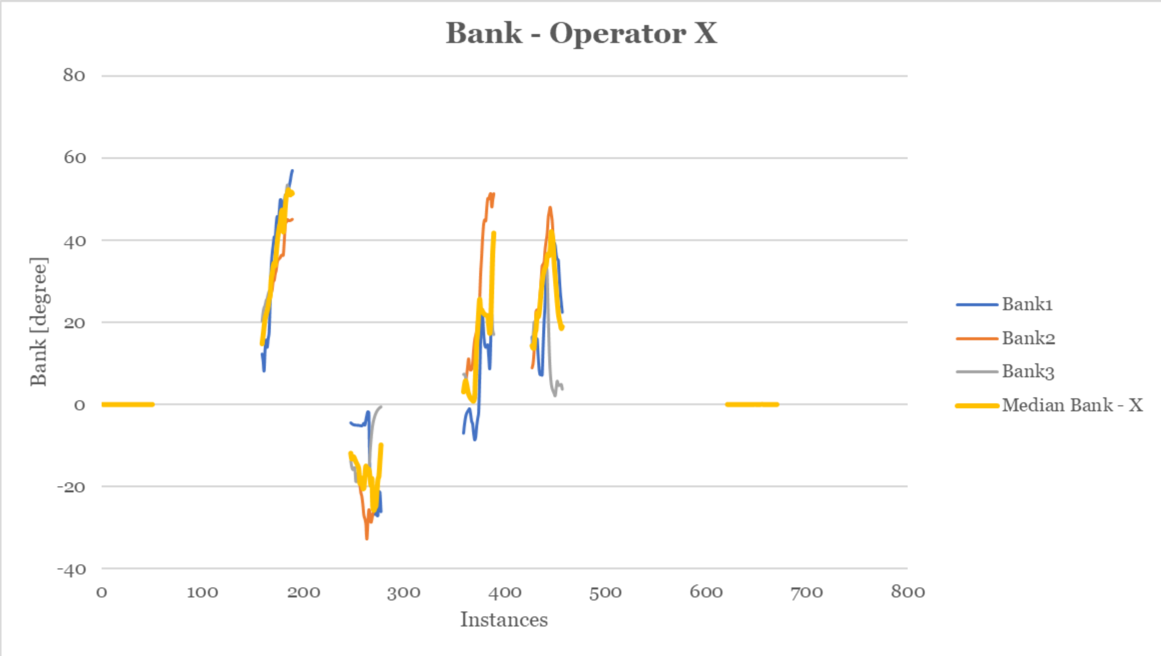


Figure C.19 - Operator X missions comparison and median values of bank angle per task

On all missions, bank values of Operator X are very similar in all phases (Figure C.19).

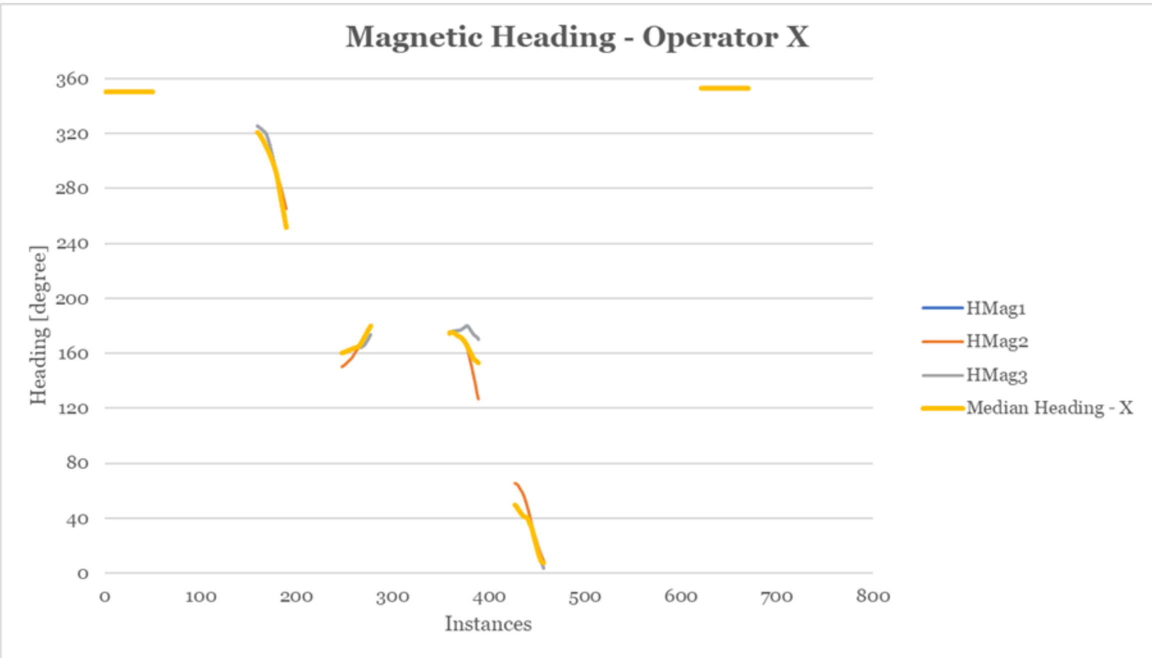


Figure C.20 - Operator X missions comparison and median values of magnetic heading per task

On all missions, heading values of Operator X are very much the same on all phases (Figure C.20).

