DOTTORATO DI RICERCA IN INGEGNERIA DELL'INFORMAZIONE

CURRICULUM: TELEMATICA E SOCIETÀ DELL'INFORMAZIONECICLO XXIX

COORDINATOR Prof. Luigi Chisci

UNDERSTANDING THE IMPACT OF MEDIATED SUPPORT ON HUMAN PERFORMANCE: A TAXONOMY TO STUDY HUMAN-MACHINE INTERACTION IN FLIGHT PATH MANAGEMENT APPLICATIONS

SETTORE SCIENTIFICO DISCIPLINARE ING-INF/05

Candidate

Ana Ferreira

Supervisor

Prof.ssa Patrizia Marti

PhD Coordinator

Prof. Luigi Chisci

2013/2016

Università degli Studi di Firenze, Dipartimento di Ingegneria
dell'Informazione (DINFO)

Thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Information Engineering.

To my family

Abstract

Technological innovation in the aviation context poses increasing pressure on the human element, which is a key element for complex socio-technical systems. This reinforces the importance of considering human factors as central aspect of innovative technological transitions. The present work responds to an increasing need of tools to support systems' design and evaluation activities to ultimately optimise human performance.

The main aim of the present work was to develop a mediation classification capable of supporting the understanding of the impact of a system or function on human performance. A Mediated Support Taxonomy was developed building upon on augmented reality, teleoperation and automation classifications and applied in two different case studies. Both case studies involved human performance assessment of flight path management and navigation applications, one in flight deck context (ALICIA project) and other in Remotely Piloted Aircraft Systems applications (RAID demonstration activity). The application of the Mediated Support Taxonomy within the two previous case studies allowed to consolidate the taxonomy itself and to gather human performance benefits, issues and respective mitigations related to the different classification categories.

The present Taxonomy was deemed useful to perform the comparison of different applications providing different types of mediated support. The identification of human performance benefits and issues according to the different classification categories is helpful to understand the source of some of the issues and how to mitigate them.

Contents

Abstract 4
Abbreviations 9
Chapter 1. Introduction 13
1.1 Motivation and Problem Statement 14
1.2 Objective 17
1.3 Hypothesis 17
1.4 Thesis Overview 17
Chapter 2. Literature Review 21
2.1 Aviation as a complex socio-technical system 21
2.2 Evolution of pilot support on the Flight Deck 24
2.3 Remotely-Piloted Aircraft Systems (RPAS) 28
2.4 Mediated Support 31
2.4.1 Real and Virtual World Display Integration 31
2.4.2 Transportation and Artificiality 34
2.4.3 Automation 37
2.5 The Importance of Human Performance in Mediated Support 39
Chapter 3. Defining a Mediated Support Taxonomy for Aviation 47
3.1 Methodological Approach 47
3.2 Mediated Support Taxonomy definition 50
3.2.1 Rendering modality 51
3.2.2 Types of visual display 52
3.2.3 Visual Display Frame of Reference (FOR) 53
3.2.4 Augmented perception (Real and Virtual Integration) 55
3.2.5 Control-Display (C/D) Congruence 57
3.2.6 Automation Level 59
3.3 Mediated Support Taxonomy to be applied 69

Chapter 4. ALICIA project: Flight Deck Navigation Applications Case Study 71
4.1 ALICIA Project Background 71
4.2 Description of Applications and Functionalities 73
4.2.1 Gate-to-Gate application (G2G) 74
4.2.2 Weather Conflict Detection and Resolution application (Weather CD&R) 75
4.2.3 Synthetic Terrain Presentation application (STP) 78
4.2.4 Enhanced Synthetic Vision application (ESV) 79
4.2.5 Head Down Synthetic Vision System (Head Down SVS) 80
4.3 ALICIA Experimental Approach 82
4.3.1 Description of the simulation testbed 84
4.3.2 Methods 87
4.3.3 Participants 88
4.3.4 Scenarios 89
4.4 ALICIA Applications Results 92
4.4.1 Gate-to-Gate application (G2G) 92
4.4.2 Weather Conflict Detection and Resolution (Weather CD&R) 97
4.4.3 Synthetic Terrain Presentation application (STP) 103
4.4.4 Enhanced Synthetic Vision application (ESV) 107
4.4.5 Head Down Synthetic Vision System 110
Chapter 5. RAID project: RPAS Case Study 113
5.1 RAID Project Background 113
5.2 Description of Applications and Functionalities 114
5.2.1 RPAS Out-of-the-Window view application 115
5.2.2 RPAS Traffic Detect and Avoid (DAA) 115
5.3 RAID Experimental Approach 117
5.3.1 Ground Control Station description 119
5.3.2 Methods 123
5.3.3 Scenarios 124

5.4 RAID Applications Results 126
5.4.1 RPAS Out-of-the-Window view application 127
5.4.2 RPAS Traffic Detect and Avoid - Self-Separation functionality 130
5.4.3 RPAS Traffic Detect and Avoid - Collision Avoidance functionality 135
Chapter 6. Mediated Support Taxonomy Discussion and Consolidation141
6.1 Consolidation of the Mediated Support Taxonomy........................ 141
6.2 Discussion on the Mediated Support Taxonomy application 145
6.2.1 Rendering modality 145
6.2.2 Types of display 147
6.2.2.1 Head Up Displays.. 147
6.2.2.1.1 Head Up Display Identified Benefits....................................... 148
6.2.2.1.2 Head Up Display Identified Issues 148
6.2.2.2 Hand Held Displays... 149
6.2.2.2.1 Hand Held Displays Identified Benefits 149
6.2.2.2.2 Hand Held Displays Identified Issues...................................... 149
6.2.2.3 Head Down Displays 151
6.2.2.3.1 Head Down Displays Identified Benefits 151
6.2.2.3.2 Head Down Displays Identified Issues.................................... 151
6.2.2.4 Summary of the recommendations for different types of display151
6.2.3 Visual Display Frame of Reference (FOR) 155
6.2.3.1 3D Egocentric Display 156
6.2.3.1.1 3D Egocentric Display Identified Benefits 156
6.2.3.1.2 3D Egocentric Display Identified Issues.................................. 156
6.2.3.2 2D Map display.. 156
6.2.3.2.1 2D Map Display Identified Benefits.. 156
6.2.3.3 2D Coplanar Display 157
6.2.3.3.1 2D Coplanar Display Identified Benefits................................. 157
6.2.3.3.2 2D Coplanar Display Identified Issues 157
6.2.3.4 Combination of more than 2 types of displays 157

6.2.3.4.1 Combination of more than 2 types of displays Identified Benefits 157
6.2.3.4.2 Combination of more than 2 types of displays Identified Issues 157
6.2.3.5 Summary of the recommendations for Visual Display Frame of Reference (FOR) 158
6.2.4 Augmented Perception 161
6.2.4.1 Virtualization and Modelled Information 161
6.2.4.1.1 Virtualization and Modelled Information Identified Benefits.. 161
6.2.4.1.2 Virtualization and Modelled Information Identified Issues 162
6.2.4.2 Summary of the recommendations for augmented perception.. 162
6.2.5 Automation 164
6.2.5.1 Information Acquisition Automation Support (A)........................ 164
6.2.5.1.1 Information Acquisition Automation Support Identified Benefits 165
6.2.5.1.2 Information Acquisition Automation Support Identified Issues 165
6.2.5.2 Information Analysis Automation Support (B)............................ 165
6.2.5.2.1 Information Analysis Automation Support Identified Benefits 166
6.2.5.2.2 Information Analysis Automation Support Identified Issues ... 166
6.2.5.3 Decision and action selection automation support (C)............... 166
6.2.5.3.1 Decision and action selection automation support Identified Benefits 166
6.2.5.3.2 Decision and action selection automation support Identified Issues 166
6.2.5.4 Action Implementation automation support (D) 167
6.2.5.5 Summary of the recommendations for cognitive function supported by automation 169
Chapter 7. Conclusions... 175
References.. 179
Appendix A 183

Abbreviations

A/C- Aircraft

ACARE - Advisory Council for Aviation Research and Innovation in Europe

ACARS- Addressing and Reporting System

ADS-B - Automatic Dependent Surveillance - Broadcast

AP – Auto-pilot

ATC – Air Traffic Control

ATM- Air Traffic Management

C2 - Command and Control

C2L- Command and Control Link

CAT –Clear Air Turbulence

CB – Cumulonimbus

CD- Conflict Detection

CD&R- Conflict Detect and Resolution

CDTI – Cockpit Display of Traffic Information

CPDLC- Controller-Pilot Data-Link Communication

CR- Conflict Resolution

CWP – Controller Working Position

DAA – Detect and Avoid System

EFB - Electronic Flight Bag

E-OCVM - European Operational Concept

ESV- Enhanced Synthetic Vision

FFD- Forward Facing Display

FMS- Flight Management System

FOR - Frame of Reference

G2G - Gate-to-Gate

GCS- Ground Control Station

HDD - Head-down display

HF- Human Factors

HHD - Hand-held display

HMD - Head-Mounted display

HMI- Human-Machine Interface

HUD- Head-Up display

ICE – Icing

ILS- Instrument Landing System

LOA – Level of Automation

MFD – Multi-Function Display

OMA – Operational Manoeuvring Area

PF- Pilot Flying

PFD – Pilot Flying Display

PM- Pilot Monitoring

R&D- Research and Development

RPA- Remotely Piloted Aircraft

RPAS – Remotely Piloted Aircraft Systems

RTS- Real-Time Simulations

RV- Real Virtuality

SA- Situation Awareness

SD – Standard Deviation

SESAR -Single European Sky ATM Research

STP – Synthetic Terrain Presentation

TA – Traffic Advisory

TCAS- Traffic Alert and Collision Avoidance System

UAS – Unmanned Aircraft Systems

VA – Volcanic Ash

VLA – Very Light Aircraft

WAS – Weather Awareness System

Chapter 1. Introduction

The technological advancements both in Aviation and Air Traffic Management (ATM) domains have led and are still leading to an increased level of tool use and automation support. This means that human operators in these specific domains, will be interacting with their environment and performing tasks using increased means of mediation. We are talking about airborne or even ground technologies and interfaces that are significantly augmenting human capabilities. The way flight crews that are currently able to land airplanes in almost zero visibility conditions with the support of their on-board computers, or aircrafts being remotely piloted from a different location on the ground are good examples of the increasing levels of technological augmentation in aviation.

In the last years I had the opportunity to work in a number of different European projects, both within Aviation and ATM context. These projects allowed me to build an integrated vision of new operational tendencies in both domains, which was a main driver for the present work. The introduction of innovation in complex socio-technical and safety critical systems like ATM, as the name recalls, it is not a straight-forward process. Research and Development (R&D) in these fields are done very often within research projects, that develop in parallel several technologies and applications that together serve a common purpose. The technologies usually with different maturity levels, are developed by different partners and bringing together expertise from different domains, which poses a challenge.

1.1 Motivation and Problem Statement

The expected overall growth of air traffic combined with new demands for operational efficiency and cost reduction in aeronautical context, can increase the occurrence of events where operators' attention and performance levels are required at their best. Therefore, there is an increasing tendency towards the development of new solutions that aim at better supporting operators to manage their performance, both from the airborne side (flight deck) and from the ground side (Remotely Piloted Aircraft Systems or ATC).

Current flight decks incorporate several systems and applications that aim at providing increased support to flight crews and current R&D continues to bring new solutions towards more efficient and safer operations. However, having many dedicated support systems that at times are not really integrated, together more automation can potentially increase the complexity level in an already complex context, which might ultimately result in pilot confusion and leaving him out-of-the-loop. These innovative concepts and solutions (tools) are also increasing the gap between the operators and the activity being performed (higher mediation levels). New systems also tend to integrate new human-machine interaction modalities and this will ultimately affect (positively or negatively) the flight crews' performance and their roles.

At the same time, we are currently witnessing the fast growth of remotely piloted aircraft systems that are sharing the same airspace with civil aviation and other types of aircraft. These unmanned aircraft can have several applications and can be used in very different types of operations. Moreover, since they are being introduced in a safety-critical context, it is crucial to consider and assess human performance while piloting these aircraft.

SESAR high-level goals are to meet future traffic capacity, augment safety and shift from the local approach to an overall European management of the sky.

This vision is based on a notion of trajectory-based operations: therefore, this innovation will involve changes both from airborne and air traffic control side. This view is enabled and responds to a progressive and fast growth in the level of automation support, implementation of virtualisation technologies and the use of standardised and interoperable systems in both airborne and ground operations (European ATM Master Plan, 2015).

In 2013, a FAA specialized Flight Deck automation working group has reported that the role and requirements for pilots' knowledge and skills has not diminished over the years as a result of automated systems or modern flight deck design. Contrariwise, the working group reported that it has actually increased, given that the pilot not only needs to maintain their previous set of knowledge and skills, but now also needs to manage all the different systems at the same time (Figure 1). "Furthermore, pilots will need to continue to perform as a system of systems manager, with additional roles and responsibilities, while retaining basic cognitive and manual handling skills necessary for evolving and reversionary operations"(PARC/CAST, 2013).

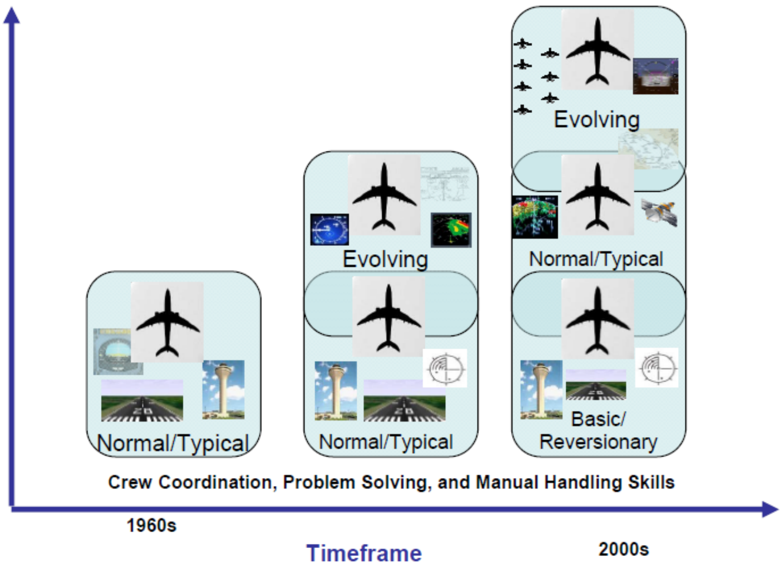


Figure 1 Pilot Knowledge and Skills Evolution over the years (PARC/CAST, 2013)

New technologies and new operational concepts, both airborne and ground, are a key step towards the transition to future airspace changes. This is the reason why it is extremely important to consider and study the impact of those concepts and changes for human performance, especially during early phases of the development and design process.

Introducing new types of displays, tools and automation in order to ultimately reduce mental workload and increasing the operators' Situation Awareness, can have also turn out to have the reverse effect on performance. This is the main reason why Human Factors and human performance expertise is being increasingly included in a multidisciplinary design and development processes. Therefore, the present work aims at responding to a growing need to consider the impacts of the higher levels of mediation on human performance. It will help to integrate and consolidate some of the work already performed in this field and at the same time to make some considerations towards the new types of technologies and concepts currently under development in aviation.

Several types of taxonomies have been used to classify different concepts that are sometimes hard to dissociate, namely, augmented reality, teleoperation and automation. Yet, there are some elements that compose each of these classifications that are important to consider at the same time, mainly because together they allow the definition of a mediation level and their impact on human performance. The taxonomy being proposed in thesis builds up on these approaches by combining some of their key elements, all based on some of the current trends of avionics innovation and ground support technologies.

1.2 Objective

The main aim of the present work was to develop a mediation classification capable of supporting the understanding of the impact of a system or function on Human Performance.

1.3 Hypothesis

The hypothesis of this research study are the following:

1. The taxonomy allows a meaningful classification of different aviation applications in terms of mediated support.
2. The use a of a Mediated Support Taxonomy supports the identification human-machine interaction issues and benefits related to a given application.
3. The classification of Mediated Support Taxonomy supports the post-analysis and systematization of human performance assessment results.

1.4 Thesis Overview

This thesis is organized around 7 chapters.

The first chapter introduces the motivation, objectives and hypothesis of the present work.

Chapter two, which corresponds to the Literature Review, presents the theoretical background of the work. It mainly focuses on the description of the application field and Aviation as complex socio-technical system. Some of the most relevant mediated interaction classifications (Augmented Reality, Telepresence and Automation) are presented along with their advantages and drawbacks. Following this part, the importance of Human Performance in Mediated Support is presented, along with the different impact factors that are relevant in the frame of this work.

Chapter three presents the overall methodological approach followed to define the Mediated Support Taxonomy. It describes the reasoning behind the choice of each of the categories that compose it.

Chapter four and five correspond to the application of the Mediated Support Taxonomy in the two different case studies, each developed within specific project and context. The first case study is based on ALICIA project flight path management and navigation supporting applications validation. The second case study is based on RAID project RPAS flight trials and Human Performance evaluation. The two case studies correspond to two different types of mediated support, since in the first the pilot is physically present in the aircraft and in the second the technologies and applications provide support to the pilot in flying the aircraft from the ground.

Chapter six discusses the results obtained on both case studies, presents recommendations for design and evaluation of interfaces that mediate human interaction along with the final consolidated Mediated Support Taxonomy.

A final section of conclusions, corresponding to chapter seven, summarises the main findings of the present work and some reflections for further research.

Chapter 2. Literature Review

2.1 Aviation as a complex socio-technical system

Aviation is considered a complex socio-technical system, since it consists of complex interactions between people and technology. Flying a commercial aircraft is not just about integrating pilots (Human) and the aircraft (Machine) to undertake the flight within the constraints imposed by the physical environment: it also involves aspects like the societal environment.

Socio-technical systems theories provide an explanation on how the different elements of a system interact in order to deliver specific operational and organisational goals (i.e. a safe flight). These theories provide an explanation of the supporting and shaping influences of different socio-technical elements (i.e. the environment, process and tools/information) on task activity.

Several different socio-technical models can be used to study the interaction between the different elements composing complex systems. SHEL is a socio-technical model that has been developed and widely used in the civil aviation domain, more specifically on the integration of the human factor in the technical parts of the system (Edwards, 1972, 1988).

From Edward's words, "System designers typically have at their disposal three types of resources. The first consists of physical property – buildings, vehicles, equipment, materials and so forth. This might be termed hardware. The second resource is much less visible, comprising the rules, regulations, laws, orders, standard operating procedures, customs, practices and habits, which govern the manner in which the system operates and in which the information within is organized. This is the software, much –but not all- of which will be set down in a collection of documents. Finally, human beings, or "liveware", make up the third resource. No arrangement of "hardware", "software" and "liveware" exists in vacuum. In reality, these resources will operate in the context of an environment made up of physical, economic, politic and social factors." (Edwards, 1988). With this model, Edwards emphasized the idea that the human factor (Liveware) cannot be studied in isolation from other system components, such as the material instruments (Hardware), the procedures and practices (Software).

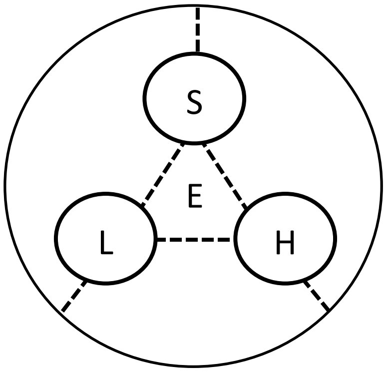


Figure 2 SHEL model (Edwards, 1988).

The interaction design activities undertaken from a Human Factors perspective normally centre the approach on the human operator in the system and from there, it starts looking into the several elements that interact with that human element.

Based on this previously presented model, in 1975 Hawkins developed SHELL. SHELL model places the focus on the Human Factor component, which is now represented in the centre and includes an extra "liveware" component. This way, the new model is able to represent the interaction, cooperation, teamwork between the operators involved in the process (Liveware-Liveware).

The simplified overview of complex socio-technical systems provided by SHELL model is applicable both within Aviation and ATM context. This model is important in the frame of this thesis because it stresses and acknowledges that the relative contribution of the different components/resources often varies. Even if each of the systems' components have reached a good level of reliability, undesired effects can still originate from the in-between interactions. Therefore, there is a need to assess the impact of the changes introduced by new elements because changes might bring either advantages or negatives effects to the overall process.

The SHELL model is one of the key HF models for aviation, widely used and referenced by most standards and guidelines, including ICAO Circular 216-AN31.

Still, one of the disadvantages of this model is how it fails to demonstrate that artefacts or tools often combine both software and hardware elements. Within this work, the "software" and "hardware" components of the tools (applications) are going to be distinguished, this way it is possible to clarify and to distinguish the impact of those elements in terms of human-machine interaction.

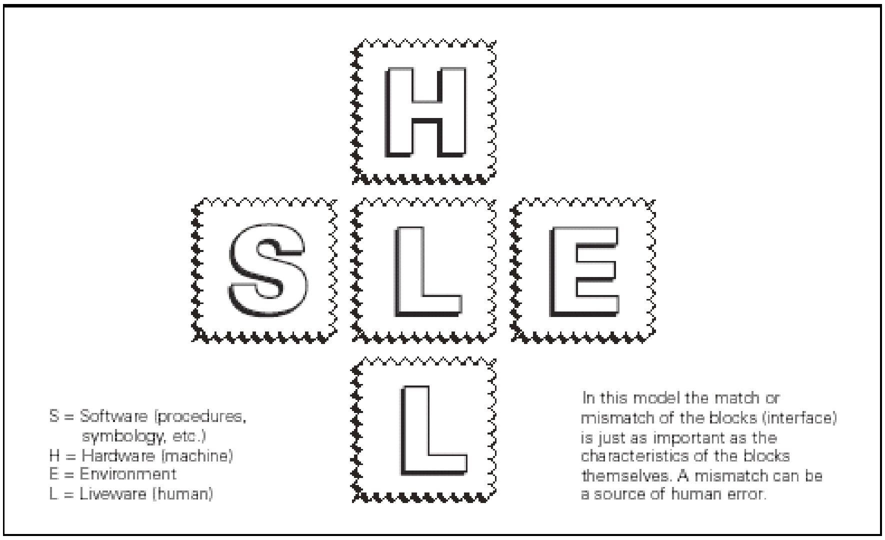


Figure 3 SHELL Model as modified by Hawkins (http://aviationknowledge.wikidot.com/aviation:shell-model)

2.2 Evolution of pilot support on the Flight Deck

In the last decades, the aviation domain has gone through quite some transformations including a gradual shift from mechanical to digital systems and the automation in support of both manual and mental workload.

In his book The Glass Cage: Automation and Us, Carr (2014) illustrated in detail the changes in the human-machine interaction process upon the introduction of the "glass cockpit" in the late 70's. In this work, he claimed that the changes brought by continuous automation and that characterise the new flight deck can turn out to be a glass cage. This highlights the importance of studying the impacts of these changes on human performance.

"To stop a bicycle, you squeeze a lever, which pulls a brake cable, which contracts the arms of a caliper, which presses pads against the tire's rim. You are, in essence, sending a command—a signal to stop—with your hand, and the brake mechanism carries the manual force of that command all the way to the wheel. Your hand then receives confirmation that your command has been received: you feel, back through the brake lever, the resistance of the caliper, the pressure of the pads against the rim, the skidding of the wheel on the road. That, on a small scale, is what it was like when pilots flew mechanically controlled planes. They became part of the machine, their bodies sensing its workings and feeling its responses, and the machine became a conduit for their will. Such a deep entanglement between human and mechanism was an elemental source of flying's thrill." He continue describing. "The A320's fly-by-wire system severed the tactile link between pilot and plane. It inserted a digital computer between human command and machine response. When a pilot moved a stick, turned a knob, or pushed a button in the Airbus cockpit, his directive was translated, via a transducer, into an electrical signal that zipped down a wire to a computer, and the computer, following the step-by-step algorithms of its software programs, calculated the various mechanical adjustments required to accomplish the pilot's wish. The computer then sent its own instructions to the digital processors that governed the workings of the plane's moving parts. Along with the replacement of mechanical movements by digital signals came a redesign of cockpit controls. The bulky, two-handed yoke that had pulled cables and compressed hydraulic fluids was replaced in the A320 by a small "sidestick" mounted beside the pilot's seat and gripped by one hand. Along the front console, knobs with small, numerical LED displays allowed the pilot to dial in settings for airspeed, altitude, and heading as inputs to the jet's computers."