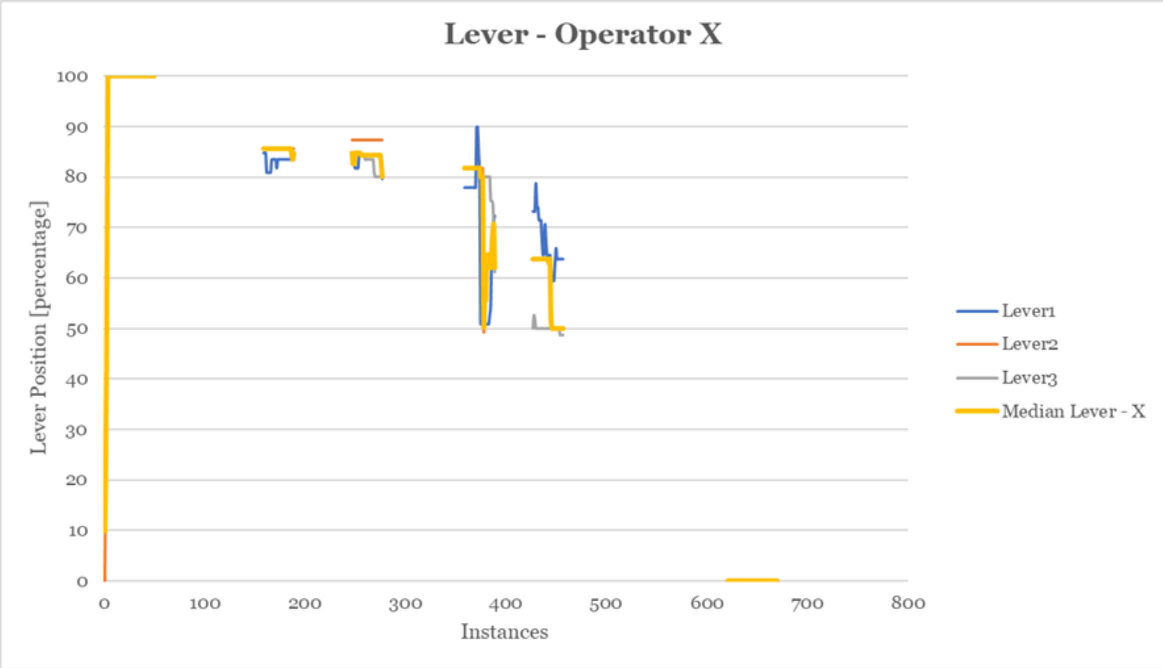


Figure C.21 - Operator X missions comparison and median values of lever position per task

On all missions, lever values of Operator X are very similar in all phases (Figure C.21).

From Figure C.22 to Figure C.35 it is possible to verify the Operator 2 and 3 median data compared with Operator X for each task, including its calculated standard deviation.

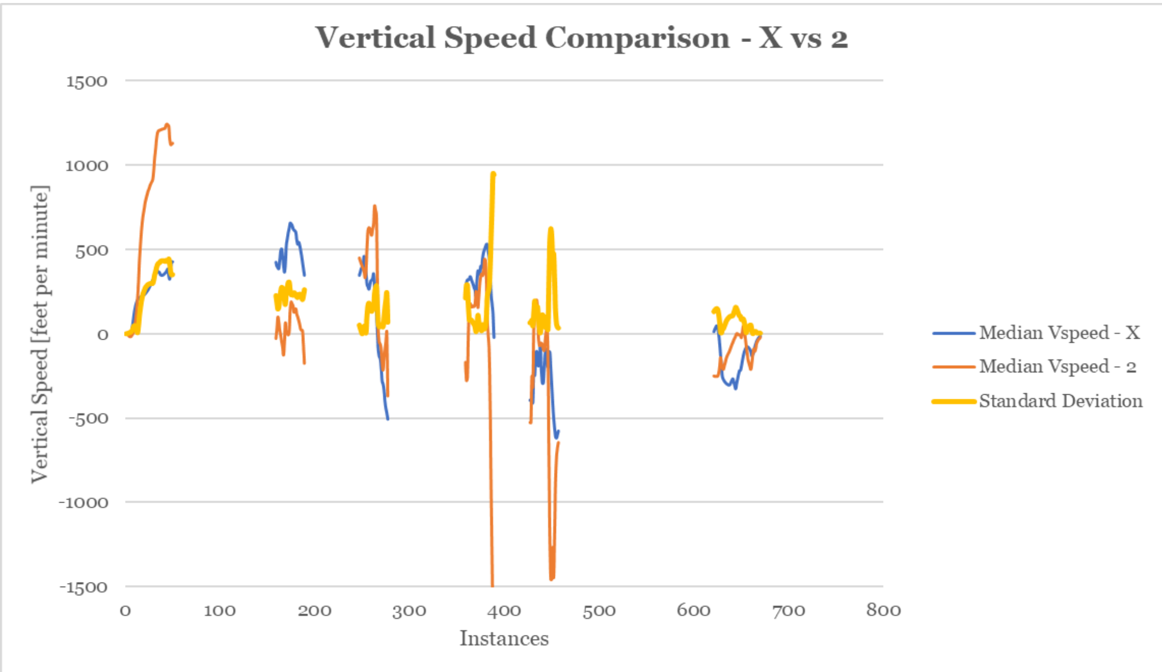


Figure C.22 - Operator X vs Operator 2 missions comparison and standard deviation values of vertical speed per task

The Operator 2 median shows a greater range of values when compared with the median of the Operator X (Figure C.22). During both takeoff and interception of gate 3 and 4, a larger standard deviation is seen, with a great variation of values. During landing, the medians show approximate values.

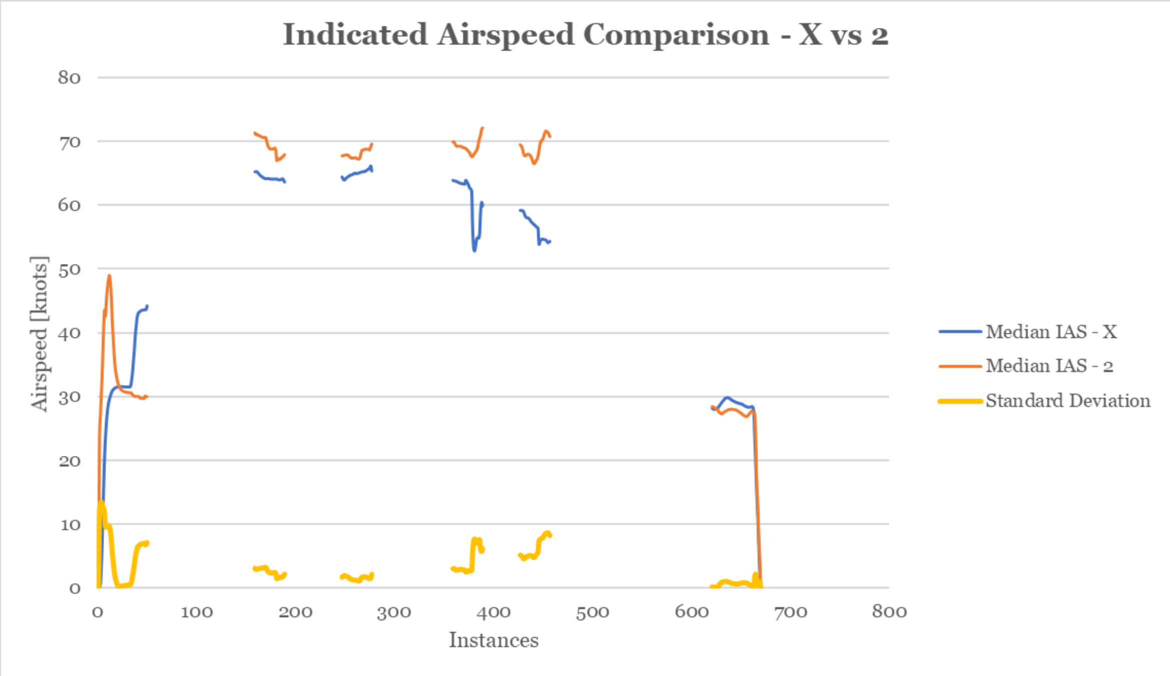


Figure C.23 - Operator X vs Operator 2 missions comparison and standard deviation values of indicated airspeed per task

It is observed that during takeoff and interception of gate 3 and 4, the Operator 2 median is greater than the median of the Operator X (Figure C.23), thus in those instances, a larger standard deviation is seen. The airspeed values for those interceptions are higher than the recommended cruise speed of 65 knots. During landing, the medians show approximate values.

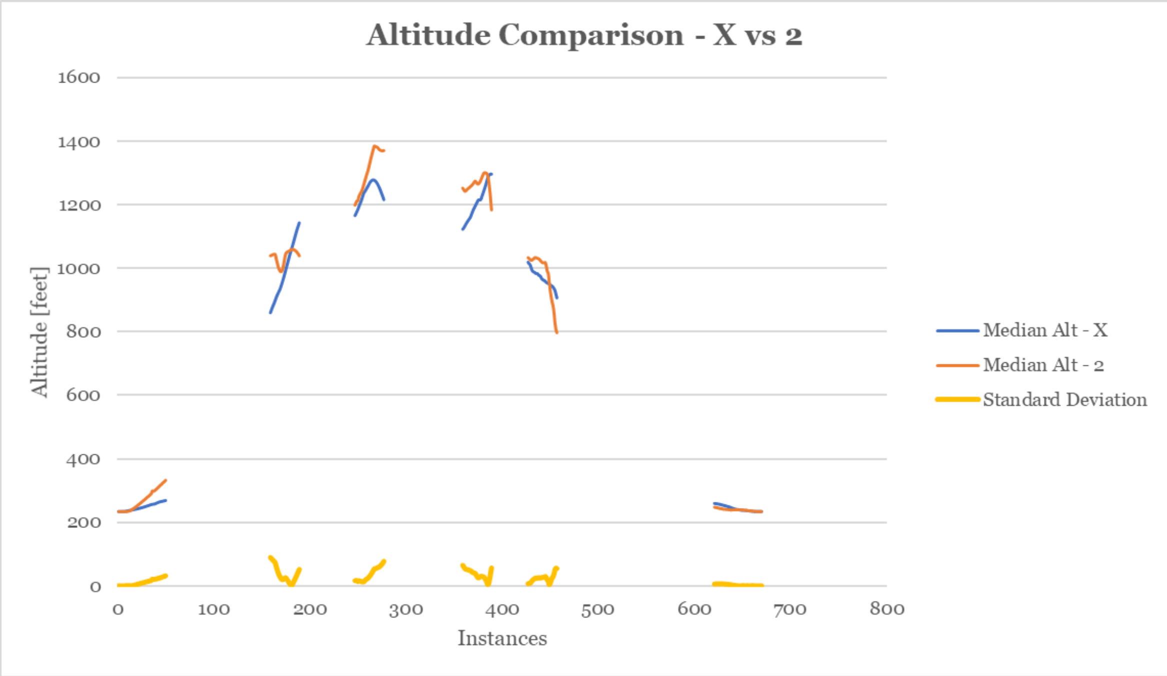


Figure C.24 - Operator X vs Operator 2 missions comparison and standard deviation values of altitude per task

It is observed that during the interception of the gates, the Operator 2 altitude median shows fewer variations than the Operator X median (Figure C.24). During both takeoff and landing, the medians show approximate values.

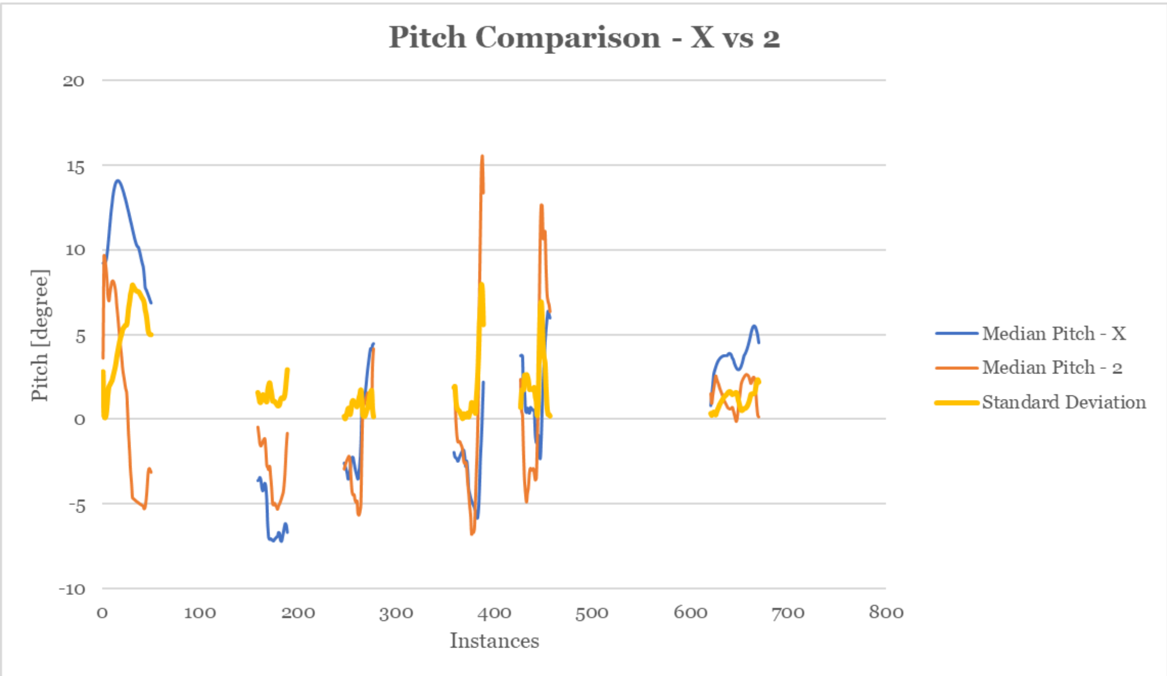


Figure C.25 - Operator X vs Operator 2 missions comparison and standard deviation values of pitch angle per task

In the interception of the gates (Figure C.25), the Operator 2 pitch median shows more accentuated values when compared with the median of the Operator X, corroborated per Figure C.22. However, during both takeoff and landing, the Operator 2 median show lower pitch values than the Operator X.