Avionics and applications in todays' flight decks already include a fair amount of automation and the level of automation is expected to increase. This does not only apply to the aircraft systems themselves, but also to the many other technological tools that have been implemented additionally by each airline to increase its operational efficiency. This includes for example a more sophisticated Aircraft Communications Addressing and Reporting System

(ACARS), a better Controller-Pilot Data-Link Communication (CPDLC) or even an Electronic Flight Bag (EFB) that is making the cockpit a paperless workplace. The inclusion of some degree of automation is mostly considered helpful during normal operations, but sometimes during abnormal scenarios, pilots will have to deal with the situations without that same automated support. If automated systems in abnormal scenarios fail the pilot, he is left to deal with the situation by himself without the support he had been provided until then. It can be very challenging for humans to deal with these situations, these surprises may lead to errors and to consequent shorter safety margins.

In recent years, the concept of single pilot operations for large commercial aircraft has been receiving growing attention in the aviation community. This concept dates back to 2005 (Deutsch & Pew, 2005) and more recently researchers at the United States National Aeronautics and Space Administration (NASA) Ames Research Centre and Langley Research Centre are jointly investigating issues associated with single pilot operations. As part of their early efforts, these NASA researchers hosted a technical interchange meeting in 2012 in order to gain insight from members of the aviation community. A shared conclusion of this meeting was that ground personnel shall have a significant role in enabling this type of operations (Comerford et al., 2013). This will involve the development of an air-ground teaming, where a ground-based operator will deal with many of the traditional roles of the pilot monitoring.

The new operational concepts being considered for the coming years, like the one mentioned in the previous paragraph, emphasize that the changes in terms of aircraft flight path control will comprise more integration and interoperability between airborne and ground solutions.

Many of those new concepts being introduced focus on the support to navigation tasks. Navigation is defined as a category of crew tasks, which involve implementing flight plan(s) taking into account and avoiding potential environmental conflicts (weather, traffic, obstacles and terrain) during the whole duration of the flight. That special focus on this type of support depends on the fact that there are several situations (environmental or internal to the pilot) that can contribute to the loss of situation awareness during critical phases of flight (such as take-off and landing), and that these situations can have serious implications for flight safety.

Flight path management systems have significantly contributed to great achievements in terms of safety in the air transportation system over the years. However, despite the improvements, recent incident and accident reports suggest that flight crews continue to struggle in this type of tasks (PARC/CAST, 2013). Therefore, appropriate design and evaluation of new operational concepts are critical to ensure an adequate and effective implementation of this type of systems, as well as maintaining or improving future safety levels.

Systems and applications that allow a more strategic decision-making process encourage a more global awareness of environmental features that are relevant to flight path planning and navigation. Therefore, in order to integrate this strategic component to the navigational tasks, new applications are integrating new types of display and interaction capabilities. Advanced sensing, ADS-B traffic and satellite navigational systems are just some of the features which will ultimately enable a change in the way the pilot interacts with instruments and performs his activity (consequently changing the mediation level).

Some of those new concepts are still at early stages of development, therefore, this taxonomy is meant as an instrument to better understand the impact that those concepts will have in the future of pilots and operations.

2.3 Remotely-Piloted Aircraft Systems (RPAS)

Remotely-Piloted Aircraft Systems (RPAS) consist of a set of elements that include a Remotely-Piloted Aircraft (RPA) from a Ground-Control Station (GCS), the required C2 links and any other system elements as may be required at any point during flight operation.

RPAS are considered a class of Unmanned Aerial Systems (UAS) which have a 'pilot' operating, while the term UAS should be used for the autonomous air vehicles (no remote pilot). The term "drone" is widely used and can be applied to all types of UAS.

The beginning of UAS had a military background and started being used by the USA Air Force between 1964 and 1974 for strategical intelligence gathering in Vietnam conflict.

The capabilities that once supported exclusively military and defence purposes are being transformed for civil and commercial applications for some years now. The repurposing these technologies in civil applications made the drone market reach a fast growing rate, evolving with many different types of aircraft, each with their own specific characteristics and operational objectives.

A core component of these new capabilities and transformations is the collection of data from strategic vantage points that have been either inaccessible or too expensive to be economically viable today. UAS are also used for operations that entail monotony or a hazard for the pilot. The type of civil application for UAS typically include monitoring and surveillance tasks in border and maritime patrol, search and rescue, fishery protection, forest fire detection, natural disaster monitoring, contamination measurement, road traffic surveillance, power and pipeline inspection, and earth observation (ICAO, 2011).

The fact that the pilot is removed from the flight deck and is operating the aircraft by means of several supporting systems from another location is known to create some human performance challenges. In fact, according to Nullmeyer & Montijo (2009), RPAS have generally experienced a higher accident rate than conventionally piloted aircraft.

Enabling successful and safe operations beyond visual line of sight is considered one of the core factors that will unlock the potential of these technologies for the following years and this requires the availability of a variety of technologies.

Some of the main R&D priorities in ATM relate to developing solutions in order to successfully and efficiently integrate drones into all areas of the airspace (e.g. controlled and uncontrolled airspace) according to the types of mission performed. The efforts in order to meet these priorities include improving situation awareness for remote pilots until it matches the one from pilots in the flight deck and increasing the levels of automated flight (SESAR Joint Undertaking, 2016).

Shively, Hobbs, Rorie, & Lyall (2015) highlighted general human factors challenges present in RPAS flight operations, some of those main challenges are listed here below:

- Reduced sensory cues. The absence of these cues (visual, auditory, proprioceptive and olfactory sensations) or the transformation of those cues when operating a RPAS can make it more difficult for the pilot to maintain an awareness of the aircraft’s state. The location of the RPAS pilot remote from the aircraft may make pilot self-correction more difficult.

- Design of the GCS. The principles that guide CGS interface somehow different from the flight deck pilots', the remote pilot relies more on monitoring tasks or other tasks rather than pure aviation. Some RPS are already starting to resemble control rooms more than cockpits.

- Handovers. Handovers between pilots at the same CGS or between different GCS can involve some particular risks associated with system mode errors and coordination breakdowns.

- Self- separation and collision avoidance. In the absence of an out-the-window view, the pilot must rely on alternative sources of information, and is unable to comply with ATC visual clearances in the usual way. Therefore, the interaction with situational displays is very important not only for human performance but to maintain safe operations.

- Management of the command and control (C2) link. In addition to flying the aircraft the remote pilot must be aware of the current status of the control link, this will help them anticipate potential actions that might be required from their side according to the changes in the quality of the link along the flight progress.

- Workload Management. A challenge for the designer of a GCS is to maintain pilot engagement during extended periods of low workload, particularly when the pilot's role is to perform supervisory control of automation (Cummings, Mastracchio, Thornburg, & Mkrtchyan, 2013).

These and other RPAS human factors related topics will be addressed in more detail in the RPAS case study (Chapter 5).

2.4 Mediated Support

This sub-chapter introduces the key concepts that provide the background on the Mediated Support Taxonomy and that helped defining it, namely the concepts of augmented reality and virtuality, transportation and artificiality and automation.

In the frame of this work, mediated support is considered any type of tool-assisted perception, elaboration and control support provided to the human operator. The different concepts presented in this sub-chapter underline the idea that the human can be provided with different levels of support in the form of different types of tools, which ultimately change the way the he perceives and interacts with his immediate surroundings.

2.4.1 Real and Virtual World Display Integration

Augmented Reality (AR) technologies are able to provide an enhanced perception of the real-world environment by means of computer-generated sensory inputs. The reality enhancement is done by the coexistence of virtual elements with real ones which finally provide an enriched informational content in a given situation.

The improvement that the world witnessed in the latest years in terms of human-machine interaction allowed the transition of AR from the academic and research and development (R&D) context to consumer markets and real-world applications. Nowadays, the application of AR ranges from fields like design, engineering, training and education to various aspects of everyday life, being personal communication devices applications one of the most familiar example nowadays. Augmented reality (AR) technologies, which allow humans to enhance perception of their environment, are already very familiar in everyday tasks, like in personal mobile devices.

1. Augmented Perception of Reality- AR constitutes a tool for assisting decision-making. It can provide information which will enable a better understanding of reality and which will ultimately optimise our action on reality.

2. Artificial Environment- In the first functionality, AR enables objects, beings or relations which exist in reality but which cannot be perceived by users to be visualised.

Several classifications of Augmented Reality have been advanced throughout the years and they mainly differ in the criteria used to classify a given application. In 1998, Milgram grouped both AR and Augmented Virtuality (AV) and defined both with the term "Mixed Reality". AR implies being immersed in reality and handling or interacting with some virtual "objects", while AV implies being primarily immersed in a virtual world increased by reality where the user mainly manipulates virtual objects. The boundary between the two definitions is tenuous and is dependent on applications and usages, for this reason, the term "Mixed Reality" allows a less constrained definition of the mixture-modes between the poles of the Reality-Virtuality continuum.

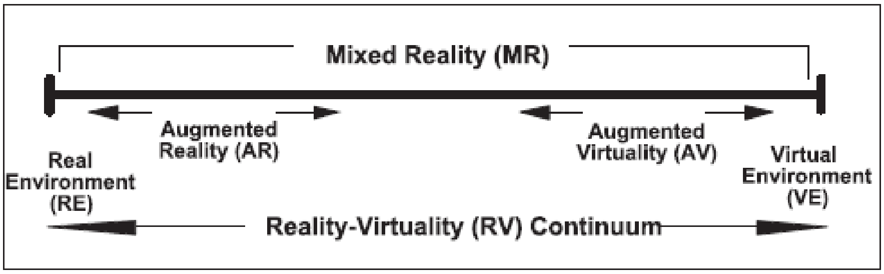


Figure 4 Definition of Mixed reality within the Reality-virtuality continuum (Milgram & Colquhoun, 1999)

The Reality-Virtuality continuum laid the groundwork for a global taxonomy of mixed reality display integration. This classification is based on three axis: (1) the reality-virtuality continuum; (2) the centricity of the type of display used (egocentric or exocentric) and (3) the congruency of the control-display mapping. However, this technique-centred taxonomy also revealed to have some drawbacks, mainly being a bit outdated in terms of not taking into account any of the mobile AR techniques currently being used and due to the use of the continuum notion instead of better clearly defined categories.

Hugues, Fuchs, & Nannipieri (2011) proposed a functional taxonomy of AR environments based on the nature of the augmented perception of reality offered by the applications on the artificiality of the environment. They presented the present taxonomy as more than a mere way to classify AR, considering it as a tool assisting the creation and design of virtual and augmented reality environments. Therefore, in their classification they proposed two main categories, augmented perception and artificial environment. The augmented perception consisted in five sub-functionalities: augmented documentation, reality with augmented perception or understanding, perceptual association of the real and virtual, behavioural association of the real and virtual, substitution of the real by the virtual or vice versa. The functionality to create an artificial environment was subdivided into three main sub-functionalities: imagine the reality as it could be in the future, imagine the reality as it was in the past and finally, imagine an impossible reality. The taxonomy presented some limitations, mainly in the artificial environment classification that did not take into account any alteration of the "present" reality only focusing on vision and covers only visual perception ignoring others senses.

Augmented reality experience is dependent on enabling technologies like computers, displays devices, tracking systems and interaction tools. The computer is responsible for creating virtual content and it manages the collimation of the virtual content and with the position of the observer with respect to the scene (information coming from the tracking system). The tracking system records the user spatial orientation in order to properly align the virtual image to the real one.

From all modalities in human sensory input, AR systems are most commonly implemented in visual, aural and haptic types of displays, being that visual sense and displays are the privileged enabling mean within AR technologies. Van Krevelen and Poelman (2010) reviewed recent applications of AR technologies and divided the different various implementations in three different categories of display devices (1) Head-mounted; (2) Hand-held; and (3) Spatial. There are control tools that are usually considered as input devices for the user such as touchpads or wireless devices.

2.4.2 Transportation and Artificiality

The concept of telepresence involves a user that experiences a remote physical space through computer and communication technologies. This often involves a remote user to view the space, to navigate the space and even to interact with objects in the space. Telepresence applications typically involve the creation of a physical proxy of the remote person in the form of a robot which has cameras attached to it and which may be able to move through the physical environment to varying degrees (Stone, 1991).

Telepresence is a field of research on its own that has a particular focus on areas and applications such as control of remote robots in hazardous or inaccessible environments and navigation through remote regions using mobile robots. In aviation, the concept of teleoperation has been applied in Remotely Piloted Aircraft Systems (RPAS) where a remote pilot can pilot aircraft from a ground-control station. This allowed aircraft operations in hazardous conditions that would be dangerous for traditional manned aircraft or human intervention, no wonder the first Unmanned Aircraft Systems (UAS) were developed with military as applications.

Benford, Brown, Reynard, & Greenhalgh (1996) proposed a classification of shared spaces that provides a clear understanding between the interactions of the user physical location versus the artificiality of the environment in which he is immersed. This classification introduced two main dimensions, the dimension of transportation and the dimension artificiality (see Figure 5).

The dimension of transportation spans from local to remote spaces. As one moves towards the totally transported extreme (remote physical environment), the immediate environment becomes less significant to the operator.

The dimension of artificiality spans between the extremes completely synthetic environments to completely physical environments, i.e. between the electronically mediated delivery of a physical place, firmly based in everyday reality, and the total synthesis of an environment independent of all external reality. Video conferencing is typical of the physical extreme (its information is all drawn from the real world), while abstract data visualisation or computer art exemplifies the synthetic extreme.

In tele-presence systems, users substitute (as much as is possible) their immediate surroundings for the representation of a remote but physically real location. In contrast, virtual reality environments tend to cut users off from their physical surroundings and, instead, immerse them in a wholly synthetic computer-generated environment.

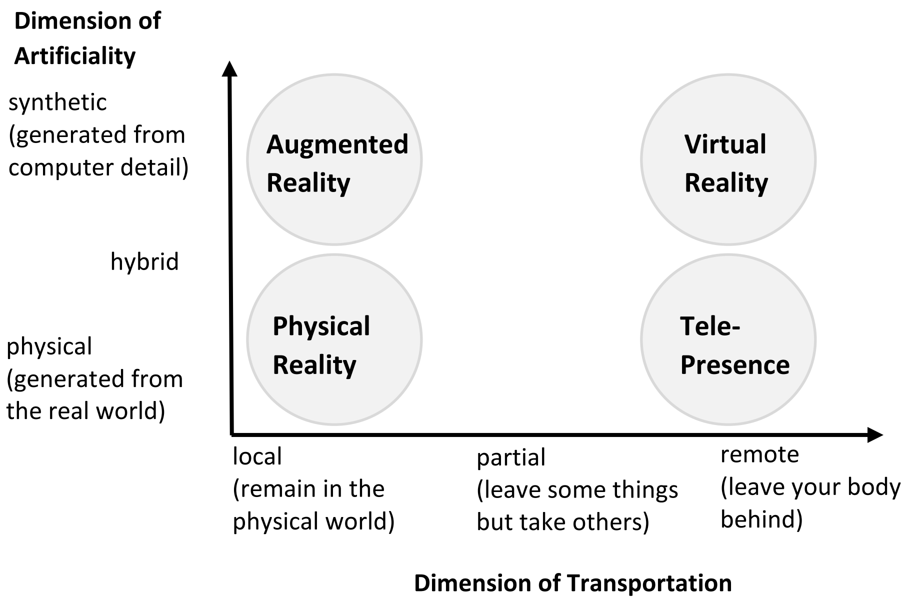


Figure 5 Classification of shared spaces according to transportation and artificiality (Benford et al., 1996)

The nature of the interfaces used may have a considerable effect on transportation. Projection based interfaces to virtual environments, whilst retaining their synthetic nature, open the user to greater local influence than immersive interfaces do, as their view is not isolated from the immediate physical context to the same extent (Benford, Brown, Reynard, & Greenhalgh, 1996). Immersive technology allows the user to experience the remote physical environment in a similar way that he would if he was physically present. In traditional cognitive currents, cognitive processing often is considered as separate from bodily mechanisms of sensory processing and motor control. More recently, a growing number of scientific studies, highlight the importance to investigate the consciousness to have a body and to interact with the environment through its action and consider the "Embodiment cognition approach". Embodied cognition aims to understand the full range of perceptual, cognitive, and motor capacities we possess as capacities that are dependent upon features of the physical body (Wilson, 2002; Borghi & Cimatti, 2010).

The idea behind embodied cognition is that cognition deeply depends on aspects of the agent's body, not exclusively on the brain. Without the involvement of the body in both sensing and acting, thoughts would be empty, and mental processes would not exhibit the characteristics and properties they do. Still, the comprehension of the person's perception, cognition and consciousness, during the natural interaction with the environment and with tools is yet a big challenge for cognitive psychology and neuroscience that will not be developed in detail in the present work.

2.4.3 Automation

Over the years, automation allowed the human to be replaced or aided in physically demanding tasks (Parasuraman & Riley, 1997). Fatigue and safety were some of the key reasons in support of automation, aiding or even replacing the human operators in some particular tasks that were too dangerous or nearly impossible to be performed. Frequently, automation is not replacing humans at all but aiding them to perform demanding tasks by extending human capabilities.

However, research on the impact of new technology proved that not all the expectations associated with automation were verified in real context, especially in complex systems. In complex systems, as the term already suggests, automation is not easy to implement and manage since tasks and activities are highly interdependent and coupled. Consequently, it is usual that not all of the anticipated benefits that were considered when deciding to automate one or more functions have in fact been verified.

Automation is a topic that has been studied widely, thus a variety of definitions of the automation concept have been developed. Billings (1997) defined automation as the use of machines to perform tasks previously done by humans. Another widely accepted definition of automation was proposed by Parasuraman and Riley (1997) who consider automation as a device or system that accomplishes (partially or fully) a function that was previously, or conceivably could be carried out (partially or fully) by a human operator. This definition implies that automation can't be seen in all or nothing terms, rather it can vary in degree across a range of levels (from a low level of automation to full automation). Moray, Inagaki and Itoh (2000) defined automation more specifically as "any sensing, detection, information-processing, decision making or control action that could be performed by humans but is actually performed by machines" (p.44). Finally and gathering the main ideas from each automation concept previously presented, it is possible to define automation as a partial or full replacement of the tasks that were previously performed by humans (e.g. sensing, detection, information-processing, decision-making, or action control) by machines. However, it is important to add that the introduction of automation does not imply only partial or full replacement of the former activity of a human operator. Hence, humans will always have a central role. The role of humans may take place in the flight deck. However, full automation concept may also result in human roles on the ground, rather than in the flight deck. Rather, the automation can also be responsible for completely new tasks, such as in the case of airborne automation performing self-separation manoeuvres. The self-separation manoeuvre is performed by automation but was not previously carried out by a human operator.

There was a time when it was assumed that new automation could replace human action without significantly impacting the system in which that action or task occurs, except in terms of output. This view was predicated on the notion that a complex system is decomposable into a set of essentially independent tasks (Parasuraman, Sheridan, & Wickens, 2000). When automation is introduced what happens is that there is a qualitative shift in the way people execute actions, rather than mere substitutions of pre-existing human tasks (Dekker & Woods, 2002). Consequently, automation can gives rise to other problems that are typically difficult to predict.

2.5 The Importance of Human Performance in Mediated Support

The success of the future Aviation and ATM depends on innovation and new concepts but also in how these innovations are introduced and managed along their life-cycle.

The operators are performing at the sharp end of complex systems in flight decks, ground control stations and in ATC. But, behind the scenes there are other groups of professionals that contribute more strategically to their final performance.

As mentioned in the white paper on Human Performance in ATM, understanding and managing human performance is critical for the integration of future concepts, no matter how advanced these concepts and systems become, because humans will remain in centre stage as the decision makers. The earlier human performance is considered in the life-cycle of a system, the easier it is to reach safety, capacity and efficiency benefits in a cost-effective way (FAA/EUROCONTROL, 2010). The costs of considering human performance in different phases of the system life-cycle is presented in the diagram below (Figure 6).

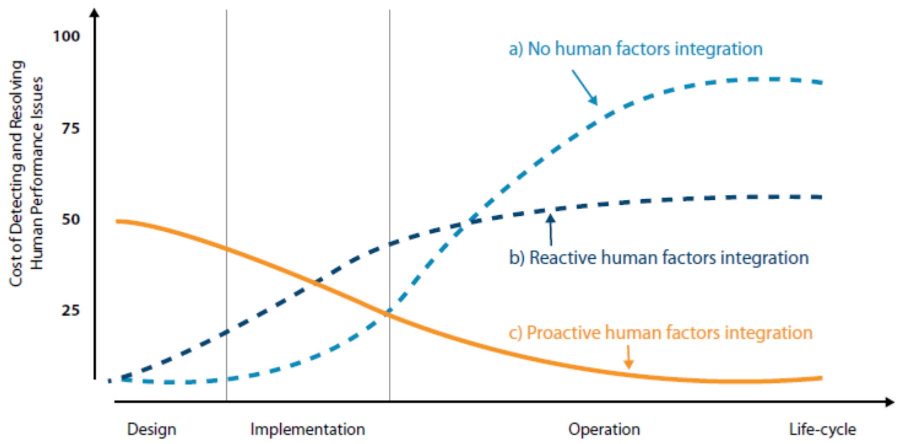


Figure 6 Cost scenarios of three different human performance implementation strategies (FAA/EUROCONTROL, 2010)

Increasing innovation and integration of advanced technology within complex systems stress even more the importance to identify and manage human performance related issues as early as possible.

Human performance can be defined as the extent to which goals for speed, accuracy, quality and other criteria are met by people functioning in their work environments.

In 2007, EUROCONTROL published the Human Factors Case, to facilitate managing Human Factors (HF) within the ATM context. It consists in a five-stage process to systematically identify and mitigate Human Factors Issues as early as possible in the project life-cycle. In other words, the HF Case is concerned with the ability of operators and maintainers to meet the system's performance standards, including reliability and maintainability, under the conditions in which the system will be employed.

This work introduced the “Human Factors Impacts”, the twelve impacts consist in factors that affect human performance in a significant way and they represent some of the most important concepts that are usually addressed in human factors (see figure below).

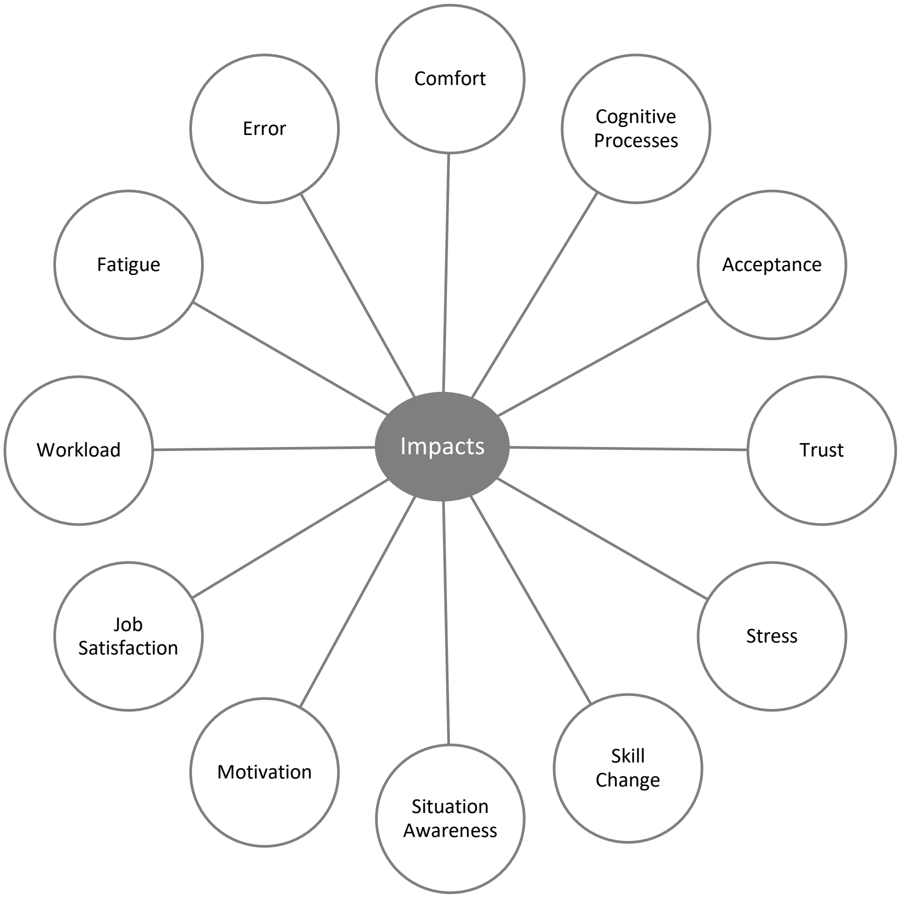


Figure 7 Human Factors Impacts (EUROCONTROL, 2007)

The Human Performance Impacts that are considered more relevant for the sake of the work presented in this thesis are detailed below.