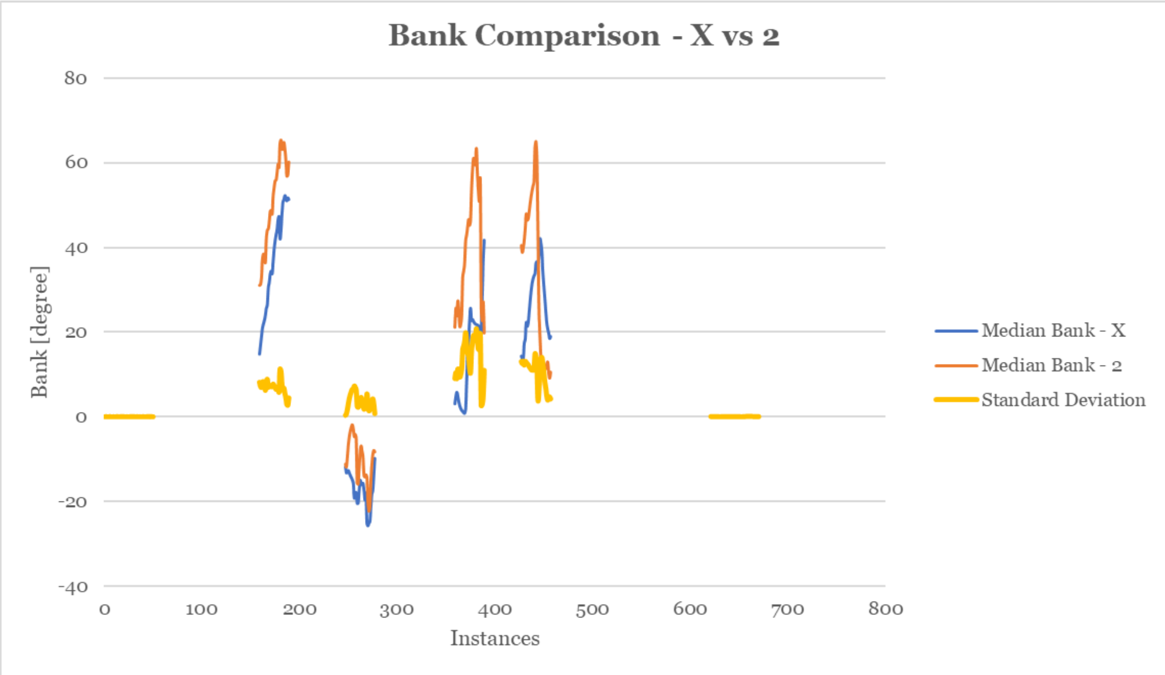


Figure C.26 - Operator X vs Operator 2 missions comparison and standard deviation values of bank angle per task

The interception of the gates 1, 3 and 4 (Figure C.26), the Operator 2 bank median shows accentuated differences when compared with the median of the Operator X, thus in those instances, a larger standard deviation is seen. During takeoff, gate 2 interception and landing, the medians show approximate values.

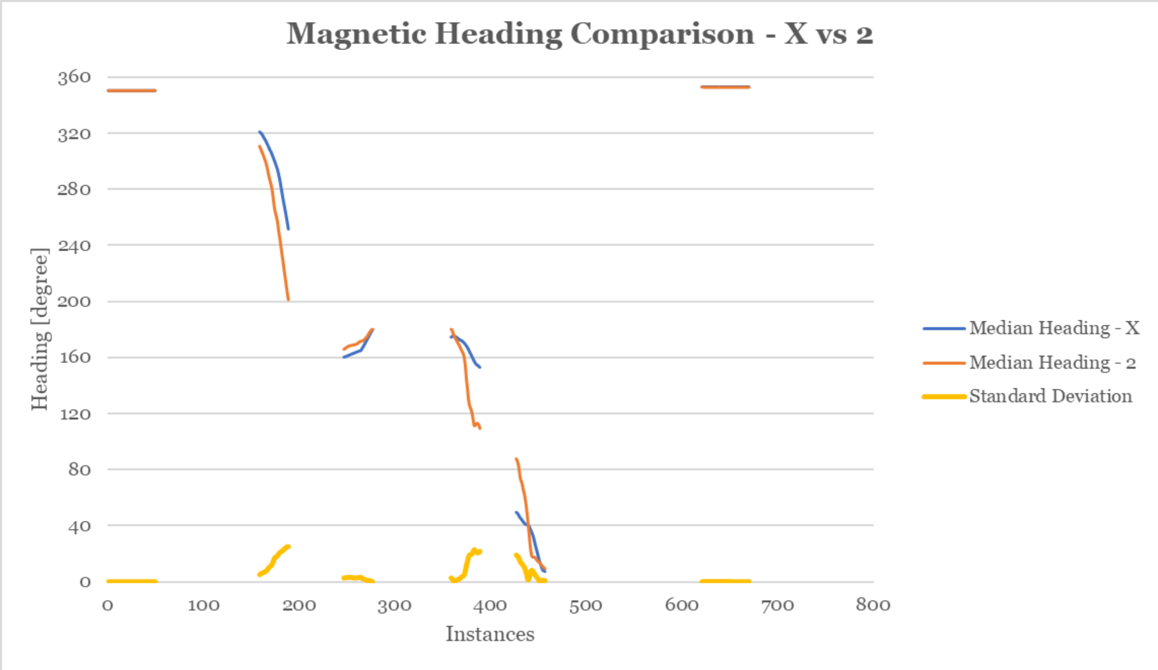


Figure C.27 - Operator X vs Operator 2 missions comparison and standard deviation values of magnetic heading per task

It is observed that during the interception of the gates 1, 3 and 4 (Figure C.27), the Operator 2 median shows accentuated differences when compared with the median of the Operator X, thus in those instances, a larger standard deviation is seen. When associated with Figure C.26, is coherent and shows that the Operator 2 was turning while intercepting the gates. During takeoff, gate 2 interception and landing, the medians show approximate values.

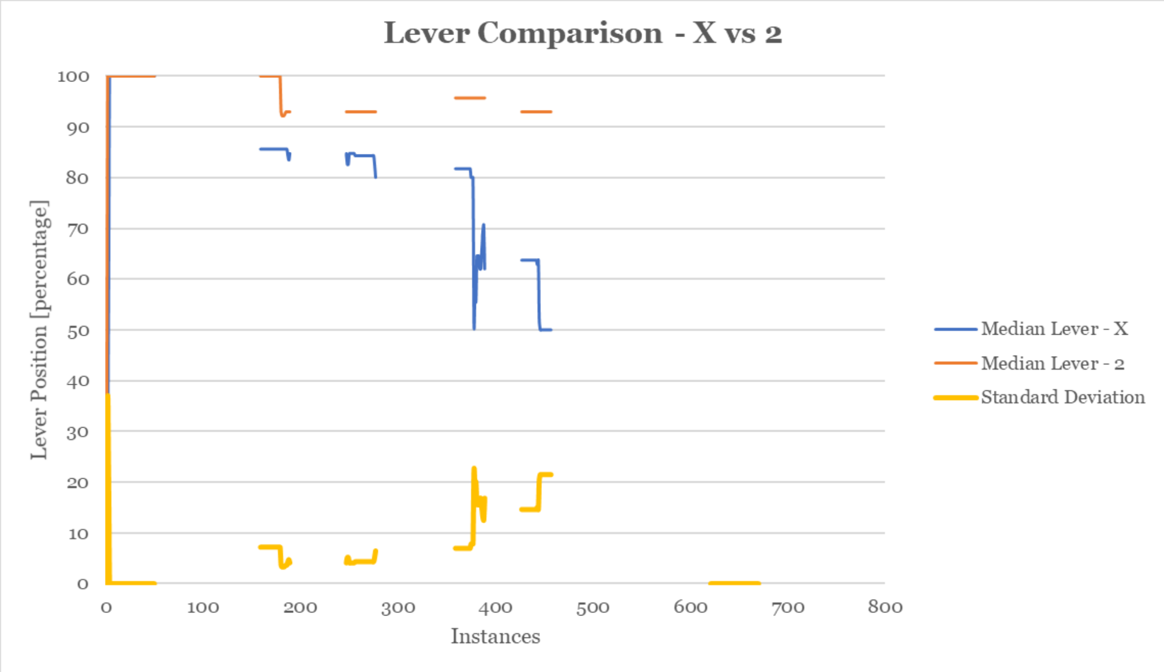


Figure C.28 - Operator X vs Operator 2 missions comparison and standard deviation values of lever position per task

It is noticed that during the interception of the gates the Operator 2 has higher values of lever position when compared with Operator X (Figure C.28). This is associated with the indicated airspeed for those particular moments, which is according to Figure C.23. During both takeoff and landing, the medians show approximate values.

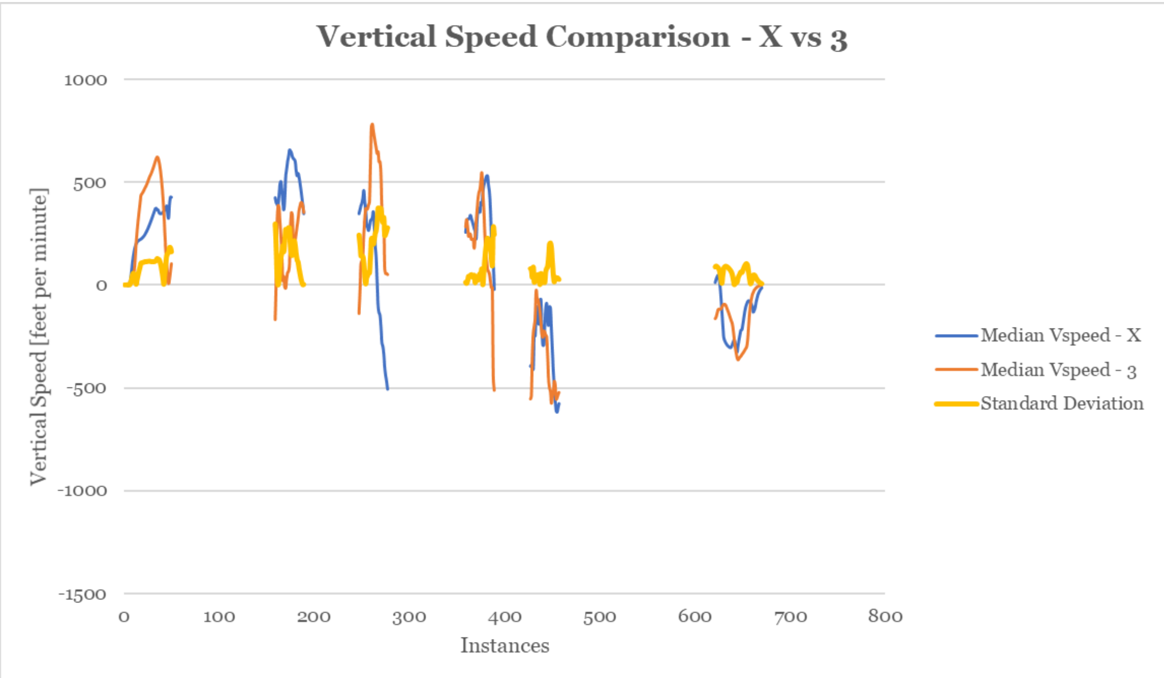


Figure C.29 - Operator X vs Operator 3 missions comparison and standard deviation values of vertical speed per task

The Operator 3 median, during takeoff and the interception of gate 2 (Figure C.29), shows a greater range of values when compared with the median of the Operator X, with an accentuated variation of values. During the interception of gate 2, the Operator 3 median shows a negative vertical speed, which is the opposite of the Operator X median. During the interception of gate 3, 4 and landing, the medians show approximate values.

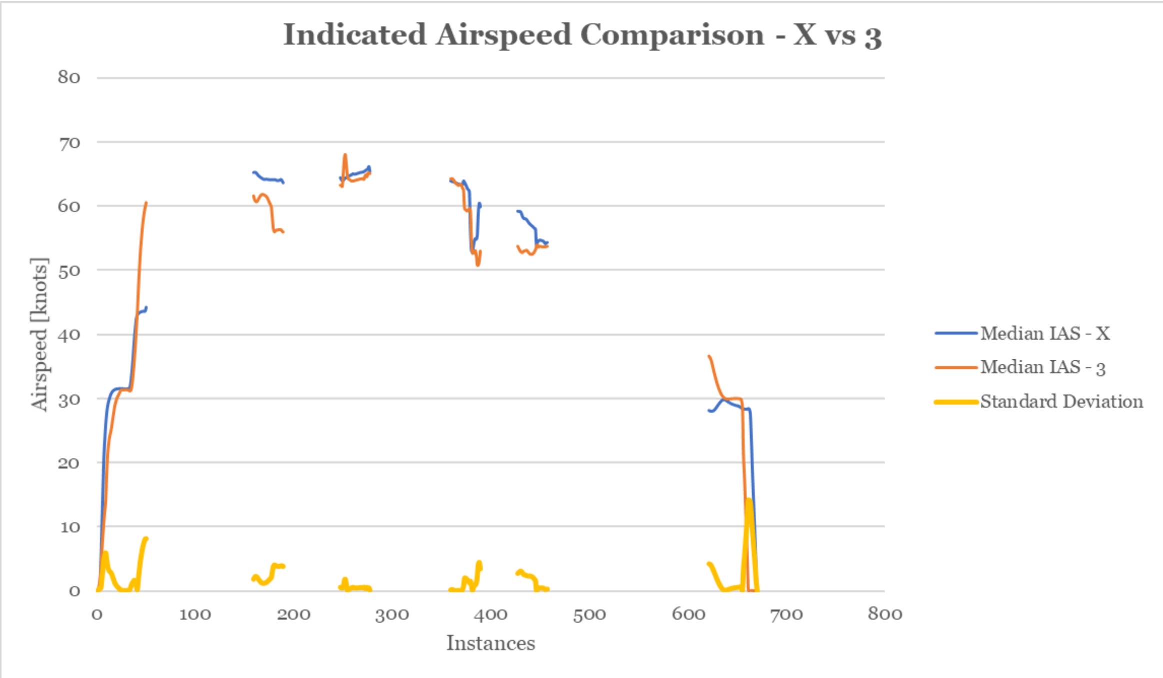


Figure C.30 - Operator X vs Operator 3 missions comparison and standard deviation values of indicated airspeed per task

It is shown that during takeoff, a higher airspeed value is reached when compared with Operator X (Figure C.30). The interception of gate 1 is performed at a lower airspeed, although on the following gates, the deviation is minimal. During the landing, is observed that the airspeed is reduced on a later stage when compared with the Operator X.