Workload

Moray (1967) hypothesised that human beings have a central processor with limited processing capacity. Capacity would be allocated to diverse mental operations that would diminish the available potential, and allocation is subjected to task demand. Kahneman (1973) argued that there would be a limited reserve of capacity available for distribution, hence suggesting that performance would depend on the intensity of allocation and that at higher allocations, performance would not last as long. Management of “capacity” becomes then a performance issue, with poor management strategies leading to poor performance and good capacity management strategies enabling optimal efficiency with the same initial potential.

Sperandio (1977) witnessed changes in cognitive resource strategies when observing aircraft controllers confronted with an increasing number of aircraft to control, thus suggesting that operators never wait for extreme work demands to adapt their work strategy. Their objective is to minimize the impact on their invested resources, keeping them in a more comfortable zone.

The mental, sensorimotor and physiological demands on an operator are what Sperandio (1971) called workload. Even though workload studies started in the 1930s, there is no universally accepted definition of mental workload (Cain, 2007). Gopher and Donchin (1986) defined it as the measurement of the mental processing demands placed on a person during the execution of a task.

In the design of aviation systems, workload can also be operationally defined in terms of the memory load imposed by the system on the pilot, the number of mental transformations of data that the system requires, or how fast and accurately the task is performed (Cardosi & Murphy, 1995).

Situation Awareness

According to Endsley (1995), Situation Awareness (SA) is "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". In aviation this term usually refers to the pilots’ understanding of what is going on with the airplane, its systems and the conditions outside the aircraft (e.g. sudden closure of airspace along the planned route or the development of degraded environmental conditions like volcanic ash clouds or cumulonimbus). This definition underscores the importance of the HMI design in establishing SA: only if the relevant information is presented in a clear and unambiguous manner are the pilots able to process and understand the situation, as well as anticipate future events.

Fatigue

Fatigue is a multidimensional state that includes physical, mental and sleepiness-related components (Åhsberg, Garnberale, & Kjellberg, 1997). Fatigue is a gradual and cumulative process associated with an aversion for effort, sensation of weariness, reduced motivation, efficiency, vigilance and alertness, and impairments in task performance (Grandjean, 1970).

Stress

Generally stress affects how pilots perceive and process information, and the kind of decisions they make. Visual scan usually becomes scattered and poorly organized and the pilots may develop perceptual tunnelling (narrower field of vision, selective hearing). Stress also reduces the pilots' ability to detect automation failures (Ahlstrom & Longo, 2003). All of these may lead to an increase in the number of errors and, therefore, to increased accidents/incidents rates (Martinussen & Hunter, 2010).

Human Error

Reason (1993) defines the error as an incorrect action with a prior intention, and classifies types of errors according to the three modes of behaviour defined by Rasmussen (1986):

- In the "skill based" level are placed failures and lapses: These errors are characterized by a prior intention and an action plan, but the execution is incorrect. In the case of slip, poor execution of an action is due to a memory problem while for the failures, one or more actions planned are executed incorrectly. In both cases, it is the loss of attention that may explain these errors (Hoc, 1996).
- The "rule based" level errors come either from the misapplication of good rules (for example an unexpected unusual situation where the operator wants to apply a general rule) or the application of bad rules, because the situation was poorly defined or because the procedure is not optimal.
- In the "knowledge based" level, the errors are related to inadequate knowledge about the domain.

Cathelain (2005) clusters the causes of errors into two classes: the causes external to the operator and the internal causes. For external causes, we can mention for example the severity of the situation, a heavy workload, inadequate procedures, and inadequate human-machine interfaces. Internal causes may be due to poor awareness of the task, poor situational awareness, lack of vigilance, lack of experience and a lack or excess of confidence.

Trust

Muir (1987) defended that humans often have a similar attitude towards human-machine relations as they have towards human-human relations. This means, that the amount of trust placed into the cooperating agent (be it a human or a machine) depends on the experience the operator has made in the course of actions of the cooperative work. The four dimensions of trust proposed are the following (see Lee & Moray, 1992):

- Foundation of trust is what makes all other levels of trust possible. It reflects the “fundamental assumption of natural and societal order”;
- Performance of the agents represents expectations of “consistent, stable, and desirable performance or behaviour”;
- Process is a dimension that is influenced by the understanding the agent has about the “underlying qualities and characteristics that govern behaviour”;
- Purpose refers to the intentions and motives behind an agent’s behaviour.

While it might take a very long time for humans to figure the intentions of other humans’ behaviour, usually the intention or purpose of a certain machine is well known to begin with. Thus, the dynamics of the relationship can vary greatly between human-human and human-machine interaction. This is also due to the special role the human agent normally is assigned, namely the position of a supervisory controller.

Chapter 3. Defining a Mediated Support Taxonomy for Aviation

This chapter describes the overall methodological approach that was followed to define the Mediated Support Taxonomy and the categories that compose it.

3.1 Methodological Approach

The overall process carried out to achieve the proposed objective was organized around four distinct phases:

1. Mediated Support Literature Review

   This phase consisted in going through a good basis of taxonomies that are related to mediated support. The review covered taxonomies related to augmented reality, transportation, artificiality and automation taxonomies. A factor that was taken in consideration while reviewing the mediated support classifications was its relevance towards current design tendencies, both for airborne and ground concepts.

2. Definition a Mediated Support Taxonomy

   The selection of the single relevant categories from the analysed taxonomies during the review phase was done according to their potential impact on the human performance. But in order to understand if the categories that were chosen to define the Mediated support were really able improve the understanding on the human interacting with the system the taxonomy had to be applied.

3. Application of the Mediated Support Taxonomy

The Mediated Support Taxonomy was applied in two different case studies also representing two different contexts. The first, on flight deck navigation solutions and the second, for flight path management solutions for RPAS.

The two case studies contributed with two different mediation perspectives, since in one context the pilot is present in the flight deck and in the other, the pilot is physically removed from the aircraft he is controlling. The pilot being removed from the aircraft environment means that the applications that are supporting him performing his work must involve a higher mediation levels.

The application of the taxonomy in the two selected case studies served two distinct objectives:

- to understand if categories and scales that were defined as the Mediated Support Taxonomy were adequate to actually classify the applications developed in within the two different contexts;
- to associate the mediated support categories with the human performance benefits and issues that were assessed in ALICIA and RAID applications validation activities.

4. Discussion and Consolidation of the Mediated Support Taxonomy

The results of the Mediated Support taxonomy application to ALICIA and RAID technologies were discussed for each of the categories that compose the taxonomy. The goal was to assess if the categories defined were indeed sensible to discriminate the different applications in terms of human performance benefits and issues. This discussion resulted in a set of benefits, issues and mitigations associated to the different levels of mediation for each category of the classification.

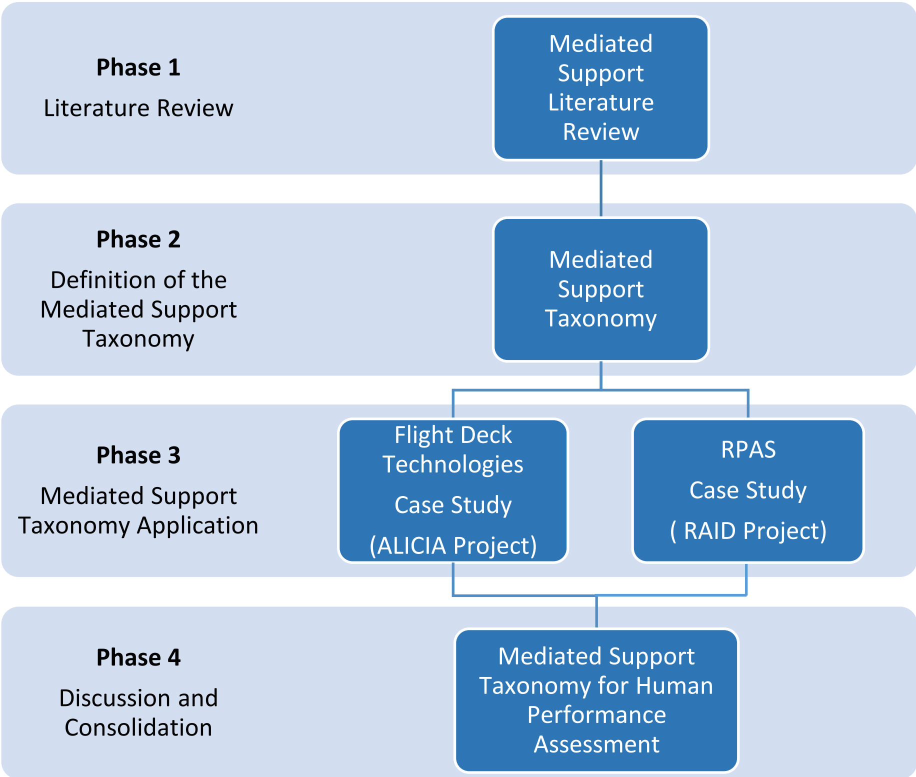


Figure 8 Overview of the methodological approach

3.2 Mediated Support Taxonomy definition

The present Mediated Support classification was elaborated by combining some elements coming from other classifications already introduced in the Literature Review chapter. Most of the classifications and taxonomies that were considered in order to define the Mediated Support Taxonomy were not specifically developed having in mind Aviation or ATM applications. But the single elements that were selected are relevant in the frame of applications and technologies that are currently being developed in these domains.

The following single elements from other mediation taxonomies or classifications were considered in the present work:

1. Rendering modalities;
2. Type of visual display;
3. Visual display frame of reference;
4. Augmented perception;
5. Control-display (C/D) congruence;
6. Level of automation.

The purpose of this taxonomy is to classify the level of mediated support in order to support the identification of potential human performance issues or benefits that can emerge from human-machine interaction. It is also useful in order to analyse and compare in more detail different types of mediation that new concepts or applications can integrate. It will help to identify the degree in which a task is mediated and it assumed that the higher the mediation, the more removed from the real physical environment the human is.

This classification is particularly useful to support Human Factors specialists in projects that involve new concepts of human-machine interaction, particularly that involve tools that increase the mediation in performing a task.

Summarizing, the present classification can provide support in the following activities:

- Analysis and comparison of different types of mediation that new concepts or applications can integrate;
- Identification of potential human performance issues or benefits that can emerge from technologies in terms of human-machine interaction;
- Definition of good practices, recommendations and requirements in terms of human-machine interaction design and evaluation.

3.2.1 Rendering modality

The rendering modality refers to the format in which the information is provided to the user.

Even though the majority of Augmented Reality applications rely mostly on the visual sense, they are not limited to it, other senses like hearing, touch and smell also play an important role in improving the sense of immersion and performance. That is why new solutions and technologies often use multimodal information to improve human performance, promoting workload reduction and increase situation awareness. Therefore, it is important to consider all the different possible rendering modalities in this taxonomy.

The term multimodal refers to combination of multiple modalities that the system responds to, the inputs can also be referred to as communication channels. The definition of these channels is inherited from human senses: Sight, Hearing, Touch, Smell, and Taste (Karray, Alemzadeh, Saleh, & Arab, 2008).

The olfactory and gustatory senses were not considered in this work because they are not explored in this specific domain of applications and are rarely used to augmented reality applications.

3.2.2 Types of visual display

Mediated support is always dependent on enabling technologies and different displays in order to combine the real and virtual worlds.

The type of display is considered a relevant criterion since it is closely related with the way the human interacts with the environment and how he feels involved in a certain physical environment (that can be local or remote). The type of displays used in new technologies being designed in aviation or ATM context play an important role at improving safety and situation awareness on threats along the different flight phases. For instance, Head-Up Displays in the flight deck are able to supplement the flight crew with additional synthetic information overlaid in the immediate physical surroundings.

There are sensors and different approaches to track user-vehicle position and orientation for an acceptable depiction of the virtual with the real elements and being able to display it. Since these technical elements are working on the background and are not directly impacting the operator interaction with the environment, they will were not be considered in the frame of the present proposed taxonomy.

The applications that are currently being used in the flight deck and being developed in aviation correspond to a limited set of visual displays. The types of visual displays considered relevant in the present taxonomy are presented in Table 1.

Table 1 Types of visual displays definitions

Definition of the types of visual displays	
Head-Mounted display (HMD)	A display that is worn on the head or as part of a helmet that projects the images (allows users to see through it).
Head-Up display (HUD)	A transparent display, sometimes windscreen, in which the information is projected and allows users to see through it.
Hand-held display (HHD)	A small display device with that is equipped with an operating system and is able to compute (e.g. mobile phone or tablet).
Head-down display (HDD)	A display that is positioned below or alongside the instrument panel.

3.2.3 Visual Display Frame of Reference (FOR)

It has been recognised that the visualisation viewpoint and the dimensionality while mixing real and virtual images can impact pilots' performance and cause some operational problems (Alexander & Wickens, 2005).

In 1999, Milgram & Colquhoun Jr. in their Real and Virtual World Display Integration Taxonomy defined the extent to which a human observer's viewpoint is removed from the human observer's viewpoint with a centricity continuum. The centricity continuum scale encompassed a variety of intermediate cases between two opposite perspectives, the egocentric perspective (local) and the exocentric perspective (global): 3D Ego-reference frame; 3D Tether; 3D World Reference Frame; 2D World Reference Frame.

Alexander & Wickens (2005) have treated very thoroughly the centricity topic with considerations with respect to interface design, most prominently in relation to aviation displays. In this work three types of frame of reference categories were analysed (Figure 9):

- 3D Displays;
- 2D coplanar displays;
- Split screen displays (combination of 2D and 3D frames of reference in a single display).

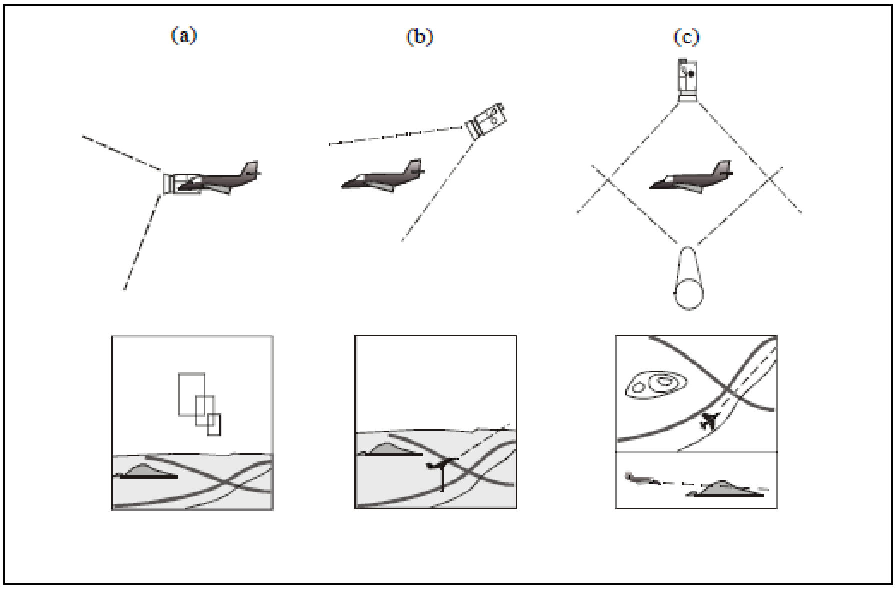


Figure 9 Three Frame of Reference (FORs) typically found in aviation displays (a) 3D egocentric or immersed, (b) 3D exocentric or tethered, (c) 2D coplanar (from Alexander & Wickens, 2005).

The different viewpoint or Frame of Reference (FOR) categories considered for the present taxonomy are presented in the table below and are based on Alexander & Wickens (2005) work.

Table 2 Visual display centricity categories (based on Alexander & Wickens, 2005)

Dimension	View	Description
3D Display	3D egocentric (immersed)	Depiction of the outside world as it would look from the pilot's position.
	3D exocentric (tethered)	Depiction of the outside world overlooking the "ownship".
2D Display	2D map view (rear-view)	Bi-dimensional top-down depiction (strategic).
	2D profile display (side-view)	Bi-dimensional longitudinal profile depiction.
	2D coplanar (map view + profile display)	Combination of 2 types of displays, top-down view and side-view.
2D + 3D Display	2D + 3D coplanar display	Combination of 2 types of displays (2D and 3D).

3.2.4 Augmented perception (Real and Virtual Integration)

Hugues et al. (2011) proposed a functional taxonomy of Augmented Reality environments (see sub-chapter 2.4.1) based on the nature of the augmented perception of reality offered by the applications on the artificiality of the environment. This classification considered two main categories, augmented perception and artificial environment, but for the purpose of this work only the augmented perception categories were considered. This is due to the artificial environment categories being focused on future or past realities concepts that do not apply to aviation tasks. A limitation of this taxonomy that is worth mentioning is that it focuses only on human visual perception only, ignoring others senses.

The Augmented Perception classification in this taxonomy considered seven sub-functionalities: (1) Documented Reality, (2) Documented Virtuality, (3) Augmented Comprehension, (4) Augmented Visibility, (5) Perceptual Association, (6) Real replaced by Virtual and (7) Behavioural association.

Table 3 Augmented Reality Taxonomy: Technologies and Features of Augmented Environment (Hugues et al., 2011)

Augmented Perception of Reality		
1. Documented Reality	Augmentation consists of informing users without the mediation of a technical device e.g. an assembly manual for kit furniture.	
2. Documented Virtuality	Real time incorporation of one or several windows displaying real parts of the process (documented images of the real object).	
3. Augmented Comprehension	This involves augmenting the understanding of images from the real scene by incrusting passive semantic information e.g. Virtual information (titles, keys, symbols, etc.), more or less visually close to real objects, providing complementary information.	
4. Augmented Visibility	Augmentation image visibility from real scenes (if we limit ourselves to visual perception).	
5. Perceptual Association (virtual objects are added to the real scene)	5.1Incrustation	Virtual objects are incrusted (overlaid) on top of real objects. Therefore, virtual objects are not concealed by

		real objects (association by superposition).
	5.2 Integration	Virtual objects are integrated with real objects. The latter conceal virtual objects which are positioned behind them (3D association).
6. Real replaced by virtual	Geometrical modellisation of the real scene observed. Replacing the video image display for the real scene by the synthetic image of the model, determined from the same point of view.	
7. Behavioural Association	Semantically modellise virtual objects by taking into account their physical properties according to the laws of gravity, contact, elasticity, fluidity, etc. so as to enrich the scene.	

3.2.5 Control-Display (C/D) Congruence

Milgram & Colquhoun Jr. (1999) in their Taxonomy of Real and Virtual World Display Integration introduced a Control-Display (C/D) Congruence Continuum. Being congruence the degree in which the control-display position and orientation allows the user a natural, or intuitive control scheme. An incongruent relationship will compel the user to perform a number of mental transformations in order to use it (see Figure 10).

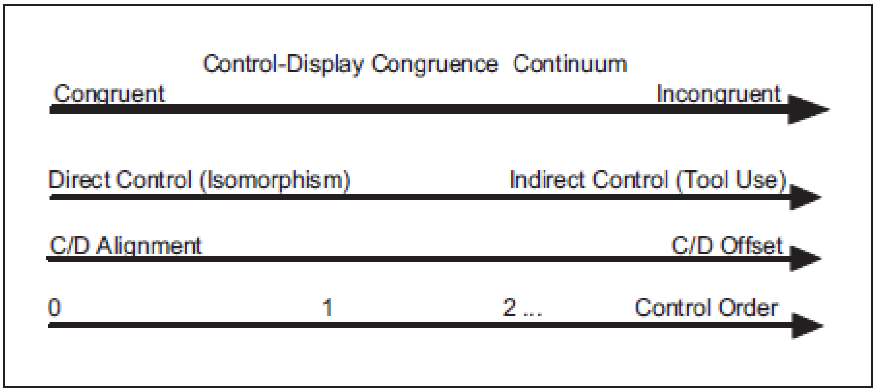


Figure 10 Control-Display (C/D) Congruence Continuum (Milgram & Colquhoun Jr., 1999)

Milgram & Colquhoun Jr. (1999) considered directness, whether the user's control actions map directly onto the display space or whether some real or metaphorical device lies between the user and the environment (indirect), to be the most encompassing factor on the Control-Display (C/D) Congruence Continuum. Based on this idea, the mediation at action implementation in terms of the directness and Control/Display (C/D) Alignment are important concepts to consider together.

The Control/Display (C/D) offset refers to a displacement between the location of the control device and the corresponding controlled object. A completely aligned mapping therefore corresponds to direct control.

For this taxonomy, the following Control-Display Congruency categories were created to be included in the taxonomy.

Table 4 Control-Display (C/D) Congruence

Control-Display (C/D) Congruence categories definition	
Indirect control with C/D offset	The system supports the control with a software-based tool in which the control space does not coincide with the display. The movements do not map directly onto the direction of the action being controlled on the display (control reversals).
Indirect control with C/D Alignment	The system supports the control with a software-based tool in which the control space does not coincide with the display. The movements map directly onto the direction of the action being controlled on the display.
Direct Control on the display	The system supports the control with a software-based tool that is in which the control is located in same display space (direct control) (e.g. touchscreen).

3.2.6 Automation Level

In specifying which entity (human or computer) is responsible for each system function, Sheridan and Verplanck (1978) described ten Levels of Automation (LOAs) for an underwater telerobot control, ranging from manual control (Level 1) to full automation (Level 10), including intermediate levels that blend human and computer control. As shown in Table 5, the mid-level in Sheridan and Verplanck's taxonomy involves the computer suggesting to a human a decision alternative and the computer executing the suggestion if the human approves. Higher intermediate LOAs involve human veto of computer decisions or automated system operation with feedback to the human upon request.

Table 5 Levels of Automation of Decision and Action Selection (Sheridan & Verplanck, 1978)

High	10.The computer decides everything, acts autonomously, ignoring the human
	9.The computer informs the human only if it, the computer, decides to
	8.The computer informs the human only if asked
	7.The computer executes automatically, then necessarily informs the human
	6.The computer allows the human a restricted time to veto before automatic execution
	5.The computer executes that suggestion if the human approves
	4.The computer suggests one alternative
	3.The computer narrows the selection down to a few
	2.The computer offers a complete set of decision/action alternatives
Low	1.The computer offers no assistance: human must take all decisions and actions

Parasuraman, Sheridan, & Wickens (2000) developed a model that demonstrates the correspondence between the human stages of information processing and system functions (Figure 11).

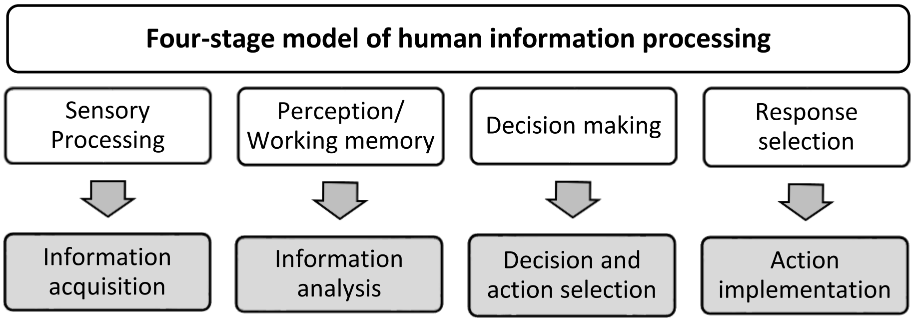


Figure 11 Four stage model of system functions equivalent to human functions that can be automated (Parasuraman, Sheridan, & Wickens, 2000)

Each of these stages represented in the table above and their associated system function can be automated:

A) Information acquisition

Automation in information acquisition replaces many cognitive processes of human selective attention, operations equivalent to the first human information processing stage, supporting human sensory processes and registration of input data. Examples of automation may involve organization of incoming information according to criteria, highlighting and filtering information.

B) Information analysis

Automation of information analysis involves cognitive functions such as working memory and inferential processes. Information analysis serves the purpose of augmenting human perception and cognition. With increasing level of automation we can have in situation assessment, integration and information managers.

C) Decision and action selection

The third stage, decision and action selection, involves selection from among decision alternatives. Automation of this stage involves varying levels of augmentation or replacement of human selection of decision options with machine decision making.

D) Action implementation

Automation at this stage involves different levels of machine execution of the choice of action. Different levels of machine execution may be defined by the relative amount of manual versus automatic activity in executing the response. Higher automation in execution usually replaces the hand or voice of the human.

The figure below (Figure 12) represents a graphical comparison between two different systems using the Level of Automation model from Parasuraman et al. (2000).