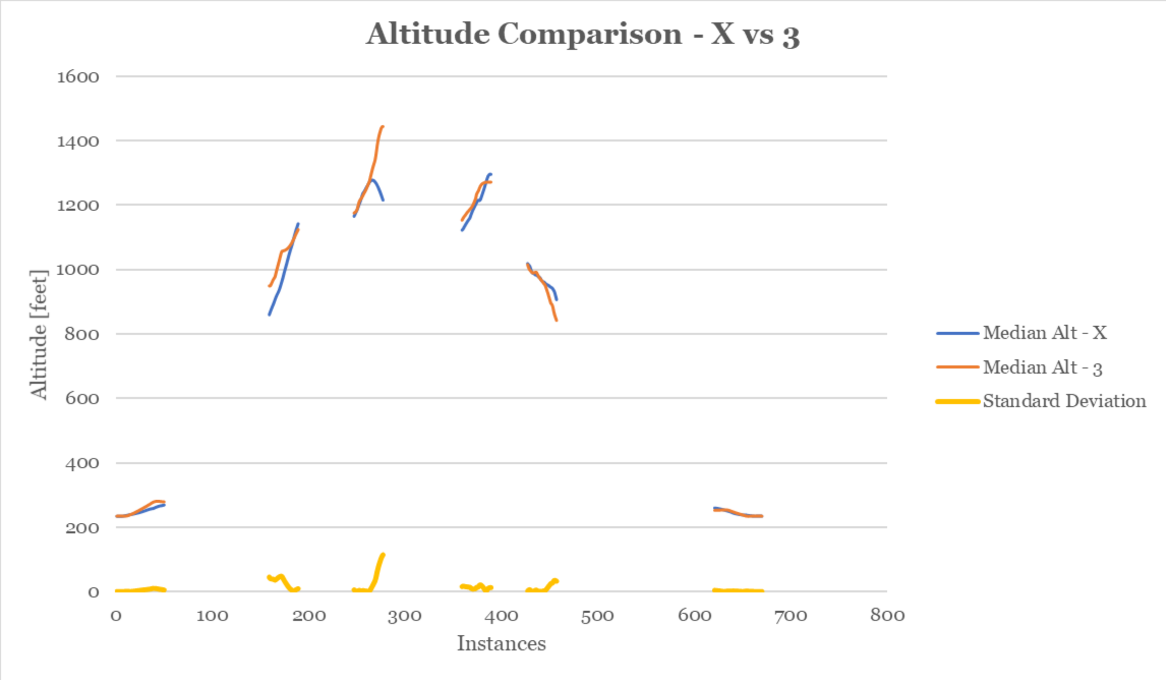


Figure C.31 - Operator X vs Operator 3 missions comparison and standard deviation values of altitude per task

On gate 2, it is observed that the Operator 3 altitude median shows a great variation than the Operator X median (Figure C.31). During both takeoff and following gate, the medians show approximate values, with few deviations.

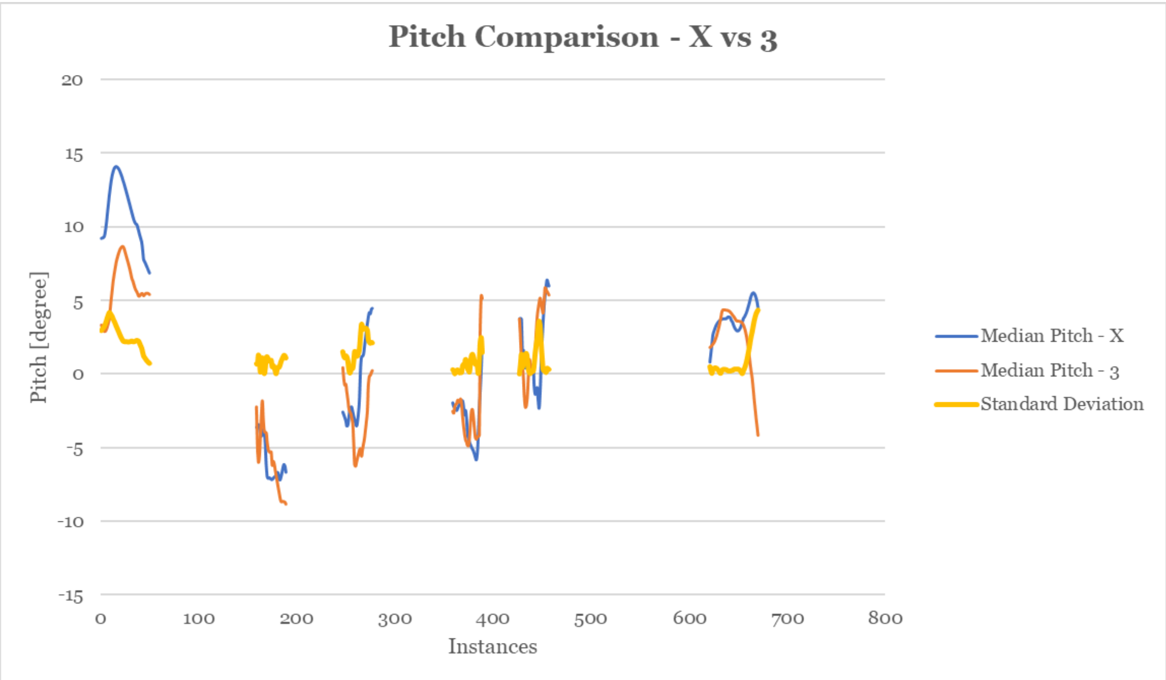


Figure C.32 - Operator X vs Operator 3 missions comparison and standard deviation values of pitch angle per task

During the takeoff (Figure C.32), the Operator 3 median shows lower pitch amplitude when compared with the Operator X, which is in accordance to the Figure C.29, as the vertical speed values are more accentuated for a longer number of instances. Other tasks are performed with approximate values regarding Operator X.

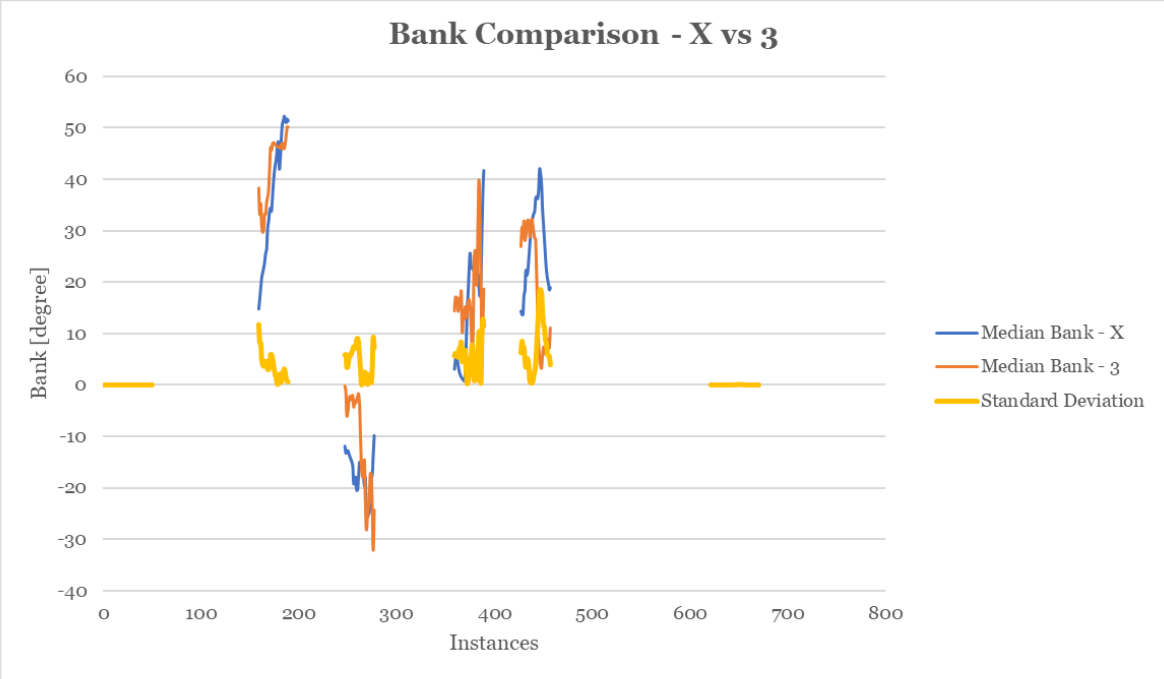


Figure C.33 - Operator X vs Operator 3 missions comparison and standard deviation values of bank angle per task

The interception of the gates 2 and 4 (Figure C.33), the Operator 3 bank median shows accentuated differences when compared with the median of the Operator X. On gate 2, a great variation of values is seen, and in gate 4, the median values show a more constant bank than the Operator X. However, in other tasks, the medians show approximate values.

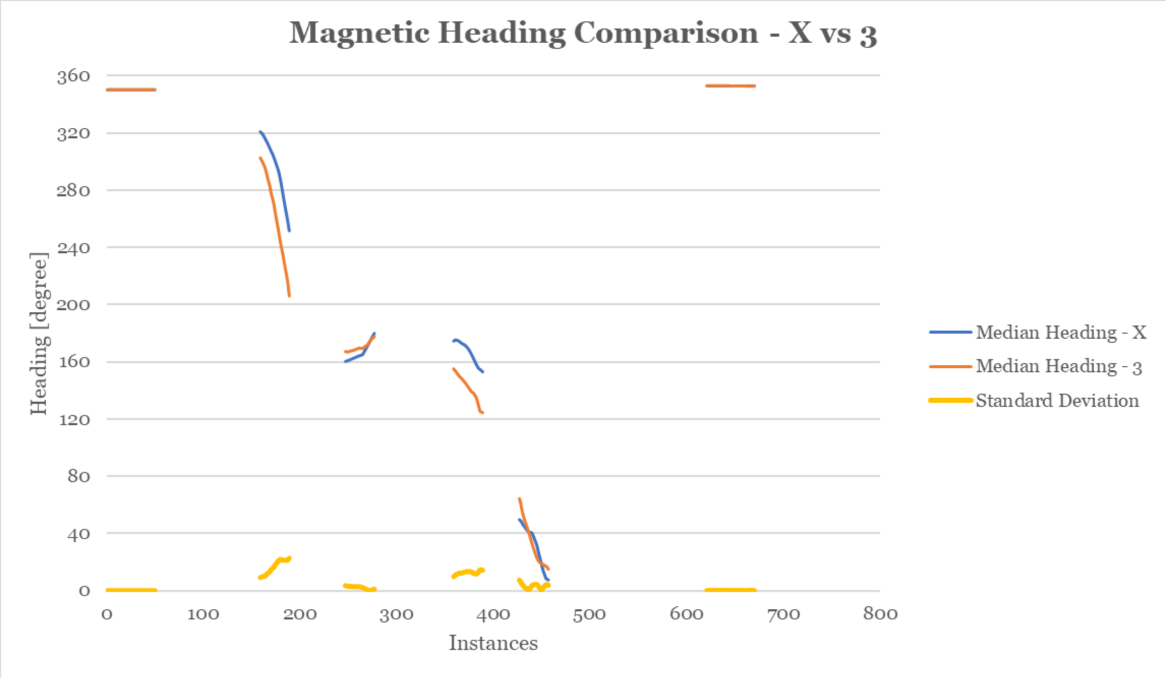


Figure C.34 - Operator X vs Operator 3 missions comparison and standard deviation values of magnetic heading per task

It is observed that during the interception of the gates 1 and 3 (Figure C.34), the Operator 3 median shows the heading values being intercepted earlier when compared with the median of the Operator X. In other tasks, the medians show approximate values.