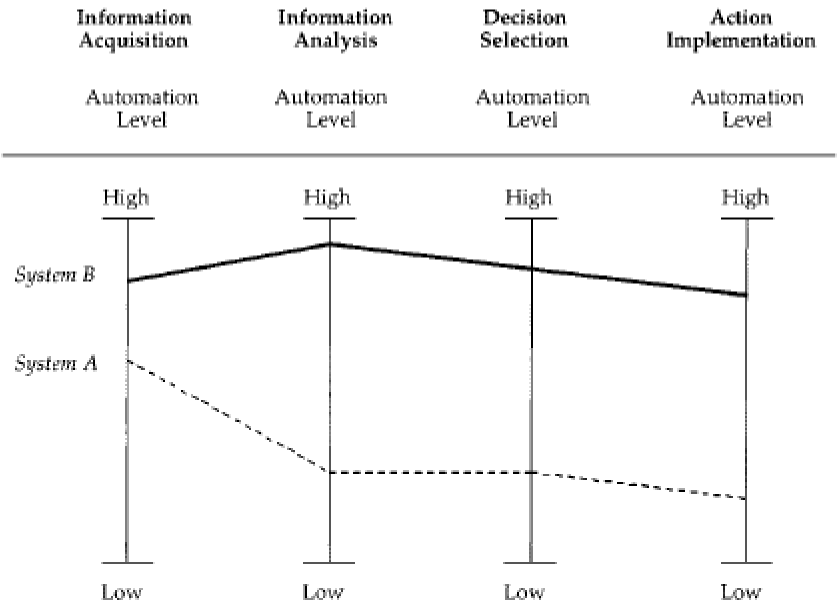


Figure 12 Graphical model of Levels of Automation differentiated by cognitive functions (Parasuraman et al., 2000)

The Level of Automation Taxonomy (LOAT) proposed by Save & Feuerberg (2011) adapted the four human cognitive functions matrix structure used by Parasuraman et al. (2000) into a specific set of automation levels for each of the human cognitive functions. This taxonomy has been developed in the ATM context but it is applicable to other domains.

Considering the different cognitive functions can be helpful in differentiating the subtleties between the support offered to the human operator in terms of different types of application and display types (see Table 6). For this reason the Save & Feuerberg (2011) Level Automation Taxonomy (LOAT) was considered to be more accurate to classify the automation levels and was integrated in the Mediated Support Taxonomy.

Table 6 Level of Automation Taxonomy (LOAT)(Save & Feuerberg, 2011)

A Information Acquisition	**B Information Analysis**	**C Decision and Action Selection**	**D Action Implementation**
A0 Direct Information Acquisition	B0 Human Info Analysis	C0 Human Decision making	D0 Manual Action and Control
The human acquires relevant information on the process s/he is following without using any tool.	The human compares, combines and analyses different information items regarding the status of the process s/he is following by way of mental elaborations. S/he does not use any tool or support external to her/his working memory.	The human generates decision options, selects the appropriate ones and decides all actions to be performed.	The human executes and controls all actions manually.
A1 Artefact-based Info Acquisition	B1 Artefact-based Info Analysis	C1 Artefact-based Decision Making	D1 Artefact-based Control
The human acquires relevant information on the process s/he is following with the support of low-tech non-digital artefacts.	The human compares, combines, and analyses different information items regarding the status of the process s/he is following utilising paper or other non-digital artefacts.	The human generates decision options, selects the appropriate ones and decides all actions to be performed utilising paper or other non-digital artefacts.	The human executes and controls actions with the help of mechanical non-software based tools.
A2 Low-Level Automation Support of Info Acquisition	B2 Low-Level Automation Support of Info Analysis	C2 Automated Decision Support	D2 Step-by-step Action Support
The system supports the human in acquiring information on the process s/he is following. Filtering and/or highlighting	Based on user's request, the system helps the human in comparing, combining and analysing different information items	The system proposes one or more decision alternatives to the human, leaving freedom to the human to	The system assists the operator in performing actions by executing part of the action and/or by providing guidance

of the most relevant information are up to the human.	regarding the status of the process being followed.	generate alternative options. The human can select one of the alternatives proposed by the system or her/his own one.	for its execution. However, each action is executed based on human initiative and the human keeps full control of its execution.
A3 Medium-Level Automation Support of Info Acquisition	B3 Medium-Level Automation Support of Info Analysis	C3 Rigid Automated Decision Support	D3 Low-Level Support of Action Sequence Execution
The system supports the human in acquiring information on the process s/he is following. It helps the human in integrating data coming from different sources and in filtering and/or highlighting the most relevant information items, based on user's settings.	Based on user's request, the system helps the human in comparing, combining and analysing different information items regarding the status of the process being followed. The system triggers visual and/or aural alerts if the analysis produces results requiring attention by the user.	The system proposes one or more decision alternatives to the human. The human can only select one of the alternatives or ask the system to generate new options.	The system performs automatically a sequence of actions after activation by the human. The human maintains full control of the sequence and can modify or interrupt the sequence during its execution.
A4 High-Level Automation Support of Info Acquisition	B4 High-Level Automation Support of Info Analysis	C4 Low-Level Automatic Decision Making	D4 High-Level Support of Action Sequence Execution
The system supports the human in acquiring information on the process s/he is following. The system integrates data coming from different sources and filters and/or highlights the information items which are	The system helps the human in comparing, combining and analysing different information items regarding the status of the process being followed, based on parameters pre-defined by the user. The system triggers visual and/or aural	The system generates options and decides autonomously on the actions to be performed. The human is informed of its decision.	The system performs automatically a sequence of actions after activation by the human. The human can monitor all the sequence and can interrupt it during its execution.

considered relevant for the user. The criteria for integrating, filtering and highlighting the relevant information are predefined at design level but visible to the user.	alerts if the analysis produces results requiring attention by the user.		
A5 Full Automation Support of Info Acquisition	B5 Full Automation Support of Info Analysis	C5 High-Level Automatic Decision Making	D5 Low-Level Automation of Action Sequence Execution
The system supports the human in acquiring info on the process s/he is following. The system integrates data coming from different sources and filters and/or highlights the information items considered relevant for the user. The criteria for integrating, filtering and highlighting are predefined at design level and not visible to the user	The system performs comparisons and analyses of data available on the status of the process being followed based on parameters defined at design level. The system triggers visual and/or aural alerts if the analysis produces results requiring attention by the user.	The system generates options and decides autonomously on the action to be performed. The human is informed of its decision only on request. (Always connected to an Action Implementation level not lower than D5.)	The system initiates and executes automatically a sequence of actions. The human can monitor all the sequence and can modify or interrupt it during its execution.
		C6 Full Automatic Decision Making	D6 Medium-Level Automation of Action Sequence Execution
		The system generates options and decides autonomously on the action to be performed without informing the human. (Always connected to an Action	The system initiates and executes automatically a sequence of actions. The human can monitor all the sequence and can interrupt it during its execution.

		Implementation level not lower than D5.)	
			D7 High-Level Automation of Action Sequence Execution
			The system initiates and executes a sequence of actions. The human can only monitor part of it and has limited opportunities to interrupt it.
			D8 Full Automation of Action Sequence Execution
			The system initiates and executes a sequence of actions. The human cannot monitor nor interrupt it until the sequence is not terminated.

3.3 Mediated Support Taxonomy to be applied

This sub-chapter provides an overview of the Mediated Support Taxonomy as well as the scales that compose it. The categories and scales that are part of it have been described individually in the previous sub-chapter.

Table 7 Defined Mediated Support Taxonomy

<table>
<tr><th colspan="12">Mediated Support Taxonomy</th></tr>
<tr><td colspan="12">1. Rendering Modality(ies)</td></tr>
<tr><td colspan="4">Visual</td><td colspan="4">Auditory</td><td colspan="4">Tactile</td></tr>
<tr><td colspan="12">2. Types of display</td></tr>
<tr><td colspan="3">Head-Up Display (HUD)</td><td colspan="3">Head-Morn Display (HMD)</td><td colspan="3">Hand Held Display (HHD)</td><td colspan="3">Head-Down Display (HDD)</td></tr>
<tr><td colspan="12">3. Visual Display Frame of Reference (FOR)</td></tr>
<tr><td colspan="4">3D Single Display</td><td colspan="5">2D Single Display</td><td colspan="3">Combined displays</td></tr>
<tr><td colspan="2">3D egocentric (immersed)</td><td colspan="2">3D exocentric (tethered)</td><td colspan="2">2D map view (rear-view)</td><td colspan="2">2D profile display (side-view)</td><td>2D coplanar display</td><td colspan="3">2D + 3D display</td></tr>
<tr><td colspan="12">4. Augmented Perception (Real-Virtual Integration)</td></tr>
<tr><td colspan="2">Documented Reality</td><td colspan="2">Documented Virtuality</td><td colspan="2">Augmented Comprehension</td><td colspan="2">Augmented Visibility</td><td colspan="2">Perceptual Association</td><td colspan="2">Behavioural Association</td></tr>
<tr><td colspan="12">5. Control-Display (C/D) Congruence</td></tr>
<tr><td colspan="4">Indirect control with C/D offset</td><td colspan="4">Indirect control with no C/D offset</td><td colspan="4">Direct Control on the display</td></tr>
<tr><td colspan="12">6. Automation Level</td></tr>
<tr><td colspan="3">A
Information Acquisition</td><td colspan="3">B
Information Analysis</td><td colspan="3">C
Decision and Action Selection</td><td colspan="3">D
Action Implementation</td></tr>
</table>

A0 Direct Information Acquisition	B0 Human Info Analysis	C0 Human Decision making	D0 Manual Action and
A1 Artefact-based Info Acquisition	B1 Artefact-based Info Analysis	C1 Artefact-based Decision Making	D1 Artefact-based Control
A2 Low-Level Automation Support of Info Acquisition	B2 Low-Level Automation Support of Info Analysis	C2 Automated Decision Support	D2 Step-by-step Action Support
A3 Medium-Level Automation Support of Info Acquisition	B3 Medium-Level Automation Support of Info Analysis	C3 Rigid Automated Decision Support	D3 Low-Level Support of Action Sequence Execution
A4 High-Level Automation Support of Info Acquisition	B4 High-Level Automation Support of Info Analysis	C4 Low-Level Automatic Decision Making	D4 High-Level Support of Action Sequence Execution
A5 Full Automation Support of Info Acquisition	B5 Full Automation Support of Info Analysis	C5 High-Level Automatic Decision Making	D5 Low-Level Automation of Action Sequence Execution
		C6 Full Automatic Decision Making	D6 Medium-Level Automation of Action Sequence Execution
			D7 High-Level Automation of Action Sequence Execution

Chapter 4. ALICIA project: Flight Deck Navigation Applications Case Study

This chapter starts by providing an overview of the ALICIA project. It includes the description of the flight path management and navigation supporting applications developed during the project duration, and the experimental approach followed during the evaluation of these applications. Finally, the chapter ends with the applications classification according to the Mediated Level Taxonomy along with the respective associated benefits and issues for human performance.

4.1 ALICIA Project Background

ALICIA was a R&D project co-founded by European Commission under the Seventh Framework Programme. The main aim was to develop a new and scalable set of cockpit applications, which can extend operations of aircraft in degraded conditions, allowing this way “All Condition Operations”. Not only the delivery of applications will enable operations in all weather conditions but it also can reduce the risk the air transport delays.

This will necessarily entail a new cockpit infrastructure capable of delivering enhanced human-machine interaction in different aircraft types (supporting better crew Situation Awareness whilst simultaneously reducing crew workload and improving overall aircraft safety). During this project the technologies were developed to integrate both airplane and helicopter flight decks.

The project also aimed at contributing to the capability to develop new technologies for the flight deck that embrace more standardisation and commonality across different aircraft types, mainly commercial airplanes and helicopters.

ALICIA future flight-deck concepts and solutions also aimed at introducing more robust operations in all weather conditions, thus supporting significant improvements in time efficiency for the future air transport system.

These new concepts and technologies particularly support different flight phases by allowing a more strategic surveillance of the aircraft environment (e.g. support the anticipation of weather-related phenomena information), enhanced flight path management and navigation. The flight phases in which pilots' workload level tend to achieve highest levels (take-off, approach, landing and taxi) was especially emphasized in terms of technological support.

The common elements that guided the technologies developed in this project were the following:

- **Support to Situational Awareness.** Achieved by means of applications that adequately support the crew in building a good and timely mental picture of the situation with minimal effort. These applications support flight path management and navigation by providing the crew with future weather and conflict data that might occur along the flight plan.

- **Improve the decision support.** The support to crew's decisions was considered an important premise in the project. This support was mainly provided by aggregating data that can usually be found in different systems and interface (consequently, the information can be found in different locations) in a single application or dedicated interface.

- **Automation of some functions.** Increased levels of cockpit automation emphasize pilots' supervisory role that has to manage a considerable number of systems while maintaining a good situation awareness of what is going on outside the aircraft. Some technologies helped the flight crew to focus their mental resources on more critical tasks by partially automating and simplifying others. This way the flight crew can better manage their time and cognitive resources e.g. by automatically downlinking flight plans for ATC approval or asking for a flight plan proposal to avoid weather phenomena, the pilot can save some resources in asking for the same via voice communication.
- **Human-Machine Interface.** The use of touchscreen interaction was considered for most technologies and applications. This type of interaction was considered because it is believed to allow a more intuitive kind of interaction while enabling a better situation awareness. The aggregation of related information in the same interface according to the phase of the flight was included as a solution for some of the new applications developed. Different types of displays were used to enable some of the developed applications, these include "eyes-out" technologies such as Head-Up displays (HUD) or Head Mounted Displays (HMD) and "eyes-in" technologies with the Hand-Held display (HHD) and Head Down Displays (HDD).

The present case study reports on the results of a commercial flight human-in-the-loop simulation carried out at Thales Avionics, focusing on the human-machine interaction and performance with the developed ALICIA applications.

4.2 Description of Applications and Functionalities

Not all of the technologies developed and evaluated within ALICIA project to improve all weather operations are addressed in the current Flight Deck case study. This was mainly due to some limitations either on the quality of the evaluations of some technologies and the sample of subjects that were part of the assessment.

The applications and functionalities presented here below support the navigation task during different phases of the flight and aim at improving the operator awareness on the surrounding environment.

4.2.1 Gate-to-Gate application (G2G)

The G2G application provides pilots with a depiction of an airport moving map that allows navigation guidance on ground during taxi operations. The application runs on a tablet (touchscreen display) with a 2D map view of the airport, allowing the pilots to visualize information features such as terminals, buildings, taxiways and runways. This is done using a high precision Aerodrome Mapping Database containing all relevant airport geometry and the corresponding intelligent information such as features and attributes. The moving map depiction shows the moving aircraft positioning on the airport.

Once the ATC communicates to the pilot (PM) the cleared taxi instructions, he must insert them via manual input on the tablet and the cleared taxi route segment is then displayed both in the 2D map and in textual format. The respective areas are depicted in an amber-like colour on the electronic chart. If an airspace restriction becomes active, its colour changes from a pale amber to an intense amber. So it is possible that its state changes right at the time when the aircraft is abeam that airspace and it is visible on the display.

The support is mainly provided during the taxi route planning, to set the cleared taxiway during departure, arrival and then on taxi phase. The application was developed to particularly assist the flight crew under low visibility conditions. The Pilot Monitoring (PM) informs the Pilot Flying (performing the taxiing) about incoming hotspots during the overall taxi route (e.g. runway cross, intersection, heading and distance to the next change in direction, and progression with regard the overall taxi route).

This application has been developed by Jeppesen.

Figure 13 Gate-to-gate application (tablet)

4.2.2 Weather Conflict Detection and Resolution application (Weather CD&R)

The Weather Conflict Detection and Resolution (Weather CD&R) application displays the weather situation around the aircraft and identifies current and potential future threats along a 4D flight path provided by the Flight Management System (FMS) and gives a measure of confidence based on probabilistic methods. The weather events are displayed on a big strategic navigation display placed between the two flight crew members, it combines a 2D map view display with a 2D side-view display (vertical profile display). Therefore, providing the pilots a strategic weather situation view along the flight path, both on the map and on the vertical display. The weather events supported the visualization of cumulonimbi (CB), icing areas (ICE), clear air turbulence (CAT) and volcanic ash (VA). The events provided by the application are based on recorded ground meteorological data that is uplinked to the a/c and they are intended to complement the existing weather information on the on-board radar.

Once all potential weather threats are processed, the Conflict Detection (CD) provides the crew with the distance and time to a potential future conflict. The system generates aural alerts inside the flight deck when hazardous weather threats interfered with the own flight plan, advising the crew on the situation and providing them conflict point and no-go zones. The conflict points are not necessarily associated to an intersection between the flight plan and a weather danger since it reveals a conflict in the future when the weather situation has evolved.

The Conflict Resolution will then compute the best manoeuvre to avoid the different weather threats and will propose the pilot an alternative route to downlink to ATC in order to divert. Pilots are also able to identify the most effective route and to propose their own flight plan, deciding a strategy to avoid the weather threats on their own.

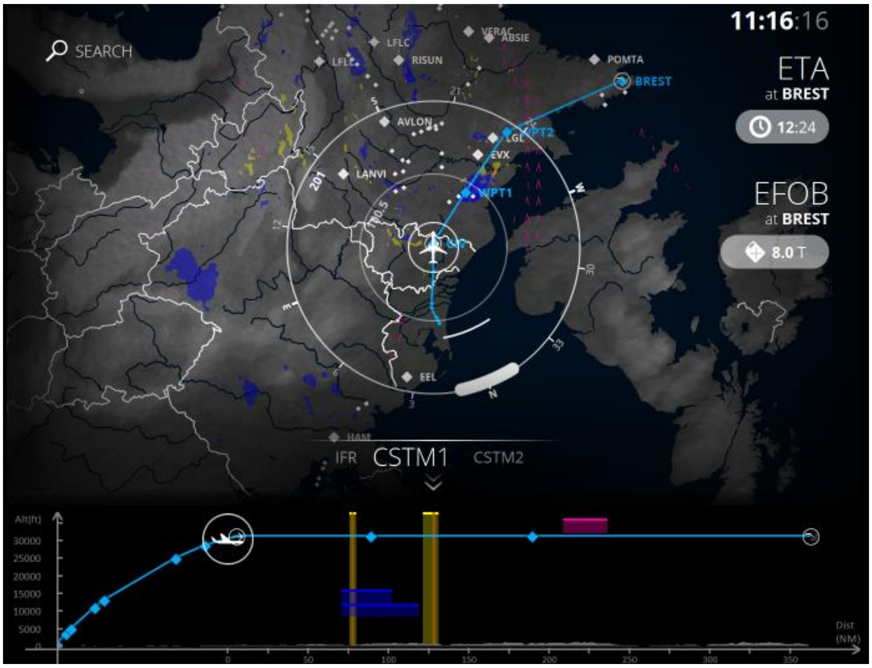


Figure 14 Weather awareness system conflict detection and resolution (CB, ICE and CAT)

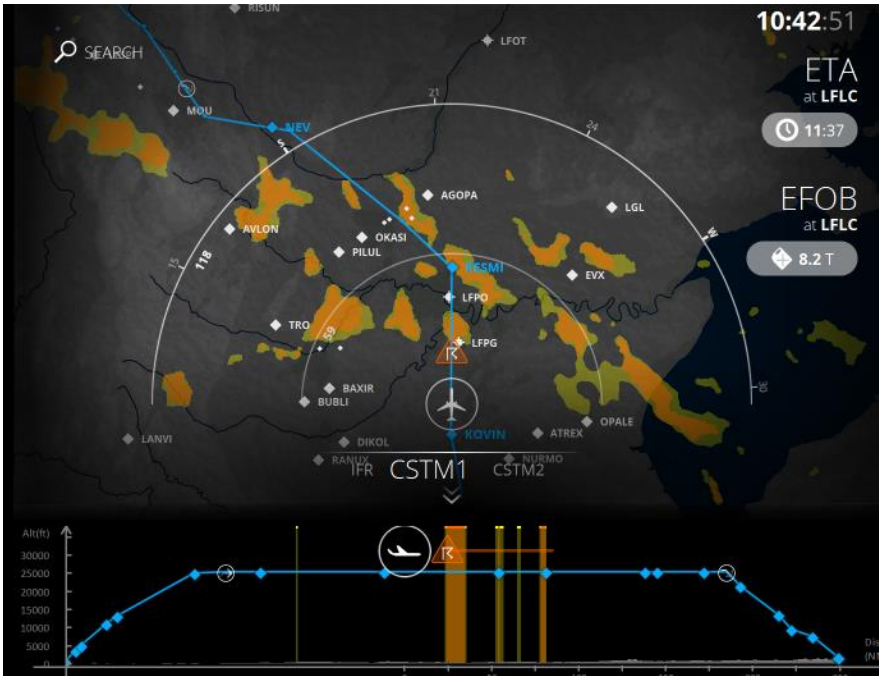


Figure 15 Weather conflict detection and resolution

During en-route evaluations the Weather Awareness Subsystem (WAS) was evaluated as a whole. It portrayed present hazardous weather event areas—namely Cumulonimbi, Icing, Clear Air Turbulence and Volcanic Ash—and displayed estimated conflict points with these areas. These areas were displayed on the strategic navigation display that was shared by the two pilots. Pilots used the system to see how these hazardous weather events interfered with the own aircraft flight plan—conflict points were automatically displayed and signalled by the system—and to devise alternative routes.

This application has been developed by Thales and Airbus Group.

4.2.3 Synthetic Terrain Presentation application (STP)

The Synthetic Terrain Presentation Application provides pilots with a synthetic view of the surrounding terrain depicted on a HUD. The depiction is based on 3D geographical data to create a conformal representation of the terrain elevation visible from the outside-view of the aircraft. The representation is composed of equidistant terrain profiles that appear perpendicular to the direction of flight and along with the runway threshold. This application is meant to enhance the pilot terrain profile awareness during approach and landing phases, mainly in degraded visibility environments.

This application was developed by BAE Systems.

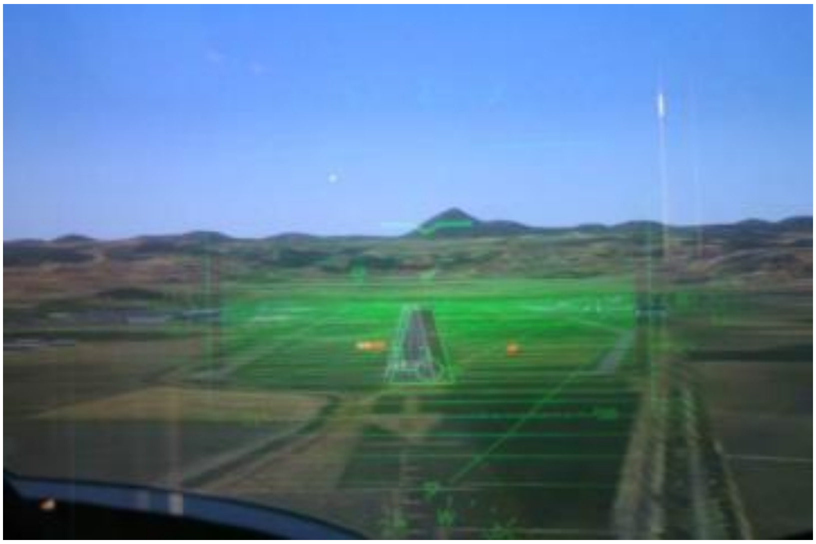


Figure 16 Synthetic Terrain Presentation Application (Head-Up Display)

4.2.4 Enhanced Synthetic Vision application (ESV)

Enhanced Synthetic Vision (ESV) application uses infrared sensor technology depicted on a HUD to provide visual guidance of the outside view in degraded visibility environments. This application provides the synthetic environment combining both image fusion and with data fusion. The visual depiction on the application specifically provides the flight crew with the approach lighting system, runway centreline, runway threshold and landing area at decision height.

This application was developed by Thales.

Figure 17 Enhanced Synthetic Vision application (Head-Up Display)

4.2.5 Head Down Synthetic Vision System (Head Down SVS)

The Head Down SVS presents a 3D synthetic terrain depiction map based on an on-board database managed by a database server. It also presents the runway and fixed ground obstacles (buildings, towers, etc.).

This application was developed by Tecnalia.