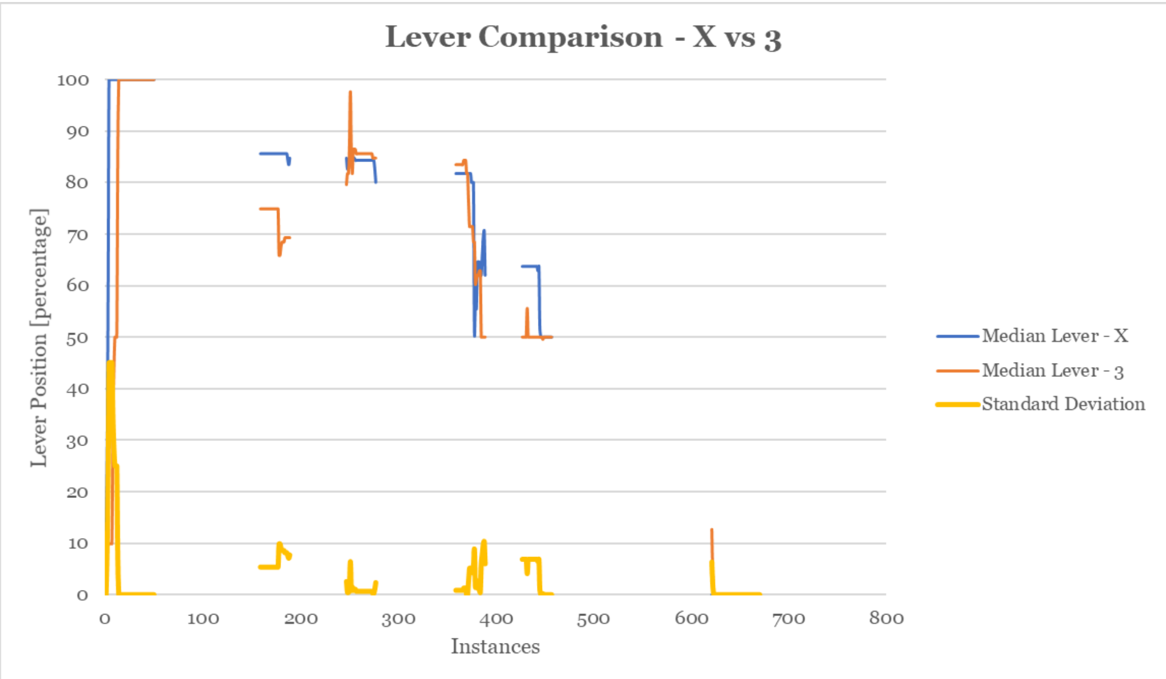


Figure C.35 - Operator X vs Operator 3 missions comparison and standard deviation values of lever position per task

It is observed that during the interception of the gates 1 and 4 (Figure C.35), the Operator 3 has higher values of lever position when compared with Operator X. On gate 2, the Operator 3 has a greater amplitude of values, although the same values are reached on a later point. These variations are related to the indicated airspeed for those particular moments, which is according to Figure C.30. During both takeoff and landing, the medians show approximate values.

Appendix D - Outputs

This appendix contains the abstracts of the articles presented at ICEUBI 2015 and at RAeS Aerodynamics 2019 conference, both produced as a result of this dissertation research.

1. Insights and Challenges of Flight Simulation Systems in Air Transportation

ICEUBI2015
University of Beira Interior
Faculty of Engineering Covilhã | Portugal

December 2 3 4
International Conference on Engineering
Engineering for Society

Insights and challenges of flight simulation systems in air transportation

Laura N. Martins - lauramartins.nit@ubi.pt
LAETA/UBI-AeroG, Aerospace Sciences Department, Faculty of Engineering, University of Beira Interior
Luís G. Trindade - a29408@ubi.pt
LAETA/UBI-AeroG, Aerospace Sciences Department, Faculty of Engineering, University of Beira Interior
João Neves - joao.a.neves@sapo.pt
LAETA/UBI-AeroG, Aerospace Sciences Department, Faculty of Engineering, University of Beira Interior
Jorge Silva - jmiguel240959@sapo.pt
LAETA/UBI-AeroG, Aerospace Sciences Department, Faculty of Engineering, University of Beira Interior
Kouamana Bousson - ksbousson@gmail.com
LAETA-UBI/AeroG, Aerospace Sciences Department, Faculty of Engineering, University of Beira Interior

Abstract

Nowadays it is necessary to produce innovative and reliable products at the lowest possible cost. Simulation is present during design, development and validation of aeronautical vehicles or systems. It is widely used, seen on design tools like Computer Aided Three-dimensional Interactive Application (CATIA), MATrix LABoraty (MATLAB) or in Flight Simulation. X-Plane, Microsoft Flight Simulator (MSFS)/Lockheed Martin Prepar3DÂ® and Flight Gear are the most used software when it comes to simulation of aeronautical systems in a virtual World. They are based on two different flight dynamics methods, the Newtonian and the Computational Fluid Dynamics (CFD), each one with different capabilities. In the beginning of Aviation, airships were used to transport passengers but today the researchers are developing further studies regarding its flight capabilities. The goal of this article is survey the tools and methods to simulation a system and research the best platform to simulation a Rigid Hybrid Airship.

Keywords

Flight Simulation, PCATD, X-Plane, FlightGear, Prepar3DÂ®, MSFS, Airship

2. Evaluation of a Modular Hybrid Airship Design using CFD Techniques

ROYAL AERONAUTICAL SOCIETY

RAeS Aerodynamics Specialist Group

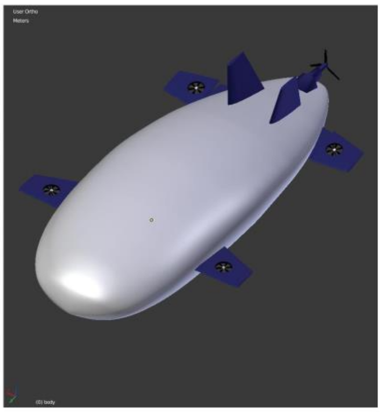
AERODYNAMICS TOOLS AND METHODS IN AIRCRAFT DESIGN

MONDAY 14 & TUESDAY 15 OCTOBER 2019 - LONDON

2.1) EVALUATION OF A MODULAR HYBRID AIRSHIP DESIGN USING CFD TECHNIQUES

New interest in airship technology has evolved in the last years particularly in design which combines buoyant lift with aerodynamic lift. Also, Computational Fluid Dynamics (CFD) has been increasingly used to evaluate new aircraft designs. Advancements in computational power allow aerodynamic data to be obtained at a lower cost than when using wind-tunnel or flight tests. Thenceforth, CFD emerges as the obvious option to validate and optimise a new modular hybrid airship design which prototype is under development. The estimated lift drag and moment coefficients of this prototype are the objectives of the study. The methodology, the mesh generation necessary, the CFD simulations of different configurations of the airship, including no aft wings and aft wings at various incidence settings at different angles of attack of the vehicle are presented in this work.

UNIVERSIDADE BEIRA INTERIOR · CERIS Civil Engineering Research and Innovation for Sustainability · ROYAL AERONAUTICAL SOCIETY · DCA DEPARTAMENTO DE CIÊNCIAS AEROESPACIAIS · NIT



Evaluation of a Modular Hybrid Airship Design using CFD Techniques

Luís G. Trindade[1,2], Laura N. Martins[1,2], João Neves[1,2], Jorge Silva[1,2], Francisco Brójo[1], Pedro V. Gamboa[1]

[1]Universidade da Beira Interior, Aerospace Science Department (DCA-UBI), Rua Marquês d'Ávila e Bolama, 6201-001, Covilhã, Portugal

[2]CERIS, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001, Lisboa, Portugal

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