Figure 18 Head Down Synthetic Vision System

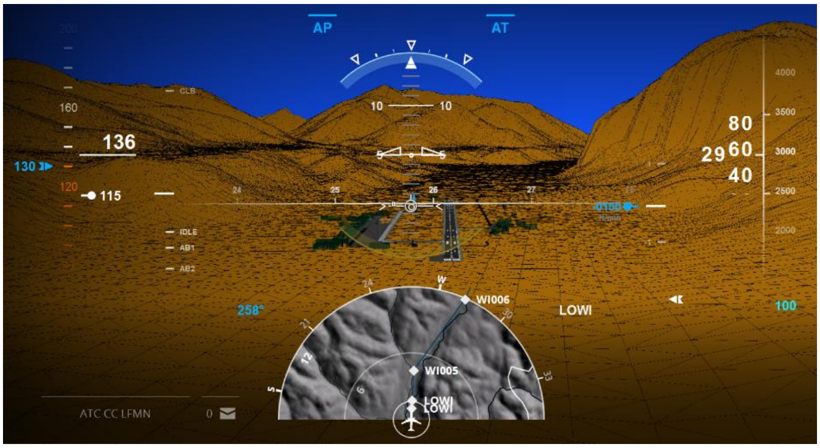


Figure 19 Depiction of the Head Down Synthetic Vision System

4.3 ALICIA Experimental Approach

The experimental approach that is described in this chapter refers exclusively to the human performance assessment carried out during ALICIA human-in-the-loop evaluation of applications.

The technologies introduced above were evaluated in a human-in-the-loop simulation carried out at Thales Avionics. The aim of the simulation was to investigate the operational benefits and limitations of the developed technologies with an emphasis on human performance and human-machine interaction.

The evaluations were performed with a total of 7 crews (14 pilots). Each crew was involved in the simulation exercise for 2 days. Simulations were conducted either on Tuesdays and Wednesdays or on Thursdays and Fridays of each simulation week.

The two-day simulation schedule was organized around 6 blocks of activities. These included:

- 2 introductory blocks: (i) Welcome and project introduction and (ii) Simulator Training and familiarization with the cockpit concept;
- 3 simulation blocks, in which pilots had to perform the actual simulation runs. Simulation blocks were distinguished based on the phase of flight: En Route, Approach and Ground. The previous three blocks shared the same structure of activity as described below.
- 1 final block, during which the final debriefing was carried out.

The full sequence of activities of the typical simulation block is described below.

1. Welcome and Introduction. During the morning, each crew was welcomed and a given a PowerPoint presentation about the objectives and background of the evaluation, the ALICIA technologies under evaluation, the organization of the simulation exercise, and the plan for the day. Pilots also filled the consent form and the biographical questionnaires at this point.
2. Simulator training and familiarization with the cockpit concept. In this phase pilots were lead to the simulation room and a presentation was given about the displays, controls and functions of the simulator. This offered the simulation team the opportunity to address exhaustively pilots' questions about the many innovative non-standard features of the simulator. This step helped to improve pilots' focus on the applications during the subsequent evaluation blocks.
3. Simulation Blocks (Approach, En Route and Ground). The three simulation blocks shared the following structure of activity:

    - Block specific Training and practice scenario. At the beginning of each simulation block, pilots received instructions about the scenarios they had to work on. Further, they received training specific for the applications to be evaluated under that block. Also, in this phase pilots completed at least two practice or warm up scenarios lasting approximately between 15 and 30 minutes.

    - Scenario Run Execution. In this phase pilots participated actively in the simulation run.

    - Block questionnaire. The Block questionnaire lasted about 45 minutes each, and included a 5 minutes break in-between the two parts of the questionnaire (see Figure 20).

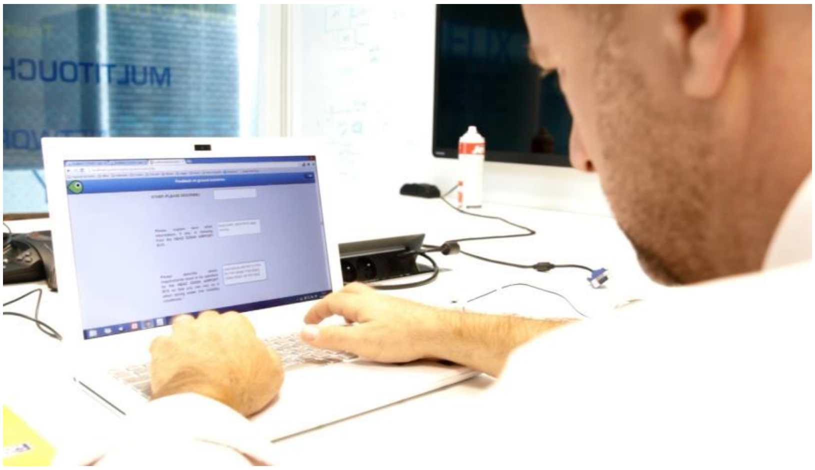


Figure 20 Pilot filling a questionnaire during the ALICIA project fixed wing evaluations

4. Debriefing. A final debriefing took place on a quiet meeting room, pilots were encouraged to report their overall feedback about the single evaluated technologies and the overall support provided by the group of technologies.

4.3.1 Description of the simulation testbed

The evaluation exercise took place at Thales Avionics in Bordeaux in the Avionics 2020 two-person crew fixed based cockpit simulator (see Figure 21). Thales carried out the integration and evaluation of the different applications developed in the context of the project by different partners.

The simulator consisted of four basic elements: (1) A Fixed Wing cockpit reproduction consisting of 8 touch screen displays; (2) An optical system providing a collimated outside view to the cockpit; (3) A control panel workstation for the evaluations manager to talk with the crew and monitor the situation on various displays; (4) A PC rack hosting the simulation platform.

Figure 21 ALICIA simulation testbed

The figure below is a representation of the functional layout of the testbed adapted to large screens. The flight controls that are not represented include side sticks, thrust levers and rudder pedals. Some items such as the landing gear lever or flaps and slats lever were not physically available.

Finally, for the present simulations only one tablet was available to the Pilot Monitoring (PM) although, in a real cockpit, the Pilot Flying (PF) would also have access to his own tablet.

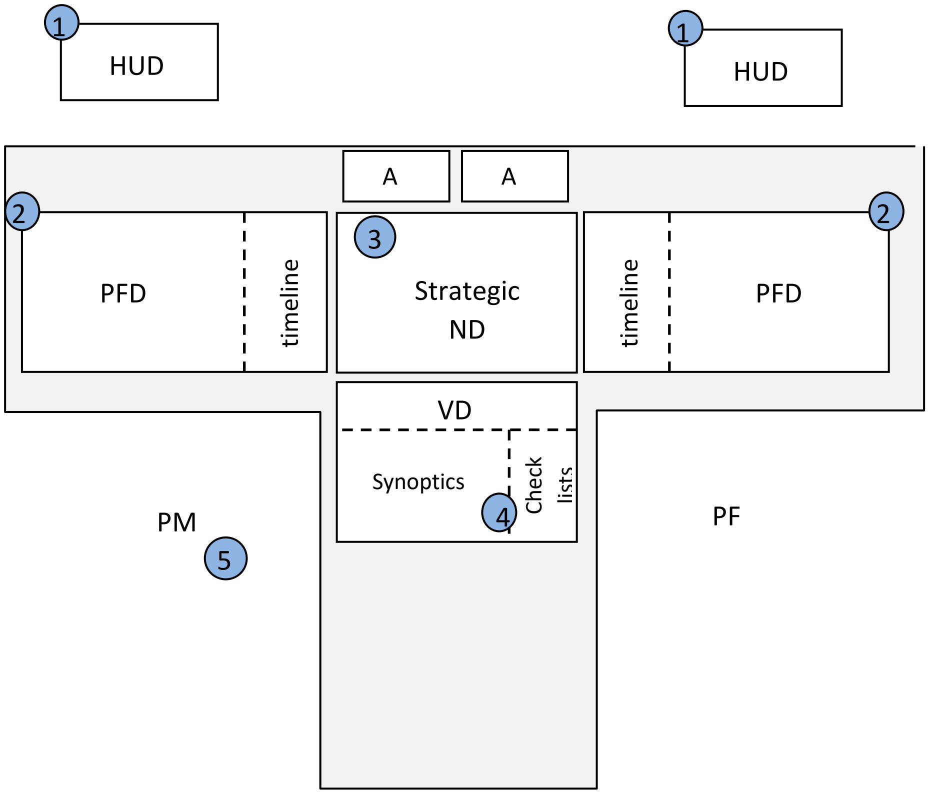


Figure 22 Flight deck testbed functional layout

The table below shows how the technologies were distributed on the simulation test-bed (Table 8).

Table 8 ALICIA Applications distribution on the flight deck test-bed

1a: HUD for Crew Member 1 Synthetic Terrain Presentation (STP)	**1b: HUD for Crew Member 2** Enhanced Vision System (EVS)
2a: TS display for Crew Member 1 Head Down SVS	**2b: TS display for Crew Member 2** Head Down SVS
3: TS central display (Strategic Navigation Display) Weather Conflict Detection and Resolution (Weather CD&R)	
4: TS lower display Vertical Display (Weather CD&R)	
5: Tablet Gate-to-Gate application (G2G)	

4.3.2 Methods

The methods used to collect pilots' feedback on the impact on performance of the applications were the following:

1. **Direct Observation.** During each simulation run, human factors researchers took expert notes of the pilots' observed behaviours. These captured the unfolding pilot interaction with the ALICIA displays, pilot-to-pilot interactions, as well as pilots' comments and impressions about the system. They allowed the research team to compile an early list of errors, shortcomings and points of strengths of the evaluated system to be used as material for discussion for the subsequent interviews and the final debriefing.

2. **Questionnaires.** Simulation runs were organized around three simulation blocks—En Route, Approach and Ground—depending on the phase of flight under evaluation. Pilots completed Post Block Questionnaire upon completion of all the runs included in each block. Both questionnaires were implemented and administered on a PC under the assistance of the HF specialists attending the simulation. Excerpts of pilots' answers or ratings have been noted down by the specialists and used during the debriefing sessions when needed.

3. **Debriefings.** The debriefings were carried out to collect pilots' feedback on the expected impact of the applications and on the overall system performance. They allowed to collect more information about specific topics emerged during the evaluation session. The final debriefing was semi-structured, partly based on pilots' feedback during the simulation and partly on the answers to the questionnaires.

4.3.3 Participants

A total of fourteen male professional airline pilots from three European airlines and two European aircraft manufacturers participated in the evaluation. Three from the fourteen pilots had previous military experience as jet fighter pilots. Flying experience ranged from a minimum of 2600 flight hours to a maximum of 20000 flight hours, with an average of 8960 flight hours. The average age of participating pilots is 53 years. The oldest participant being 68 years old, the youngest 35 years old (SD=10 years). All pilots were familiar with electronic displays. All but two pilots were familiar with touchscreen technology. All but four pilots reported to have previously flown with Head Up Displays.

4.3.4 Scenarios

The table below summarizes the scenarios used during the simulations to evaluate the different applications.

Table 9 ALCIA Fixed wing scenarios used for the evaluation of technologies

Scenario Category	#	High Level Scenario	Relevant Technologies: FW Simulator
Taxi	S1	Taxi-Out: Charles De Gaulle Airport	Gate to Gate application
	S2	Taxi In: Charles De Gaulle Airport	
En Route	S3	Amsterdam Schiphol (EHAM) to Clermont Ferrand Auvergne (LFLC), with squall line crossing the intended flight route. The scenario started about 40 minutes from landing.	Weather Conflict Detection and Resolution
	S4	Display of static situations for HMI evaluation: - Ice and CAT on a flight from Amsterdam to Clermont. - Volcanic Ash (VA) on a flight from Barcelona to Istanbul. The objective was to compare the user interface with existing tools.	
Approach	S5	Approach to Clermont-Ferrand Auvergne Airport, Low Visibility Conditions and Elevated Terrain. Also include: approach with rapidly Changing Weather Conditions, simulation of no ILS at Airport.	Enhanced Synthetic Vision application (HUD) Synthetic Terrain

	S6	Approach to Innsbruck (LOWI), Low Visibility Conditions and Elevated Terrain. Ceiling slightly below minima to force a go around procedure.	Presentation application (HUD) Runway Detection and depiction Head Down Synthetic Vision System

Taxi scenarios

Two taxi scenarios were conducted at Paris Charles De Gaulle airport under low visibility conditions. The first and second scenario were conducted with a setting of 125m, since from pilots' experience that is the lowest visibility at which they can operate.

En-Route scenarios

All the weather situations presented to the crews were reproductions of real phenomena stored in the weather database. During the evaluation these functionalities were displayed on the strategic navigation display. Pilots were free to interact with these functionalities as flight progressed and the weather situation evolved and then commented on the benefit and criticalities of the presented technologies.

Three different scenarios were run: scenario 3; 4a and 4b.

Scenario 3 consisted in a flight from Amsterdam Schiphol to Clermont Ferrand Auvergne. It involved a conflict with CB and conflict resolution by the on-board system. While cruising at flight level 310, the a/c encountered severe developing cumulonimbus that crossed the intended route at various points.

Pilots were requested to use the cumulonimbi information provided by the ALICIA weather application on the navigation display, and attempt to modify the remaining part of the plan by using the touch screen re-planning function supported by ALICIA.

Scenario 4a included a departure from Amsterdam Schiphol bound to Brest – Guipavas airport. The weather situation was perturbed by turbulence and icing areas. The objective here was to evaluate the suitability of the HMI and how the presented situation influenced the situation awareness and contributed to the decision making process.

Scenario 4b was a flight from Barcelona to Istanbul with volcanic ash along the flight plan. The objectives were similar to the previous scenario but with a special focus on the HMI related to a situation with volcanic ash.

Approach scenarios

Scenario 5 was an approach to Clermont Ferrand Auvergne with weather conditions slightly below the minima in terms of visibility and ILS unserviceable.

Scenario 6 was an approach to Innsbruck with visibility conditions that eventually forced the crew to perform a go around in a deep valley. The choice to perform the go-round was left to pilots', either by using the autopilot or manual operations.

4.4 ALICIA Applications Results

This sub-chapter contains two types of results that originate from two distinct activities:

1. The first set of results comes from the classification of ALICIA applications according to the Mediated Support Taxonomy defined in Chapter 3.
2. The second set of results reports on the ALICIA project human performance assessment outcomes.
   The results that were obtained during the human-in-the-loop simulations were organized for the purpose of this thesis work around human performance benefits and issues for each of the considered applications. Each benefit and issue was in its turn categorized according to the Human Performance Impactors that they affected (see Chapter 2.5).

4.4.1 Gate-to-Gate application (G2G)

The Gate to Gate application classification according to the Mediated Support Taxonomy was the following.

Table 10 G2G application classification

Gate to Gate application						
Context of the supported						
1	**Flight phase supported**					
	Taxi	x	Take-off/Climb		En-route	
	Descent		Approach		Landing	

2	**Supported tasks**							
	Aviate		Navigate	x	Communicate		Manage	
3	**Involved actors**							
	Flight deck: Pilot Flying(PF) and Pilot Monitoring (PM) **Ground:** ATCO (TWR)							

Mediated Control Classification	
1	**Rendering modality(ies)**
Visual	
2	**Type of Visual Display**
Hand-held display (Tablet)	
3	**Visual Display Frame of Reference (FOR)**
2D modelled moving map of the airport	
4	**Augmented Perception (Real-Virtual Integration)**
2D map view (rear-view) - Bi-dimensional top-down depiction (strategic)	
5	**Control-Display (C/D) Congruence**
Direct Control on the display (touchscreen display)	
6	**Automation Level Classification**

Automation level for supported cognitive functions							
Information Acquisition (A)	**A2**	**Information Analysis (B)**		**Decision and Action Selection (C)**		**Action Implementation (D)**	**D2**
Rationale:							

- **Information Acquisition (A) –** The application provides the pilot with a 2D moving map of the airport and with the route that the a/c is cleared to follow based on its current position (push back to the runway and vice versa). Previously, this information was only provided via voice communication between the Pilot Monitoring and the Tower ATCO.

- **Action Implementation (D)-** This application highlights the cleared taxiways the pilots should follow until the runway.

Benefits

Benefit 1: The application reduced the pilot effort in navigating during the taxi phase.

Pilots reported that the G2G application reduces the perceptual effort needed to acquire and maintain the whole picture (‘*less effort is put on taxing, as the system is supporting in understanding whether you are going right or wrong’*).

The workload allocated to the continuous communication with the Tower ATCO is also reduced since the communication with him is only done in order to obtain the approval to perform the taxi and to obtain the taxi route he should follow. Pilots considered this to be a noticeable improvement compared to current operations, mainly because sometimes it is easy to miss some instructions. The mentioned that understanding taxiway instructions delivered by busy controllers can be difficult to follow, especially in complex airports and when communicating with Tower ATCOs with particular pronunciations.

Human Performance Impact: Cognitive Workload; Situation Awareness

Benefit 2: The navigation support during the planning of the taxi phase might reduce pilots’ error rate.

Pilots considered the G2G application as a useful navigation aid for the taxiing phase, both in low and clear visibility conditions, since it enables them to have a global overview of the airport. This overview is important to understand where they are, where do they need to go to and which taxi route they have to take. The increased spatial awareness provided was reported as positive and particularly effective against runway incursions, although they also mentioned that the display needs to make hot spots more salient. Pilots also considered the applications could mitigate the risk of a/c taking off from taxiway or even support the crew to react more quickly in case wrong taxiway entry.

Human Performance Impact: Cognitive Workload; Situation Awareness; Human Error

Issues

Issue 1: Increased effort in case there is a need to re-plan the taxi route can lead to increased workload.

Some pilots expressed some concern about the effort needed to re-plan a new taxi route in the G2G once they are already performing the taxi. They mentioned this could lead to increased "head-down" time, which could be dangerous in a big an airport with a lot of ground movement.

Human Performance Impact: Cognitive Workload; Situation Awareness

Issue 2: The use of a hand-held display can result in an unbalanced awareness between the two flight crew members.

The fact that the G2G application is provided in a hand-held display (tablet) can result in unbalanced distribution of information between the two flight crew members: only one pilot, the one using the G2G would develop and maintain the global picture, while the PF would be out-of-the loop since s/he focuses solely on executing the taxi. A bad shared situation awareness among flight crew members reduces the opportunities for cross checks, hence reducing the opportunities for good Crew Resource Management and cooperation on the flight deck.

Human Performance Impact: Situation Awareness

Issue 3: The hand-held display can increase flight crews' head-down time.

The airport navigation information on the G2G hand-held display can lead the pilot to spend more time looking inside the aircraft when taxiing. This might decrease the overall situation awareness and even be dangerous since the crew can might miss critical information, traffic and features available outside the aircraft.

Human Performance Impact: Situation Awareness

Issue 4: Excessive trust in the information could lead to error.

Pilots mentioned that if the application provides inaccurate information or aircraft positioning on the airport map it can lead the pilot to commit errors, especially if he has no means to confirm the accuracy of the information. For this reason, pilots mentioned that displaying an indicator of data integrity/uncertainty could increase their trust on the information (e.g. like a spiral indicator that is available for certain GPS systems).

Human Performance Impact: Trust; Human Error

4.4.2 Weather Conflict Detection and Resolution (Weather CD&R)

The Weather CD&R application classification according to the Mediated Support Taxonomy was the following.

Table 11 Weather Conflict Detection and Resolution application classification

Weather Conflict Detection and Resolution application								
Context of the supported								
1	**Flight phase supported**							
	Taxi		Take-off/Climb		En-route	x		
	Descent		Approach		Landing			
2	**Supported tasks**							
	Aviate		Navigate	x	Communicate		Manage	
3	**Involved actors**							
	Flight deck: Pilot Flying(PF) and Pilot Monitoring (PM) **Ground:** ATCO (TWR)							
Mediated Control Classification								
1	**Rendering modality(ies)**							
Visual								
2	**Type of Visual Display**							
Head-down display (Touchscreen)								
3	**Visual Display Frame of Reference (FOR)**							
2D coplanar displays (map view display + profile display)								
4	**Augmented Perception (Real-Virtual Integration)**							
2D map view (rear-view) and 2D top-down depiction (strategic)								

<table>
<tr><td>5</td><td colspan="8">Control-Display (C/D) Congruence</td></tr>
<tr><td colspan="9">Direct Control on the display (touchscreen display)</td></tr>
<tr><td>6</td><td colspan="8">Automation Level Classification</td></tr>
<tr><td colspan="9">Automation level for supported cognitive functions</td></tr>
<tr><td>Information Acquisition (A)</td><td>A3</td><td>Information Analysis (B)</td><td>B5</td><td>Decision and Action Selection (C)</td><td>C2</td><td>Action Implementation (D)</td><td></td></tr>
<tr><td colspan="9">Rationale:</td></tr>
<tr><td colspan="9">

Information acquisition (A) – The weather depiction around the aircraft on a 2D coplanar display (map view + vertical situation display) provides pilots the image of the future weather situation they will encounter along their flight path.
Information Analysis (B) – The application supports the pilot in the weather information analysis by highlighting the weather events that can pose a threat given the flight plan that is being flown. Once a threat is identified, it is highlighted and an alert is provided to the flight crew members to direct their attention to a weather conflict area that should be considered. The parameters considered by the system to alert the flight crew are defined at design-level.
Decision and Action Selection (C) – The decision support provided by the weather conflict detection and resolution to the flight crew consists in generating a single flight plan alternative to avoid the detected weather conflict. The flight crew is also given the freedom of proposing their own flight plan in order to deviate the bad weather events (by adding waypoints).

</td></tr>
</table>

Benefits

Benefit 1: A long range weather picture reduced the pilot effort to perform navigation tasks.

The long range weather picture provided by the application facilitated pilots' assessment on the existence of a dangerous weather condition for the flight. Upon detection of a weather conflict by the on-board system, the crew was notified by means of attention getters and was able request an avoidance route. The application allowed more time and information to make strategic decisions concerning what should be done. The system allows pilots to make earlier decisions compared to current operations.

Human Performance Impact: Cognitive Workload

Benefit 2: The provision of the weather evolution allowed an improved awareness on future events.

The provision of current and future weather events (growing rate, movement, intensity) evolution and, in particular, the depiction of highly dynamic and rapidly changing weather events, improved pilots' Situation Awareness. The application provided means to anticipate where potential conflicts could occur and possibly reduce the likelihood of flying into a hazardous weather areas.

The position and location of this head-down touchscreen display between the PF and the PM allowed access to the same information and ultimately facilitated the interaction and coordination between them.

Human Performance Impact: Situation Awareness

Benefit 3: The decision making support by providing an alternative flight plan in case of bad weather reduced pilot workload.

The application provided the flight crew with a flight plan proposal in case a weather conflict is detected. If the flight crew accepted the proposal, there is an option to downlink it for approval by the ATC and then insert the proposal as the active flight plan in case of ATC approval.

Human Performance Impact: Cognitive Workload

Benefit 4: The weather threats avoidance management is done at a strategic level rather than tactical level.

Workload related to weather threats avoidance management gets redistributed effectively in time with the support of this application. The decision process is passing from a tactical to the strategic level. This means that weather avoidance and re-routing decisions are being made earlier, at longer distance and time frame; the pilot can better manage its tasks in ahead of time and consequently manage his workload. From a pilot's view, this is beneficial as it eliminates the intense workload demanded for responding to a severe weather event at closer distance and timeframe (tactical level).

Pilots mentioned that the system allowed them to implement a global diversion strategy, rather than a number of small range diversions, that would involve a constant coordination with the ATC. By allowing the implementation of a global diversion strategy the system supports workload distribution over the flight duration.

Human Performance Impact: Cognitive Workload

Issues

Issue 1: The lack of a complete integration between vertical display and the map view display.

The vertical display was not completely integrated with the actions performed on the map view display. When the pilot selected a flight leg on the map view display this selection was not visible in the vertical display. Actions on both displays should be integrated to support operations and pilot Situation Awareness.

Human Performance Impact: Situation Awareness

Issue 2: Reduced involvement in the weather avoidance manoeuvres may lead to loss of skill and proficiency.

If pilots continuously fly with aircraft equipped with this type of application to predict and divert weather events, they will get used to this kind of support. This continuous support might lead to a loss of skill using less advanced weather radar and working with short-term information to define a conflict definition strategy.

Human Performance Impact: Skill

Issue 3: Excessive trust and familiarization with the application may lead to complacency and Situation Awareness reduction.

The continuous use of a reliable weather CD&R application might lead flight crews to rely on it by default, also when flying over regions that are not equipped with the necessary ground-based infrastructure to support it. In this case, no or limited weather information supplied on the application might lead to a possible false idea that there are no weather hazards ahead.

The source and accuracy of the weather information being displayed was not clear for pilots and they consider it very important to be able to make informed decisions.

Human Performance Impact: Situation Awareness; Trust; Human Error

Issue 4: The lack of confirmation step in touchscreen interaction could lead the errors.

The use of touchscreen HDD allowed the pilot to interact directly where the information is being provided. Pilots mentioned that operating with this type of display during turbulence conditions might easily lead to unwanted actions or errors. Therefore, critical actions should have a confirmation step. Mechanisms to recover from unwanted actions should also be implemented.

Human Performance Impact: Trust; Human Error

Issue 5: The criteria and logic used for the conflict avoidance proposed by the application should be clear to the flight crew.

The underlying logic behind the conflict diversion route proposed by the system should be clear to the pilot, otherwise, it is very difficult for them to trust the proposed avoidance trajectory.

Human Performance Impact: Trust

4.4.3 Synthetic Terrain Presentation application (STP)

The Synthetic Terrain Presentation application classification according to the Mediated Support Taxonomy was the following.

Table 12 Synthetic Terrain Presentation application classification

<table>
<tr><td colspan="9">Synthetic Terrain Presentation application</td></tr>
<tr><td colspan="9">Context of the supported</td></tr>
<tr><td rowspan="3">1</td><td colspan="8">Flight phase supported</td></tr>
<tr><td colspan="2">Taxi</td><td></td><td colspan="2">Take-off/Climb</td><td></td><td>En-route</td><td></td></tr>
<tr><td colspan="2">Descent</td><td></td><td colspan="2">Approach</td><td>x</td><td>Landing</td><td></td></tr>
<tr><td rowspan="2">2</td><td colspan="8">Supported tasks</td></tr>
<tr><td>Aviate</td><td></td><td>Navigate</td><td>x</td><td>Communicate</td><td></td><td>Manage</td><td></td></tr>
<tr><td rowspan="2">3</td><td colspan="8">Involved actors</td></tr>
<tr><td colspan="8">Flight deck: Pilot Flying(PF) and Pilot Monitoring (PM)</td></tr>
<tr><td colspan="9">Mediated Control Classification</td></tr>
<tr><td>1</td><td colspan="8">Rendering modality(ies)</td></tr>
<tr><td colspan="9">Visual</td></tr>
<tr><td>2</td><td colspan="8">Type of Visual Display</td></tr>
<tr><td colspan="9">Head-Up Display (HUD)</td></tr>
<tr><td>3</td><td colspan="8">Visual Display Frame of Reference (FOR)</td></tr>
<tr><td colspan="9">3D egocentric (immersed)</td></tr>
<tr><td>4</td><td colspan="8">Augmented Perception (Real-Virtual Integration)</td></tr>
<tr><td colspan="9">Perceptual association. Virtual object (terrain grid) are overlaid on the real scene.</td></tr>
<tr><td>5</td><td colspan="8">Control-Display (C/D) Congruence</td></tr>
</table>

-							
6	**Automation Level Classification**						
Automation level for supported cognitive functions							
Information Acquisition (A)	**A4**	**Information Analysis (B)**		**Decision and Action Selection (C)**		**Action Implementation (D)**	
Rationale:							
▪ **Information acquisition (A) –** This application provide pilots' with a 3D conformal representation overlaid on the terrain in front of the aircraft during degraded visibility operations. The pilots were able to use this application on the HUD whenever they would like to improve the visibility over terrain.							

Benefits

Benefit 1: The synthetic terrain depiction on the HUD improves pilots' Situation Awareness on low visibility approaches.

Pilots admitted that during low visibility approaches the intuitive acquisition of information on terrain from the system was beneficial in degraded visibility conditions. The information on surrounding high or hazardous terrain and estimate distance (lateral and vertical) provided by the system improved their Situation Awareness.

The STP application was considered especially useful during operations over mountainous areas, providing pilots with a clearer view of what and where terrain obstacles are.

Human Performance Impact: Situation Awareness

Issues

Issue 1: The synthetic terrain view on the HUD impaired the perception of some important elements outside the aircraft.

Pilots mentioned that the use of the HUD display impaired their perception of some of the external information cues because of the overlaid terrain grid that cluttered their field of view. The density of the grid lines could prevent pilots from seeing surrounding traffic (on the outer view).

Human Performance Impact: Situation Awareness

Issue 2: The synthetic terrain view grid on the HUD created the perceptual illusion that the terrain is closer.

Pilots admitted that the terrain grid magnified the mountain and the terrain, giving them the illusion that the terrain is closer than actually is, and thus, possibly leading to commit erroneous judgement or even to anticipate procedures. Pilots also mentioned that the scale of the terrain grid was unknown and this did not help them in making distance judgments.

Human Performance Impact: Situation Awareness; Human Error

Issue 3: The synthetic terrain depiction on the HUD could impair the distinction of runway elements.

The STP did not include a clear representation of the start of the runway, touchdown, and runway lateral borders. The lack of ILS information also made difficult for the pilot to monitor the deviations from intended trajectory and this could lead to errors.

Human Performance Impact: Human Error; Situation Awareness

Issue 4: The HUD in approach and landing phases can increase workload because the pilot should also monitor information inside the flight deck.

During approach and landing phases pilots usually experience high workload levels because they need to monitor several parameters on instruments on-board, like ILS and perform checklists. Pilots mentioned that the system was missing critical information that are important during this phase of flight (e.g. a/c height above terrain and distance to the runway). This means that even though the system improves their awareness on the terrain features, the fact that it is missing other critical information can increase their workload.

Human Performance Impact: Workload

Issue 5: The use of Head Up Display can result in an unbalanced awareness between the two flight crew members.

The fact that only one pilot has access to the HUD and in case both pilots have access to the HUD but the information provided is not the same, have been mentioned by pilots as possible cause for unbalanced situation awareness between the two flight crew members. Consequently, a bad shared situation awareness among flight crew members reduces the opportunities for cross checks, hence reducing the opportunities for good Crew Resource Management and cooperation on the flight deck.

Human Performance Impact: Situation Awareness

4.4.4 Enhanced Synthetic Vision application (ESV)

The Enhanced Synthetic Vision application classification according to the Mediated Support Taxonomy was the following.

Table 13 Enhanced Synthetic Vision application classification

<table>
<tr><td colspan="9">Enhanced Synthetic Vision application</td></tr>
<tr><td colspan="9">Context of the supported</td></tr>
<tr><td rowspan="3">1</td><td colspan="8">Flight phase supported</td></tr>
<tr><td colspan="2">Taxi</td><td></td><td colspan="2">Take-off/Climb</td><td></td><td>En-route</td><td></td></tr>
<tr><td colspan="2">Descent</td><td></td><td colspan="2">Approach</td><td>x</td><td>Landing</td><td></td></tr>
<tr><td rowspan="2">2</td><td colspan="8">Supported tasks</td></tr>
<tr><td>Aviate</td><td></td><td>Navigate</td><td>x</td><td>Communica te</td><td></td><td>Manage</td><td></td></tr>
<tr><td rowspan="2">3</td><td colspan="8">Involved actors</td></tr>
<tr><td colspan="8">Flight deck: Pilot Flying (PF) and Pilot Monitoring (PM)</td></tr>
<tr><td colspan="9">Mediated Control Classification</td></tr>
<tr><td>1</td><td colspan="8">Rendering modality(ies)</td></tr>
<tr><td colspan="9">Visual</td></tr>
<tr><td>2</td><td colspan="8">Type of Visual Display</td></tr>
<tr><td colspan="9">Head-Up Display (HUD)</td></tr>
<tr><td>3</td><td colspan="8">Visual Display Frame of Reference (FOR)</td></tr>
<tr><td colspan="9">3D egocentric (immersed)</td></tr>
<tr><td>4</td><td colspan="8">Augmented Perception (Real-Virtual Integration)</td></tr>
<tr><td colspan="9">Perceptual association. Virtual objects are incrusted (overlaid) on top of real objects. Therefore virtual objects are not concealed by real objects. We can refer to this as association by superposition.</td></tr>
</table>

5	Control-Display (C/D) Congruence						
-							
6	**Automation Level Classification**						
Automation level for supported cognitive functions							
Informatio n Acquisitio n (A)	**A4**	**Informatio n Analysis (B)**		**Decision and Action Selection (C)**		**Action Implementati on (D)**	
Rationale:							
▪ **Information acquisition (A) –** This application provides pilots a conformal depiction of the runway lighting system, runway centreline, threshold and landing area at decision height in degraded visibility operations.							

Benefits

Benefit 1: The ESV on the HUD improves pilots Situation Awareness in low visibility approaches.

The application provided pilots with clear and intuitive means of understanding their flying environment and provided increased situational awareness under degraded visibility conditions. For this reason, pilots mentioned the EVS system could allow descending below the published decision height designed for direct visual contact.

Human Performance Impact: Situation Awareness

Issues

Issue 1: The cluttering on the HUD can increase pilot workload during approach phase.

The sensed runway lights appear in the same area of the display where the other symbology and radio altimeter digits appear. This HUD cluttering degrade the visual acquisition of the runway approach lights depicted by the ESV.

The difficulty in distinguishing between different elements could increase pilot workload in a phase of flight that is already critical and characterized by high workload levels.

Human Performance Impact: Workload

Issue 2: The ESV runway light depiction can induce confusion in the presence of other lights.

Some pilots mentioned that runway lights could easily be confused with general lights. If this happens once, it is very much likely happen repeatedly, and pilots will have problems in trusting the system (e.g. approaches on airports close to roads or cities).

Human Performance Impact: Trust; Human Error

4.4.5 Head Down Synthetic Vision System

The Head Down Synthetic Vision system classification according to the Mediated Support Taxonomy was the following.

Table 14 Head Down Synthetic Vision System classification

<table>
<tr><td colspan="9">Head Down Synthetic Vision System</td></tr>
<tr><td colspan="9">Context of the supported</td></tr>
<tr><td rowspan="3">1</td><td colspan="8">Flight phase supported</td></tr>
<tr><td>Taxi</td><td></td><td>Take-off/Climb</td><td></td><td>En-route</td><td></td><td colspan="2"></td></tr>
<tr><td>Descent</td><td></td><td>Approach</td><td>x</td><td>Landing</td><td></td><td colspan="2"></td></tr>
<tr><td rowspan="2">2</td><td colspan="8">Supported tasks</td></tr>
<tr><td>Aviate</td><td></td><td>Navigate</td><td>x</td><td>Communicate</td><td></td><td>Manage</td><td></td></tr>
<tr><td rowspan="2">3</td><td colspan="8">Involved actors</td></tr>
<tr><td colspan="8">Flight deck: Pilot Flying (PF) and Pilot Monitoring (PM)</td></tr>
<tr><td colspan="9">Mediated Control Classification</td></tr>
<tr><td>1</td><td colspan="8">Rendering modality(ies)</td></tr>
<tr><td colspan="9">Visual</td></tr>
<tr><td>2</td><td colspan="8">Type of Visual Display</td></tr>
<tr><td colspan="9">Head-down display (Touchscreen)</td></tr>
<tr><td>3</td><td colspan="8">Visual Display Frame of Reference (FOR)</td></tr>
<tr><td colspan="9">3D egocentric (immersed)</td></tr>
<tr><td>4</td><td colspan="8">Augmented Perception (Real-Virtual Integration)</td></tr>
<tr><td colspan="9">Real replaced by virtual. Synthetic the model presented from the same (immersed) point of view.</td></tr>
<tr><td>5</td><td colspan="8">Control-Display (C/D) Congruence</td></tr>
</table>

-							
6	**Automation Level classification**						
Automation level for supported cognitive functions							
Information Acquisition (A)	**A4**	**Information Analysis (B)**		**Decision and Action Selection (C)**		**Action Implementation (D)**	
Rationale:							
▪ **Information acquisition (A) –** The application provides support to the pilot in perceiving the terrain using a 3D synthetic terrain depiction along with runway and fixed ground obstacles (buildings, towers, etc.).							

Benefits

Benefit 1: The Head Down SVS improves pilots' Situation Awareness.

Pilots considered the application very useful in providing a better understanding of the surrounding terrain and important elements like the runway or buildings. The operational benefit was considered more relevant during approaches in the proximity of buildings, high terrains and mountain areas.

Human Performance Impact: Situation Awareness

Benefit 2: The Head Down SVS supports flight crew awareness on the transition between airborne phase and ground phase.

The representation of runways and taxiways on the Head Down SVS offer a seamless transition from ground to airborne operation and the other way around, improving this way pilots' Situation Awareness.

Human Performance Impact: Situation Awareness; Workload

Issues

Issue 1: The Head Down SVS can increase pilot "head-down" time in critical phases of the flight

Due to the attractiveness of SVS images there is the risk that at some point pilots could pay more attention to elements inside the cockpit than outside. Not detecting critical out-of-the window information or even an unexpected obstacle appearing on the taxiway during approach can be very critical.

Human Performance Impact: Situation Awareness

Issue 2: The excessive trust in the synthetic information may lead to complacency and Situation Awareness reduction.

The depiction of terrain, obstacles and runway information on the SVS display could lead the pilot to overtrust the system and to reduce the number of crosschecks with out-the-window information in a critical flight phase.

Human Performance Impact: Trust; Situation Awareness

Chapter 5. RAID project: RPAS Case Study

This chapter provides an overview on RAID project and on the experimental approach followed during the performed RPAS flight trials. The chapter ends with the classification of the RPAS Ground Control Station applications according to the defined Mediated Level Taxonomy, followed by the presentation of the respective associated benefits and issues for human performance that were measured within the project validation activities.

5.1 RAID Project Background

RAID was one of the eight European projects co-financed by SESAR Joint Undertaking with the purpose of demonstrating the integration of Remotely Piloted Aircraft System (RPAS) in unsegregated airspace. It was coordinated by the Italian Aerospace Research Centre (CIRA). The project initiated on January 2014 and lasted until June 2016.

This project had as main aim the evaluation of the impact of RPAS integration into unrestricted airspace in the current and future (short-term) ATM environment. This objective was achieved through the completion of several demonstration activities, including both Real-Time Simulations (RTS) and Flight Trials. It also provided a contribution to the assessment of the level of maturity, performance, procedures, limitations and compatibility within the current infrastructures used in RPAS. The procedures included the use of temporary (dynamic) operational segregation areas and involved technologies like Detect and Avoid System (DAA) that can be used as an automatic function or a human decision support tool.

The project's specific objectives were the following:

1. Quantify and demonstrate the level of maturity, performance, limitations and compatibility with current infrastructures and procedures, of detect and avoid technology and of technologies for secure C2L;
2. Assess the impact RPAS integration into un-segregated airspace could have on safety, the RPAS pilot, Air Traffic Control Officers and ATM procedures and operations;
3. Identify the similarities between the operation of RPASs and manned aircraft in the ATM environment, as well as specificities to RPAS operation in terms of constraints and new requirements for the ATM operations;
4. Compare technological requirements between current (manned) flight operations and RPAS operations within the flight and air traffic management environments.

The operational concept addressed in the flight trials and reported in this work focuses on the RPAS integration in the ATM system during the en-route flight phase.

5.2 Description of Applications and Functionalities

The human performance assessment carried out during the flight trials considered the remote pilot interaction with the Ground Control Station as a whole and not to the single applications that composed it. The applications that are presented here below were selected in the frame of the present work according to their relevance.

The applications support the RPAS navigation, flight environment awareness and traffic detection and avoidance.

5.2.1 RPAS Out-of-the-Window view application

The Out-of-the-Window view display provides the remote pilot with live video from the Remotely Piloted Aircraft on-board camera.

5.2.2 RPAS Traffic Detect and Avoid (DAA)

The DAA system processes the traffic data provided by the ADS-B (IN) device installed on-board in order to assess the traffic situation in the surrounding airspace. This means that the system is able to detect only other aircraft equipped with ADS-B (OUT) transponder and to display the processed traffic data on the Ground Control Station interface. The remote pilot is able to interact with the DAA function through a dedicated interface integrated in a touchscreen display.

The Detect and Avoid system has two different functionalities, the Separation Assurance and Collision Avoidance, based on the risk associated to the surrounding aircraft. Being that the Collision Avoidance manoeuvre is only proposed in case the separation envelope of the aircraft was already breached. Both, separation assurance and collision avoidance, provide the remote pilot with a time margin to decide and to implement the intended action.

RPAS Traffic Detect and Avoid - Self-Separation functionality

The RPAS DAA Self-Separation functionality detects a possible loss of separation condition occurring over a specified time horizon and it provides the remote pilot with indication of a proper manoeuver aimed to restore the considered separation minima. The remote pilot is then in charge of evaluating the feasibility of the proposed manoeuvre, to accept it or not according to the traffic scenario and to decide about its implementation. He then can choose to perform the separation using the autopilot functionalities or to implement it automatically with the help of the system.

RPAS Traffic Detect and Avoid - Collision Avoidance functionality

Once an aircraft imminent collision is predicted by the DAA, the system alerts (visual alert) the remote pilot and automatically elaborates a collision avoidance manoeuver with respect to the higher priority aircraft. The manoeuver, due to the nature of its emergency, is automatically implemented, but the remote pilot can abort it and take the direct control of the aircraft at any moment.

5.3 RAID Experimental Approach

The experimental approach that is described in this chapter refers exclusively to the human performance assessment carried out during RAID project. The human performance assessment involved the Ground Control Station evaluation and consequently the applications that composed it.

The Real-Time Simulations (RTS) that were initially carried out in RAID project allowed a preliminary collection of results on the roles of the ground pilot, his interaction with the Ground Control Station (GCS) in the scenarios that would be later tested in the Flight Trials and on the interaction with the other actors (Air Traffic Control and the Pilot on-board the Remotely Piloted Aircraft). This step allowed to fine tune the GCS Interface and worked as a preliminary activity for the actual Flight Trail phase.

The results presented on this case study are coming from the Flight Trials that were carried out at the end of the project. The Flight Trials included a total of 12 flights that were carried out between 27th of April and the 6th May 2016 in "Capua" airport, close to CIRA premises.

The Flight Trials involved a total of 3 aircraft, a Remoted Piloted Aircraft (RPA) operated from a Ground Control Station and related command and control data-link (FLARE), a manned Very Light Aircraft (VLA) acting as cooperative traffic vehicle and finally a small RPAS acting as unmanned cooperative traffic. The RPA had an on-board safety pilot that was responsible of flying the aircraft into the Operational Manoeuvring Area (OMA) and that was making sure that the tests were being carried out under an acceptable safety limits.

RAID flight facilities included a Ground Control Station from where the pilot was able to control the RPA and a customised Test Controller Working Position (CWP), which was fed only with real data from an Automatic Dependent

Surveillance - Broadcast (ADSB-IN) device (see Figure 23). During the exercise standard existing ATC procedures were applied.

Figure 23 RAID Ground Control Station facility (left) and Controller Working Position facility (right)

The operative base for RAID flights, both FLARE RPA and manned intruder, was “O. Salomone” civil airport located in Capua, around 30 Km North of Naples (Italy) under control of the Italian Aviation Civil Authority (ENAC).

The Flight Test Area (FTA) was located close to the “O. Salomone” airport and the limits of this area were shaped like a polygon (see Figure 24). The vertical limits of this FTA were defined between the 1500 ft and 8200 ft of altitude.

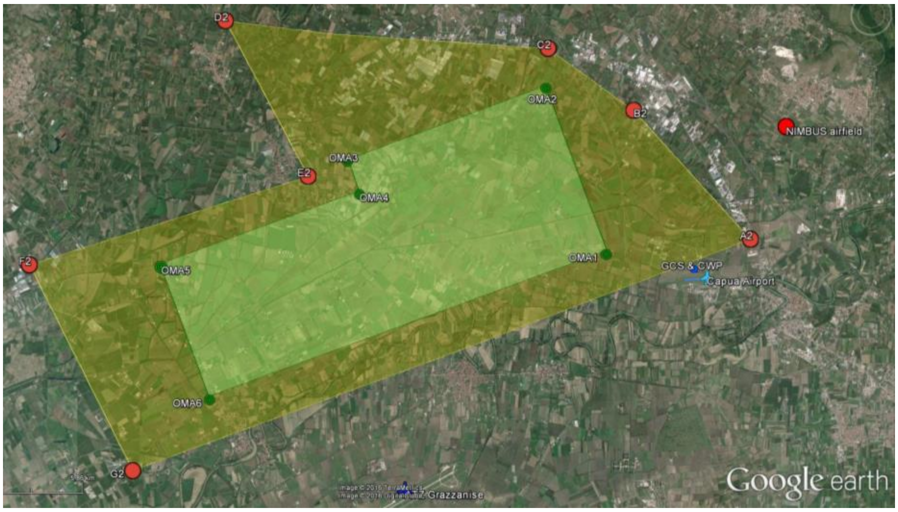


Figure 24 RAID RPAS Flight Test Area (larger polygon) and Operative Manoeuvring Area (internal polygon).

Only a single remote pilot participated in the RAID Flight Trials since, in order to operate the CGS the pilot had to be familiarized with it (the pilot had previous training).

The methods used to collect data on human performance while operating the GCS and the applications that composed it were: (1) direct observations; (2) post-flight questionnaires and (3) debriefings. After each flight run, the pilot had to fill a questionnaire and a debriefing was carried out to better understand some events or situations that occurred on that specific run.

5.3.1 Ground Control Station description

The Remoted Piloted Aircraft (RPA) was operated from a Ground Control Station (GCS) from a single interface. Since the remote pilot is operating from the ground, he does not have the same perception of the environment as he would from the aircraft (lack of auditory and other physical cues). Remote piloting tasks rely mostly on the visual channel. The information is collected by sensors on-board of the RPA and transmitted to the GCS interface.

The Ground Control Station (GCS) was equipped with different modules that allowed the remote pilot to fly the FLARE aircraft. The modules that composed the Ground Control Station were the following:

- A complete set of end effectors for the remote manual piloting of the FLARE aircraft (side-stick, throttle command, pedals).
- A customized touchscreen HMI.

  Besides the classical CDTI, PFD and MFD, it included:

  - A dedicated section for selecting the Remote piloting mode among the ones available,
  - A panel to select waypoints when in the Automatic Flight execution mode;
  - Information panels showing status of the RPA engine, surface and throttle positions, the engaged remote piloting mode and current waypoint list;
  - A dedicated panel with on-board avionic setup failures information.
  - Information about cooperative traffic such as loss of separation alert and suggested separation assurance manoeuvers as derived by the “sense & avoid”.
- A VHF radio to communicate with the test controllers located in test CWP;
- A out-of-the-window screen with the live video from the RPA on-board camera.

- The RPA could be piloted using different piloting modes. The RPAS piloting flight modes available were the following:
  - Direct Manual in which the position of the ground inceptors is proportional to the position of the aircraft surfaces and throttle.
  - Augmented Manual in which the aircraft aerodynamic surfaces and throttle are actuated through a Stability Control and Augmentation module.
  - Autopilot flight modes. The pilot mainly alternated between the two main autopilot modes:
    - Select/Hold of attitudes, altitude, vertical speed, track, heading, IAS;
    - Flight Plan execution function allowed performing a mission in a completely automatic mode. The RFO can select, load, activate, suspend and modify a flight plan among the ones available in a list to be preloaded in the GCS before flight.
    - Automatic execution of on-board calculated separation assurance manoeuvre and collision avoidance manoeuvre (part of Traffic Detect and Avoid function).

Figure 25 Ground Control Station Set-up

Figure 26 Depiction of the Ground Control Station HMI

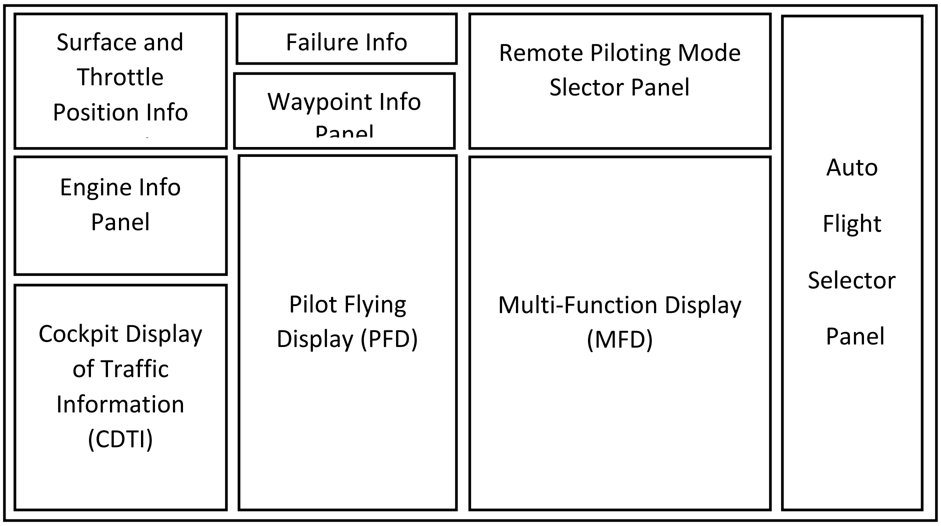


Figure 27 Ground Control Station multi-display legend

5.3.2 Methods

The methods used to carry out the human performance assessment were mainly subjective measurement methods and therefore, the type of data collected data was mainly qualitative. The qualitative methods, given the limited size of the participants involved in the study, allowed to obtain more rich insight on human performance that was then explored and understood in detail during the debriefings that were performed after the each flight.

The subjective measurement methods used included Observations, Questionnaire and Debriefing sessions.

1. Direct Observations. During each of the test flights one human factors expert was present in the ground station observing the activities and collecting insights about remote performance, interface interaction, communication and about possible difficulties experienced. The information collected during this phase was used as a basis to carry out the debriefing performed after each flight run.

2. Post-Flight Questionnaires. Customised questionnaires were filled in after each of the flights performed. The questionnaires aimed to capture workload, situation awareness, level of performance, quality of interaction with the systems, quality of communication and error propensity during each flight scenario in a standardised way (see Appendix A).
3. Debriefing sessions. The debriefing sessions were carried out after each test flight, once both the pilot had filled out the questionnaire. The debriefing addressed the main difficulties the operator experienced as well as any other relevant events that occurred. The operators were confronted with the notes taken during the observations in order to clarify the collected information. A final debriefing at the end of the day was carried out with all participants involved in the flight trials.

5.3.3 Scenarios

The flight scenarios that were performed during the flight trials were the following:

1. En-Route Operations of the RPAS, entering and leaving a Temporary Segregated Area from/to an unrestricted managed airspace;
2. En-Route Operations of the RPAS in presence of potentially conflicting manned traffic;
3. Detect and Avoid testing (Traffic Avoidance) – One manned vehicle involved;
4. Detect and Avoid testing (Traffic Avoidance) – Unmanned vehicle involved;

5. En-Route Operations of the RPAS, under C3L security threats (spoofing, jamming).

5.4 RAID Applications Results

This sub-chapter contains two types of results that originate from two distinct activities:

1. The first set of results comes from the classification of RAID applications according to the Mediated Support Taxonomy defined in Chapter 3.
2. The second set of results reports on the RAID project human performance assessment outcomes.

   The results that were obtained during the human-in-the-loop simulations were organized for the purpose of this thesis work around human performance benefits and issues for each of the considered applications. Each benefit and issue was in its turn categorized according to the Human Performance Impactors that it affected (sub-chapter 2.5).

5.4.1 RPAS Out-of-the-Window view application

The RPAS Out-of-the-Window view application classification according to the Mediated Support Taxonomy is presented in the table below.

Table 15 RPAS Out-of-the-Window view application classification

RPAS Out-of-the-Window view application							
Context of the supported							
1	**Flight phase supported**						
	Taxi	x	Take-off/Climb	x	En-route	x	
	Descent	x	Approach	x	Landing	x	
2	**Supported tasks**						
	Aviate		Navigate	x	Communicate		Manage
3	**Involved actors**						
	Remote Pilot						
Mediated Control Classification							
1	**Rendering modality(ies)**						
Visual							
2	**Type of Visual Display**						
Forward-Facing Display							
3	**Visual Display Frame of Reference (FOR)**						
3D egocentric (immersed)							
4	**Augmented Perception (Real-Virtual Integration)**						
Visibility of the real live view of the scene.							

5	Control-Display (C/D) Congruence						
-							
6	Automation Level classification						
Automation level for supported cognitive functions							
Information Acquisition (A)	A2	Information Analysis (B)		Decision and Action Selection (C)		Action Implementation (D)	
Rationale:							
▪ **Information Acquisition (A) –** The application provides the pilot with the live video from the RPA on-board camera.							

Benefits

Benefit 1: The RPA outside-view display improves the pilot confidence level and trust in the navigation information provided on the other displays.

The RPA outside view information was used by the remote pilot as confirmation means for the navigation information provided by the other displays. The outside view camera was mainly used by the remote pilot during datalink spoofing to understand/confirm the manoeuvres the RPA was performing and the direction it was flying.

Human Performance Impact: Trust

Issues

Issue 1: The positioning of Out-of-the-Window view display far from the other displays can distract the remote pilot.

During the flight trials the outside view camera was not placed directly in front of the pilot, it was placed on the left side of the remote pilot instead, due to technical problems (see Figure 25 Ground Control Station Set-upFigure 25). This made difficult for the pilot to compare the navigation information from the system, displayed in the MFD with the outside view.

Human Performance Impact: Situation Awareness

Issue 2: The number of displays provided to the pilot can increase the cognitive workload to process different types of information.

The RPA the outside view display is a complement to the main GCS split screen display. The fact that there are several displays provided to the pilot might result in an increased cognitive effort to distribute attention between several displays.

Human Performance Impact: Cognitive Workload

Issue 3: The lack of integration between the outside-view display and the information on the other displays might increase pilot workload.

The information displayed from the RPA the outside view display was not integrated with the information displayed on the main display. The pilot mentioned that having a collimated vision of the flight director could provide him some support in performing a separation manoeuvre.

Human Performance Impact: Cognitive Workload

5.4.2 RPAS Traffic Detect and Avoid - Self-Separation functionality

The RPAS DAA Self-Separation functionality view application classification according to the Mediated Support Taxonomy is presented in the table below.

Table 16 RPAS DAA - Self-Separation functionality classification

RPAS DAA - Self-Separation functionality								
Context of the supported								
1	**Flight phase supported**							
	Taxi		Take-off/Climb		En-route	x		
	Descent	x	Approach	x	Landing			
2	**Supported tasks**							
	Aviate	x	Navigate	x	Communica te		Manage	
3	**Involved actors**							
	Remote pilot and Air Traffic Controller							
Mediated Control Classification								
1	**Rendering modality(ies)**							
Visual								
2	**Type of Visual Display**							
Forward-Facing Display (touchscreen)								
3	**Visual Display Frame of Reference (FOR)**							
2D display Map view display (MFD) + Pilot Flying Display (PFD) + 2D Cockpit Display of Traffic Information display (CDTI). The separation manoeuvre is displayed on the MFD, the surrounding traffic information is continuously displayed on the CDTI and the separation alert is displayed on the PFD.								
4	**Augmented Perception (Real-Virtual Integration)**							

<table>
<tr><td colspan="8">Real replaced by virtual. Synthetic 2D representation models of the situation.</td></tr>
<tr><td>5</td><td colspan="7">Control-Display (C/D) Congruence</td></tr>
<tr><td colspan="8">Direct Control on the display (touchscreen display)</td></tr>
<tr><td>6</td><td colspan="7">Automation Level classification</td></tr>
<tr><td colspan="8">Automation level for supported cognitive functions</td></tr>
<tr><td>Information Acquisition (A)</td><td></td><td>Information Analysis (B)</td><td>B5</td><td>Decision and Action Selection (C)</td><td>C3</td><td>Action Implementation (D)</td><td>D4</td></tr>
<tr><td colspan="8">Rationale:</td></tr>
<tr><td colspan="8">
Information Analysis (B) – The application detects a possible loss of separation and provides a visual alert to the pilot (displayed on the Pilot Flying Display).
Decision and Action Selection (C) – The application proposes the remote pilot a self-separation manoeuver to restore the considered separation minima.
Action Implementation (D) – If the pilot accepts the automatic self-separation manoeuvre proposed to him the system implements automatically the manoeuvre in autopilot.
</td></tr>
</table>

Benefits

Benefit 1: Automatic traffic separation manoeuvre reduces the remote pilot workload.

The fact that the RPA performs an automated separation manoeuvre to avoid the traffic relieves the pilot from having to decide and implement a manoeuvre with time pressure.

Human Performance Impact: Cognitive Workload

Benefit 2: Automatic traffic separation manoeuvre might reduce pilots' error rate due to increased support in implementing an action.

In case there is a need to implement a separation manoeuvre, the automatic separation function can reduce the remote pilot workload, preventing that he commits an error due to pressure.

Human Performance Impact: Human Error

Issues

Issue 1: Lack of awareness on the separation manoeuvre proposal.

The functionality proposed a self-separation manoeuvre option that was not conspicuous enough to the remote pilot. The self-separation manoeuvre is only displayed for a short amount of time on the map view display before the pilot is able to accept it or not. If the pilot is distracted or was paying attention to other display, not noticing the proposed manoeuvre, he will then be out-of-loop.

During the flight trials it was not clear enough for the remote pilot if the self-separation manoeuvre function was active or not. This happened because the button was not visible enough and also because the remote pilot was paying attention to the map view display and therefore, he preferred to perform the manoeuvre manually (see Figure 28).

Human Performance Impact: Situation Awareness

Figure 28 Automatic Separation manoeuvre function display

Issue 2: If there is a problem with the self-separation manoeuvre and the remote pilot has to take back the control of the RPA, this may increase cognitive workload and the propensity to commit erroneous actions.

If the remote pilot decides to take back the control of the RPA because the separation manoeuvre is not being executed correctly, he might experience high workload and probability to commit an error might be higher. The fact that he/she is not physically present in the aircraft when he/she is piloting, along with the lack of haptic, acoustic and visual cues, might lead to high workload scenarios. He has limited access to information that is important to rapidly be able to decide and implement a strategy to take the control of the RPA and to avoid the surrounding traffic.

During the flight trials when the remote pilot needed to perform critical actions in a limited amount of time, he had more difficulties interacting with the ground control station and he mentioned that his cognitive workload increased in these situations.

Human Performance Impact: Cognitive Workload; Human Error

Issue 3: Excessive trust in the separation avoidance functionality may lead to complacency and Situation Awareness reduction.

If the remote pilot over trusts this functionality he might decrease his attention levels and therefore miss critical information that he should be supervising.

During the flight trials, in case of loss of separation with an intruder in the operative manoeuvring area, the pilot often preferred to perform the separation manoeuvre manually.

Human Performance Impact: Trust; Situation Awareness

Issue 4: Reduced involvement in the traffic avoidance manoeuvres may lead to loss of skill and proficiency.

The fact that the remote pilot has a more tactical role while flying the RPA and the traffic avoidance manoeuvres proposed can be automatically implemented might degrade his flying skills on the long run.

Human Performance Impact: Skill

5.4.3 RPAS Traffic Detect and Avoid - Collision Avoidance functionality

The RPAS DAA Collision Avoidance functionality view application classification according to the Mediated Support Taxonomy is presented in the table below.

Table 17 RPAS DAA - Collison Avoidance functionality

<table>
<tr><td colspan="9">RPAS DAA Collision Avoidance functionality</td></tr>
<tr><td colspan="9">Context of the supported</td></tr>
<tr><td rowspan="3">1</td><td colspan="8">Flight phase supported</td></tr>
<tr><td colspan="2">Taxi</td><td></td><td colspan="2">Take-off/Climb</td><td></td><td>En-route</td><td>x</td></tr>
<tr><td colspan="2">Descent</td><td>x</td><td colspan="2">Approach</td><td>x</td><td>Landing</td><td></td></tr>
<tr><td rowspan="2">2</td><td colspan="8">Supported tasks</td></tr>
<tr><td>Aviate</td><td>x</td><td>Navigate</td><td>x</td><td>Communica te</td><td></td><td>Manage</td><td></td></tr>
<tr><td rowspan="2">3</td><td colspan="8">Involved actors</td></tr>
<tr><td colspan="8">Remote pilot and Air Traffic Controller</td></tr>
<tr><td colspan="9">Mediated Control Classification</td></tr>
<tr><td>1</td><td colspan="8">Rendering modality(ies)</td></tr>
<tr><td colspan="9">Visual</td></tr>
<tr><td>2</td><td colspan="8">Type of Visual Display</td></tr>
<tr><td colspan="9">Forward-Facing Display (touchscreen)</td></tr>
<tr><td>3</td><td colspan="8">Visual Display Frame of Reference (FOR)</td></tr>
<tr><td colspan="9">2D display Map view display (MFD) + Pilot Flying Display (PFD) + 2D Cockpit Display of Traffic Information display (CDTI). The separation manoeuvre is</td></tr>
</table>

displayed on the MFD, the surrounding traffic information is continuously displayed on the CDTI and the separation alert is displayed on the PFD.	
4	**Augmented Perception (Real-Virtual Integration)**
Real replaced by virtual. Synthetic the 2D representation models of the situation.	
5	**Control-Display (C/D) Congruence**
Direct Control on the display (touchscreen display)	
6	**Automation Level classification**
Automation level for supported cognitive functions	

Information Acquisition (A)		**Information Analysis (B)**	**B5**	**Decision and Action Selection (C)**	**C4**	**Action Implementation (D)**	**D6**
Rationale:							

- **Information Analysis (B) –** The application detects a possible collision and provides a visual alert to the pilot (Pilot Flying Display).
- **Decision and Action Selection (C) –** The application automatically elaborates a collision avoidance manoeuver with respect to the higher priority aircraft.
- **Action Implementation (D) –** The manoeuver is automatically taken over by the system. The remote pilot can monitor, interrupt and take the control of the manoeuvre at any moment.

Benefits

Benefit 1: Automatic traffic avoidance manoeuvre reduces the remote pilot workload.

The fact that the RPA performs the traffic avoidance manoeuvre independently relieves the pilot from having to quickly implement a manoeuvre.

Human Performance Impact: Cognitive Workload

Benefit 2: Automatic collision avoidance manoeuvre might reduce error rate due increased support to implement an action.

In case there is a need to implement a separation manoeuvre the automatic separation can reduce the remote pilot workload and prevent this way that he commits an error due to pressure.

Human Performance Impact: Human Error

Issues

Issue 1: Lack of awareness on the collision avoidance manoeuvre.

The fact that the traffic avoidance manoeuvre is automatically implemented may leave the remote pilot out of the process that he should be monitoring. The manoeuvre is displayed to the remote pilot on the map view display before being implemented, disappears from the interface while it is being executed. If the pilot is distracted he might not see the manoeuvre that the system is about to implement, thus leaving him out-of-the-loop. One consequence might be the lack of trust in this functionality because he might miss the action that is about to be automatically implemented.

Human Performance Impact: Situation Awareness

Issue 2: If there is a problem with the collision avoidance manoeuvre and the remote pilot has to take back the control of the RPA, his cognitive workload and the propensity to commit erroneous actions may increase.

If the remote pilot decides to take the back the control of the RPA because the collision avoidance manoeuvre is not being executed correctly, he might experience high workload and the probability to commit an error might be higher. The fact that he/she is not physically present in the aircraft when he/she is piloting, along with the lack of haptic, acoustic and visual cues, might lead to high workload scenarios. He has limited access to information that is important to rapidly be able to decide and implement a strategy to take the control of the RPA and to avoid the surrounding traffic.

Human Performance Impact: Cognitive Workload; Human Error

Issue 3: Excessive trust in the automatic collision avoidance functionality could lead to complacency and Situation Awareness reduction.

If the remote pilot starts to over trust this functionality he might decrease his attention levels and miss critical information that he should be supervising during the implementation of a collision avoidance manoeuvre. This could lead to dangerous situations where the pilot misses a failure or a problem in the system. During the flight trials, the RPA was flying in a segregated Operational Manoeuvring Area: In the future, if the RPA is flying in unsegregated airspace this might turn out to be an issue that can decrease operational safety levels.

Human Performance Impact: Trust; Situation Awareness

Issue 4: Reduced involvement in the traffic avoidance manoeuvres may lead to loss of skill and proficiency.

The fact that the remote pilot has a more tactical role while flying the RPA and the traffic avoidance manoeuvres proposed can be automatically implemented might degrade his flying skills on the long run.

Human Performance Impact: Skill

Chapter 6. Mediated Support Taxonomy Discussion and Consolidation

This chapter presents the consolidation and discussion of the Mediated Support Taxonomy according to the results obtained in each of the case studies presented previously.

The discussion consists in an association between the categories of the mediated support classification results with the human performance issues and benefits.

6.1 Consolidation of the Mediated Support Taxonomy

The application of the Mediated Support classification defined in Chapter 3 to technologies of the two different case studies motivated the some changes to the taxonomy that are explained below.

The rendering modalities and the Levels of Automation adopted remained untouched in the consolidated scale since they did not introduce any categorization issue or doubts during the classification.

Types of display

During the application of the taxonomy the analysis of the Head Down Display use generated some classification issues if applied outside of the flight deck context, because it referred to the direction where the pilot on deck is looking. If we are considering remote piloting from an RPAS Ground Control Station, the term Head Down Display is not meaningful anymore, for this reason a new category of display has been proposed, the Forward Facing Display.

Visual Display Frame of Reference

The Visual Frame of Reference Classification maintained the three main categories: 3D Display, 2D Display and Multiple displays. The Multiple displays category was defined as a combination of two or more frames of reference in a single display and the 2D coplanar display was moved under this hat. Also, under the “Multiple Displays” category a new category was added to accommodate the combination of more than two types of displays, like the case of RPAS Traffic Detect and Avoid functionalities.

Augmented Perception

The functional taxonomy of AR environment categories from Hugues et al. (2011) that was used to classify the applications analysed in the case studies was also re-defined after the application to the functionalities in the two case studies. The scale re-definition had the intent to integrate the “Modelled information” category that was missing. The categories “Direct Information Acquisition” and “Artefact-based- Information Acquisition were also added to cover the real environment on a Real-Virtual continuous scale. As represented in the table below, the new scale now ranges from the direct acquisition from the real environment (Real) up to the acquisition of modelled information (Virtual).

Table 18 Definition of the new concepts on the Augmented Perception scale

Definition of the new categories Augmented Perception		
Real	Direct Information Acquisition	The human acquires the information directly from environment without the mediation of any tool.

Virtual	Artefact-based Info Acquisition	The human acquires relevant information on the process s/he is following with the support of low-tech non-digital artefacts.
	Augmented Visibility	The system supports perception real physical environment by reproducing real information that is not visible from his location (e.g. zoomed camera video from an inaccessible location).
	Augmented Comprehension	The system supports perception of real physical environment by highlighting and improving this information (virtual objects overlaid on the real scene).
	Virtualisation	The system supports by replacing the physical environment with synthetic reproduction of those elements.
	Modelled Information	The system supports the human by transforming the physical environment into modelled representation of it (e.g. 3D or 2D graphical elements or values that represent real information).

Control-Display (C/D) Congruence

The Control-Display (C/D) Congruence classification did not reveal any advantage in terms of classification and identification of human performance issues for the studied applications.

This could be related to the limited sample of applications or functionalities investigated in this work, some of which did not even involve control, like in the case Head Up Display applications. The remaining applications involved direct control with touchscreen displays but the level of detail of the assessed human performance benefits and issues did not allow to identify any particular trends. This is in a way correlated to the focus of the human performance assessment during the validation exercises, which did not go into much detail concerning control modalities.

A consolidated Mediated Support Taxonomy is presented here below.

Table 19 Mediated Support Taxonomy

Mediated Support Taxonomy

1. Rendering Modality(ies)

Visual	Auditory	Tactile

2. Types of display

Head-Up Display (HUD)	Head-Worn Display (HMD)	Hand Held Display (HHD)	Head-Down Display (HDD)	Forward Facing Display (FFD)

3. Visual Display Frame of Reference (FOR)

3D Single Display		2D Single Display		Multiple Displays		
3D egocentric (immersed)	3D exocentric (tethered)	2D map view (rear-view)	2D profile display (side-view)	2D coplanar display	2D + 3D display	Combination of more than 2 displays

4. Augmented Perception (Real-Virtual Integration)

Direct Information Acquisition	Artefact-based Info Acquisition	Augmented Visibility	Augmented Comprehension	Virtualization	Modelled Information

5. Automation Level

A Information Acquisition	**B Information Analysis**	**C Decision and Action Selection**	**D Action Implementation**
A0 Direct Information Acquisition	B0 Human Info Analysis	C0 Human Decision making	D0 Manual Action and
A1 Artefact-based Info Acquisition	B1 Artefact-based Info Analysis	C1 Artefact-based Decision Making	D1 Artefact-based Control
A2 Low-Level Automation Support of Info Acquisition	B2 Low-Level Automation Support of Info Analysis	C2 Automated Decision Support	D2 Step-by-step Action Support
A3 Medium-Level	B3 Medium-Level	C3 Rigid Automated	D3 Low-Level Support of

Automation Support of Info Acquisition	Automation Support of Info Analysis	Decision Support	Action Sequence Execution
A4 High-Level Automation Support of Info Acquisition	B4 High-Level Automation Support of Info Analysis	C4 Low-Level Automatic Decision Making	D4 High-Level Support of Action Sequence Execution
A5 Full Automation Support of Info Acquisition	B5 Full Automation Support of Info Analysis	C5 High-Level Automatic Decision Making	D5 Low-Level Automation of Action Sequence Execution
		C6 Full Automatic Decision Making	D6 Medium-Level Automation of Action Sequence Execution
			D7 High-Level Automation of Action Sequence Execution

6.2 Discussion on the Mediated Support Taxonomy application

This sub-chapter discusses the main results gathered by confronting the application of the Mediated Support Taxonomy with the associated human performance results.

6.2.1 Rendering modality

The rendering modalities of the applications and functionalities explored in both case studies (Flight Deck and RPAS) were exclusively visual. This was mainly due to the fact that the applications studied did have a relatively low maturity level (reaching up to a pre-industrial maturity phase).

Visual displays are the most important source of information for the flight crew in an aircraft and, therefore, it is normal that applications in early maturity phases pose a greater focus on this rendering modality.

Even though the applications were only rendered visually, the importance of having the information rendered in more than a single modality was demonstrated by the human performance results (issues) of the RPAS Traffic detect and avoid functionalities. The lack of awareness of the remote pilot on the status of the separation manoeuvre support was a good example on the importance of alerts and warnings functionalities design.

Cardosi & Murphy (1995) highlighted the importance of adequate HMI design in helping pilots focusing their attention on the appropriate displays and messages, avoiding distraction from other sources and compensating for cognitive tunnelling. The easier it is to detect and identify important information, the lower the task demand and consequently the workload level (Ahlstrom & Longo, 2003). The rendering modality can play an important role in highlighting and directing pilots' attention to the most relevant elements.

The combined use of both visual and auditory information is often recommended in order to attract attention, improving this way Situation Awareness and decreasing workload (Simpson & Williams, 1980). The alert or warning provided in the form of an auditory signal has the advantage to be quickly perceived by the operator.

The combination of more than one rendering modality provides a greater probability of detection of an issue for the user. This is especially important for alerting and warning functionalities. The most used combination of rendering modalities to attract attention is the visual and auditory information.

The provision of auditory alerts and warnings could help to distinguish the status (urgency) of an event. In addition, more conspicuous visual alert information could improve the pilots' workload and situation awareness during operations.

6.2.2 Types of display

The applications investigated in the case studies were also classified by type of displays, as it can be seen in the figure below.

Table 20 Distribution of the analysed technologies according to the type of display

Applications and functionalities mapped on the type of displays	
Head Up Display (HUD)	Synthetic Terrain Presentation Application Enhanced Synthetic Vision application
Hand Held Display (HHD)	Gate-to-Gate application
Head Down Display (HDD)	Head Down Synthetic Vision System Weather Conflict Detection and Resolution
Forward Facing Display (FFD) (RPAS)	Out-of-the-Window view application RPAS Traffic Detect and Avoid Self-Separation functionality RPAS Traffic Detect and Avoid Collision Avoidance functionality

6.2.2.1 Head Up Displays

Head-Up Displays (HUD) allow overlaying imagery directly over the real-world domain, such that when the pilot moves his/her head the imagery moves in synchrony.

6.2.2.1.1 Head Up Display Identified Benefits

The HUD was considered useful to support local navigation guidance and improve awareness on the aircraft immediate surrounding environments e.g. terrain and obstacles. Therefore, this type of displays are adequate for tasks and flight phases in which it is crucial for the pilot to continuously keep monitoring out-of-the-window scene or to check for congruency in information outside (e.g. taxi, take-off, climb, approach and landing phases).
The results have also demonstrated that HUDs are particularly useful in providing pilots with important terrain information, hazards and obstacles related information, particularly in degraded visual conditions.

6.2.2.1.2 Head Up Display Identified Issues

Results have shown that the use of HUD can result in unbalanced awareness between the two flight crew members if only one pilot is using the HUD or if both are using this type of display but are not provided with the same information. This can ultimately impact the quality of their communication, cooperation and shared situation awareness.
<u>Mitigations:</u>

- Both pilots should have access to the same application in the same type of display. This will promotes an adequate shared Situation Awareness inside the flight deck.
- Both pilots should have access to the same information, this way they can adequately coordinate and still apply good CRM procedures.

- Training, good distribution of tasks and communication between flight crew members can help pilots maintain a good situation awareness.

One of the most prevalent issues reported on HUDs during the evaluations was the cluttered display. This type of displays get easily cluttered and the information provided can mask other relevant information outside the aircraft. This can degrade visual detection and cause attention tunnelling phenomena, reducing in this sense the pilots' awareness on the surroundings. This is a well-documented drawback of this HUDs in literature (Ververs and Wickens, 1998; Hofer, Braune, Boucek, & Pfaff, 2000).

<u>Mitigations:</u>

- Head Up Displays should allow pilots' the option to declutter the visual elements being provided to him.
- Head Up Displays are adequate to improve monitoring and comparing out-of-the-window elements, therefore the information should be provided in a very simple and meaningful way to the pilot, avoiding that he focuses on irrelevant elements for the task being performed.

6.2.2.2 Hand Held Displays

6.2.2.2.1 Hand Held Displays Identified Benefits

The map information on the HHD provided good global awareness of the airport map, extending the human "Situation Awareness envelope" into being able to anticipate future events.

6.2.2.2.2 Hand Held Displays Identified Issues

The fact that the G2G application is provided in a hand-held display (tablet) resulted in unbalanced distribution of information between the two flight crew members: only one pilot, the one using the G2G would develop and maintain the global picture, while the PF would be out-of-the loop concerning such picture as s/he focuses solely on executing the taxi. Such distribution of SA among the crew members would reduce opportunities for cross checks and affect good Crew Resource Management on the flight deck.

Mitigations:

- Both pilots should have access to the same information, this way they can adequately coordinate and still apply good CRM procedures, it is something that promotes an adequate shared situation awareness and cooperation inside the flight deck.
- Training, good distribution of tasks and communication between flight crew members can help pilots maintain a good situation awareness.

Hand-Held Displays can increase the head-down time of pilots. This can turn out to be particularly critical in flight phases in which pilots should be continuously monitoring out-of-the-window scene or in which they need to check for congruency in information outside (e.g. taxi, take-off, climb, approach and landing phases).

Mitigations:

- The use of this type of displays should be privileged in phases in which the pilot does not need to focus on information outside the aircraft.
- The use of this type of displays should be avoided in phases that the crew workload levels are higher. HHD is a good type of display for planning tasks.

6.2.2.3 Head Down Displays

6.2.2.3.1 Head Down Displays Identified Benefits

The results showed that the Head-Down Display positioned between the PF and the PM allowed easy access to the same information, facilitating their interaction and promoting the Crew Resource Management.

6.2.2.3.2 Head Down Displays Identified Issues

Head-Down Displays in the aircraft can increase pilots' head-down time. This can turn out to be particularly critical in flight phases that pilots need to continuously keep monitoring the out-of-the-window scene or/and check for congruency in outside information (e.g. taxi, take-off, climb, approach and landing phases).

Mitigations:

- These type of displays should be privileged for phases in which pilots do not need to focus on information outside the aircraft.
- If the head-down display is positioned within the visual scan range from the pilot and closer to the window, pilots might not miss important information on the aircraft outside surrounding environment.

6.2.2.4 Summary of the recommendations for different types of display

The table below provides a synthetic presentation of the results, relating the different types of display with the benefits and issues identified in the case studies. The table puts in evidence the human performance impact of those benefits and issues and can be used as guidance by designers in making human-machine interface choices.

Table 21 Design recommendations for the different types of display

Design recommendations for different Types of display (HP impact)			
Type of display	**HP Benefits**	**HP Issues**	**Mitigations**
Head Up Display (HUD)	1. HUD improves local navigation guidance and awareness on the aircraft immediate surrounding environment.(Situation Awareness) 2. HUD support is adequate for tasks and flight phases in which the pilot should continuously keep monitoring the out-of-the-window scene (taxi, take-off, climb, approach and landing phases). (Situation Awareness) 3. HUDs are useful in providing pilots with important terrain-related information, particularly in degraded visual conditions. (Situation Awareness)	1. Both flight crew members should have the same information on the HUD, otherwise there will be an unbalanced awareness between the two of them. (Situation Awareness) 2. HUD get easily cluttered and the information provided can mask other relevant information outside the aircraft, degrading visual detection and the sense the pilots' awareness on the surroundings. (Workload)	▪ Issue 1: Both pilots should have access to the same application in the same type of display. ▪ Issue 1: Both pilots should have access to the same information, this way they can adequately coordinate and still apply good CRM procedures. ▪ Issue 1: Training, good distribution of tasks and communication between flight crew members can help pilots maintain a good situation awareness. ▪ Issue 2: Head Up Displays should allow pilots' the option to declutter the visual elements being provided to him. ▪ Issue 2: Head Up Displays are adequate to improve monitoring and comparing out-of-the-window elements, therefore the information should be provided in a very simple and meaningful way to the

			pilot, avoiding that he focuses on irrelevant elements for the task being performed.
Hand Held Display (HHD)	1. This type of displays are adequate to provide a good global awareness and a wider Situation Awareness range. (<u>Situation Awareness</u>)	1. HHD can promote a bad shared situation awareness between the two flight crew members. (<u>Situation Awareness)</u> 2. HHD can increase pilots' head-down time in flight phases where pilots need to continuously keep monitoring the out-of-the-window scene. (<u>Situation Awareness)</u>	▪ <u>Issue 1:</u> Both pilots should have access to the same information, this way they can adequately coordinate and still apply good CRM procedures. ▪ <u>Issue 1:</u> Training and good distribution of tasks will improve communication between flight crew members. ▪ <u>Issue 2:</u> The use of this type of displays should be privileged in phases in which the pilot does not need to focus on information outside the aircraft. ▪ <u>Issue 2:</u> The use of this type of displays should be avoided in phases that the crew workload levels are higher. HHD is a good type of display for planning tasks.
Head Down Display (HDD)	1. HDD placed between PF and the PM allows easy access to the same information, facilitating a shared SA and	1. HDD can increase pilots' head-down time in flight phases where pilots need to continuously keep	▪ <u>Issue 1:</u> HHD use should be privileged in phases in which pilots do not need to focus

	interaction. (<u>Situation Awareness</u>)	monitoring the out-of-the-window scene. (<u>Situation Awareness)</u>	on information outside the aircraft. ▪ <u>Issue 1:</u> If HDD is positioned within the pilots' visual scan range and closer to the window, pilots might not miss important information on the aircraft outside surrounding environment.

6.2.3 Visual Display Frame of Reference (FOR)

The applications evaluated in the two case studies covered all three main categories considered to visual frame of reference: 3D displays, 2D displays and multiple displays.

It is not possible to assume that there is a single best visual frame of reference for all possible aviation tasks, in fact, current flight path management and navigation applications include different types of displays, all with different frames of reference according to the type of tasks that are being performed.

The applications and functionalities studied in this work are distributed according to their visual frame of reference in the table below.

Table 22 Distribution of the analysed technologies according to visual display frame of reference

Applications and functionalities mapped on the visual display frame of reference		
3D Display	3D egocentric (immersed)	Synthetic Terrain Presentation Application Enhanced Vision System Application RPAS Out-of-the-window view Head Down Synthetic Vision System
	3D exocentric (tethered)	_
2D Display	2D map display (rear-view)	Gate to Gate application
	2D profile display (side-view)	_
Multiple Display	2D coplanar display (2D map + 2D profile)	Weather Conflict Detection and Resolution
	2D + 3D display	_
	Combination of more than 2 types of displays	RPAS Traffic Detect and Avoid - Self-Separation functionality RPAS Traffic Detect and Avoid - Self-Separation functionality

6.2.3.1 3D Egocentric Display

6.2.3.1.1 3D Egocentric Display Identified Benefits

The 3D visual frame of reference provided support to tasks that require immediate surrounding awareness and local guidance. It also provides a more “natural” representation of the 3D world.

The 3D egocentric display from the Head Down SVS was particularly useful in supporting pilots' awareness and seamless transition from the airborne phase to the ground phase.

6.2.3.1.2 3D Egocentric Display Identified Issues

3D displays impose a cost in terms of global awareness and anticipation of future events.

Mitigations:

- 3D Egocentric displays should be avoided to support the anticipation of future events or to depict future scenarios.

Pilots reported that this type of frame of reference tends to create the perceptual illusion that the terrain is closer than it actually is. This impacts pilots' capacity to judge distance and possibly increasing the propensity to human error. Spatial awareness biases and distortions have been reported in other studies, like Alexander & Wickens (2005), where they also deemed as critical if the aircraft is flying to close ground, like the scenarios considered in the case studies where these applications are intended to support, namely approach and landing.

Mitigations:

- Pilots should be provided with relevant supplementary information to compensate for the spatial awareness biases (e.g. numeric distance references).

6.2.3.2 2D Map display

6.2.3.2.1 2D Map Display Identified Benefits

The 2D map display gave pilots' a more global awareness of the aircraft surroundings, in particular by providing a more strategical and complete view. Having access to information on a more global and future timeframe allowed pilots to anticipate their decisions and consequently managing their tasks in order to reduce cognitive workload further down the line.

This overview is important for the crew to know where they are, where do they need to go to and which taxi route they have to take. This type of display was useful to present hazards along the path.

6.2.3.3 2D Coplanar Display

6.2.3.3.1 2D Coplanar Display Identified Benefits

The 2D map display provided pilots' with a more global awareness of surrounding hazards and enabling strategic management. Having access to information on a more global and future timeframe allowed pilots to anticipate their decisions and consequently manage their tasks in order to reduce cognitive workload further down the line.

6.2.3.3.2 2D Coplanar Display Identified Issues

The lack of integration between the two views that compose the 2D coplanar display can cause some confusion and increase the pilot effort to understand certain information.
Mitigation:

- The two displays should be consistent in the way they present information and phenomena.
- The information displayed in the two displays should be integrated and complementary.

6.2.3.4 Combination of more than 2 types of displays

6.2.3.4.1 Combination of more than 2 types of displays Identified Benefits

The RPAS ground control station consists in the combination of different types of displays on a single interface. This combination allowed to keep the pilot informed about all of the important processes and information on-board of remoted pilot aircraft.

6.2.3.4.2 Combination of more than 2 types of displays Identified Issues

The multiple display combination imposed a visual scanning cost that will be higher according to a higher number of displays provided for the specific task and the distance between them. This situation was illustrated during the RPAS DAA evaluation results by the fact that the pilot failed to recognise that the automatic separation avoidance manoeuvre was active and was being proposed to him.

Mitigations:

- Displays that support related tasks should be located physically close, this will help reduce the visual scanning effort and possibly cognitive workload associated to attentional allocation.
- HMI design should support the pilot by highlighting and steering his attention to the display with information he should attending at a given moment.
- The multiple displays should be consistent in the way they present information and phenomena.
- The information displayed in the multiple displays should be integrated and complementary.

6.2.3.5 Summary of the recommendations for Visual Display Frame of Reference (FOR)

The table below provides a synthetic presentation of the results, relating the different visual frame of reference types with the benefits and issues identified in the case studies. The table puts in evidence the human performance impact of those benefits and issues and can be used as guidance by designers in making human-machine interface choices.

Table 23 Design recommendations for the different visual frame of the reference types

Design recommendations for different Visual Frame Of Reference (HP impact)			
Visual Frame Of Reference	**HP Benefits**	**HP Issues**	**Mitigations**
3D Egocentric Display	1. The 3D visual frame of reference provided support to tasks that require immediate surrounding awareness and local guidance. (Situation Awareness) 2. The 3D egocentric display allows a more seamless transition from airborne phase to the ground phase. (Situation Awareness)	1. 3D displays impose a cost in terms of global awareness and anticipation of future events. (Situation Awareness) 2. This type of frame of reference tends to create the perceptual illusion that the terrain is closer than it actually is. (Human Error)	▪ Issue 1: This type of display should be avoided to support anticipation of future events or scenarios. ▪ Issue 2: Supplementary information should be provided to compensate for the spatial awareness biases.
2D Map display	1. 2D map display provides pilots' a better global awareness of surrounding hazards, giving a strategic view over the flight path. (Situation Awareness) 2. This type of display is useful to present hazards along the flight path. (Workload)		
2D Coplanar Display	1. 2D coplanar display provided pilots' with a more global awareness of surrounding hazards with a focus on strategic management and	1. Lack of integration between the two views that compose the 2D coplanar display can cause some confusion and increase pilots' effort to understand certain	▪ Issue 1: The two displays should be consistent in the way they present information and phenomena.

	complete view. <u>(Situation Awareness)</u>	information. <u>(Situation Awareness)</u>	▪ <u>Issue 1:</u> The information displayed in the two displays should be integrated and complementary.
Combination of more than 2 types of displays	1. The multiple display combination allows to keep the pilot informed about all of the important processes and information on-board of the RPA. <u>(Situation Awareness)</u>	1. The multiple display combination imposes a visual scanning cost that will be higher according to a higher number of displays provided for the specific task and the distance between them. <u>(Workload)</u>	▪ <u>Issue 1:</u> Displays that support related tasks should be located physically close, this will help reduce the visual scanning effort and possibly cognitive workload associated to attentional allocation. ▪ <u>Issue 1:</u> HMI design should support the pilot by highlighting and steering his attention to the display with information he should attending at a given moment. ▪ <u>Issue 1:</u> The multiple displays should be consistent in the way they present information and phenomena. ▪ <u>Issue 1:</u> The information displayed in the multiple displays should be integrated and complementary.

6.2.4 Augmented Perception

The studied applications covered almost all of the re-defined categories that were considered in the augmented perception scale (see Table 24).

Table 24 Distribution of the analysed technologies according to the augmented perception categories

Applications and functionalities mapped on Augmented Perception categories		
Real	Direct Information Acquisition	_
	Artefact-based Info Acquisition	_
	Augmented Visibility	RPAS Out-of-the-Window view application
	Augmented Comprehension	Synthetic Terrain Presentation application Enhanced Vision System application
	Virtualisation	Head Down Synthetic Vision System
Virtual	Modelled Information	Weather Conflict Detection and Resolution Gate to Gate application RPAS Traffic Detect and Avoid - Self-Separation functionality RPAS Traffic Detect and Avoid - Self-Separation functionality

6.2.4.1 Virtualization and Modelled Information

6.2.4.1.1 Virtualization and Modelled Information Identified Benefits

Functionalities revealed that virtual representation and modelling of real world information can improve pilots' situation awareness, highlighting important elements and supporting them in managing their cognitive resources in a given task. Higher levels of modulation and abstraction enable the representation of future events that can have positive impact on pilot performance, enabling a more strategic approach in terms of decision-making and implementation of actions towards this type of tasks.

Virtual and modelled rendering of real world features helped in simplifying and optimizing the way information is provided to the user. This type of augmentation also allowed to minimize and filter the presentation of information to user. This will help pilots in better managing their workload and maintain an acceptable situation awareness of the task they are performing.

6.2.4.1.2 Virtualization and Modelled Information Identified Issues

The problem related to the prevalence in the use of virtual or modelled information was overtrust and complacency. If pilots overly trust the application they are using and the information that it provided to them, they might stop searching for other sources of information as confirmation and might focus too much on one source for that information. This overtrust might lead to an increased propensity to commit errors or "out-of-the-loop" scenarios.
A good example of this was the Head down SVS in which the pilots reported that the virtualization of the outside environment (terrain, runway and obstacles) might make the pilots focus on the information provided there and check less the elements surrounding the aircraft. The more realistic and immersive the environment is the higher is the probability that the pilot will trust the information.
Mitigations:

- Adequate training and knowledge on the applications' use and limitations will support pilots on managing their expectation levels and actions.
- The virtual environment design helps managing the user expectations and level of trust in the system. The more realistic the immersive virtual environment the more the pilot will tend to trust on the information.

6.2.4.2 Summary of the recommendations for augmented perception

The table below provides a synthetic presentation of the results presented above, relating augmented perception categories with the benefits and issues identified in the case studies. The table puts in evidence the human performance impact of those benefits and issues and can be used as guidance by designers in making human-machine interface choices.

Table 25 Design recommendations for the augmented perception categories

Design recommendations for Augmented Perception Categories (HP impact)			
Augmented Perception	**HP Benefits**	**HP Issues**	**Mitigations**
Virtualization	1. Higher levels of modulation and abstraction enable the representation of future events. (Situation Awareness) 2. Virtual and modelled rendering of real world features helps simplifying and optimizing the way information is provided to the user. (Workload; Situation Awareness)	1. The virtualization and modelling of information tends to increase pilots overtrust and complacency. They might focus too much on one source of information and confirm less other related information sources. (Trust; Human Error)	1. Issue 1: Adequate training and knowledge on the applications' use and limitations will support pilots on managing their expectation level and actions. *2.* Issue 1: The virtual environment design helps managing the user expectations and level of trust in the system. The more realistic the immersive virtual environment the more the pilot will tend to trust on the information.
Modelled information			

6.2.5 Automation

The table below summarises the distribution of the different levels of automation included in each of the applications studied. The automation levels for each of the applications are provided by cognitive function supported.

Table 26 Distribution of the analysed technologies according to the automation levels supported by cognitive function

Applications / Functionalities	A Information Acquisition	B Information Analysis	C Decision and Action Selection	D Action Implementation
Gate-to-gate	A2			D2
Weather CD &R	A3	B5	C2	
Synthetic Terrain Presentation	A4			
Enhanced Synthetic Vision	A4			
Head Down Synthetic Vision	A4			
RPAS Out-Of-The-Window application	A2			
RPAS Traffic DAA - Self-Separation Functionality		B5	C3	D4
RPAS Traffic DAA – Collision Avoidance Functionality		B5	C4	D6

6.2.5.1 Information Acquisition Automation Support (A)

The Gate-to-gate and RPAS Out-Of-The-Window view application supported pilots in acquiring information on the process they were following without any filtering of relevant information.

Weather CD &R application automation-level supported the integration of data coming from different sources and filtered and/or highlighted the most relevant information item. In this case the filtering was based on user's settings.

The applications that provided the highest level of information acquisition automation support were the Synthetic Terrain Presentation, Enhanced Synthetic Vision and Head Down Synthetic Vision. They integrated data coming from different sources that were then filtered and highlighted for the pilot.

6.2.5.1.1 Information Acquisition Automation Support Identified Benefits

Filtering and integrating important data coming from different sources in a given task supported the pilot in acquiring information more easily from the surrounding environment.

6.2.5.1.2 Information Acquisition Automation Support Identified Issues

Higher levels of automation in information acquisition were associated to a reduced effort in searching for information since the main information on the process should be highlighted and conspicuous. In case there is a failure in the automated function that filters and highlights information this can increase pilot complacency situation or late detection of a failure.

<u>Mitigations:</u>

- The pilots' should have means to confirm the information that is being provided by the functionality is attend able (e.g. source, time, etc.) in order to be able to an adequate awareness of the process that is going on.
- If the criteria for integrating, filtering and highlighting the relevant information can be set by the pilot, the HMI design should make sure the pilot is aware of the mode selection of the application to avoid human error.

6.2.5.2 Information Analysis Automation Support (B)

Weather CD &R and RPAS Detect and Avoid functionalities provided the highest level of information analysis automation support (B5). The applications performed the respective information analysis and triggered visual alerts on safety critical information or information that required problem resolution (bad weather phenomena and surrounding traffic).

6.2.5.2.1 Information Analysis Automation Support Identified Benefits

Alerts on safety critical information support pilots allocating their attention to information that requires to be analysed or an immediate action from their side.

6.2.5.2.2 Information Analysis Automation Support Identified Issues

Higher automation levels of information analysis support are associated with the possibility of attentional reduction, since pilots are expecting the system to alert them on degraded situations and events. If there is a failure in automation or if the pilot disables the alerting system without remembering it, this can lead to human error.

Mitigations:

- If the pilots are given the option to suppress alerts in the application, it should be evident for them the current status of the system (active or not);
- If the alerting function of the application has a malfunction the pilot should have the means to quickly identify the situation in order to act on it.

6.2.5.3 Decision and action selection automation support (C)

6.2.5.3.1 Decision and action selection automation support Identified Benefits

The automation on decision and action support assisted pilots elaborating decisions and solving issues in due time, reducing this way the probability to commit errors and cognitive workload. The application with a lower decision and action automation support was the Weather CD&R (a single alternative flight plan was automatically suggested to avoid the bad weather phenomena), while the RPAS DAA functionalities achieved higher decision-support levels, up to the system generating options and deciding autonomously on the actions (C4). Higher levels of automation in decision and action selection support the reduction of workload in high pressure contexts (e.g. collision avoidance in remote piloting).

6.2.5.3.2 Decision and action selection automation support Identified Issues

If the remote pilot starts to over trust the decisions that are proposed by the system he might decrease his attention levels and miss critical information on the options provided by the system. This might make him fail to detect an erroneous system function.

Mitigations:

- Adequate training and knowledge on the applications' use and limitations will support pilots in managing their expectation levels and actions.

Higher level of automation in decision-making processes may lead to loss of skill and proficiency in the activities performed over time.

Mitigations:

- The choice of lower levels of automation in decision making lead to better user engagement and control on the process. In case of system malfunction the probability that the problem can be detected in due time is higher and the complacency effect can be reduced.

The RPAS functionality proposed a self-separation manoeuvre that required pilot input to be implemented, but that was not conspicuous and clear enough for the remote pilot.

Mitigations:

- If the automated function needs the user input to decide or implement a critical automated step, then it should be clear to the pilot that the system requires his input. The system should provide adequate feedback.

6.2.5.4 Action Implementation automation support (D)

The Gate to Gate application included a low action implementation support by guiding the operator with the highlighted path to follow on the airport.
The action implementation automation levels were higher in the RPAS Traffic DAA, both for the Self-Separation Functionality and for the Collision avoidance functionality. In the first one, the application performed automatically the self-separation manoeuvre by pilot activation, in the second one, the system initiated and executed automatically the sequence of actions.

6.2.5.3.2 Action Implementation automation support Identified Benefits

Higher action implementation automation levels can support to the pilot in high pressure contexts and contributed to the reduction of pilot workload.

6.2.5.3.3 Action Implementation automation support Identified Issues

If the pilot starts to over trust the actions implemented by the system he might reduce his attention level and miss critical information to detect a system failure.

Mitigations:

- Pilots should be able to take back control and operate manual flight if they are expected to revert to more basic and less automated modes of operations.
- Adequate training and knowledge on the applications' use and limitations will support pilots in managing their expectation levels and actions.

If the remote pilot decides to take back the control of the RPA because the separation manoeuvre is not being executed correctly, he might experience high workload and the probability to commit an error might be increased.

Mitigations:

- The automated function must constantly provide the user with appropriate and clear feedback on the status of the processes being carried out (independently on the level of automation). This will positively impact pilots' Situation Awareness and Workload.
- Pilots should be able to operate in manual or less automated flight modes if they are expected to revert to more basic and less automated modes of operation.

Higher automation levels in action implementation were associated to loss of skill and proficiency over time.

Mitigations:

- The choice of lower action implementation automation levels lead to better user engagement and control on the process. In case of system malfunction, the probability that the problem can be detected in due time is higher and the complacency effect can be reduced.

- When an automated function has different stages or working modes, the HMI must insure that the user is informed on the current mode engaged and anytime there is a mode change. This will help prevent the risk of mode errors that consist in the user mistaking or forgetting the mode the system is on.

6.2.5.5 Summary of the recommendations for cognitive function supported by automation

The table below provides a synthetic presentation of the results presented above, relating the different types of cognitive functions supported by automation with the benefits and issues identified in the case studies. The table puts in evidence the human performance impact of those benefits and issues and can be used as guidance by designers in making human-machine interface choices.

Table 27 Design recommendations for the different cognitive functions supported by automation

Design recommendations for different cognitive functions supported by automation (HP impact)			
Cognitive function	**HP Benefits**	**HP Issues**	**Mitigations**
Information Acquisition (A)	1. Filtering and integrating important data coming from different sources in a given task supports the pilot in acquiring information more easily from the surrounding environment. <u>(Situation Awareness)</u>	1. If there is a failure in the automated function that filters and highlights information this can increase pilot complacency and delay the detection of that failure. <u>(Situation Awareness)</u>	▪ <u>Issue 1:</u> The pilots' should have means to confirm the information that is being provided by the functionality is attend able (e.g. source, time, etc.). ▪ <u>Issue 1:</u> If the criteria for integrating, filtering and highlighting the relevant information can be set by the pilot, the HMI design should make sure the pilot is aware of the mode selection of the application to avoid human error.
Information Analysis (B)	1. Alerts on safety critical information support pilots allocating their attention to information that requires to be analysed or an immediate action from their side. (<u>Situation Awareness)</u>	1. Higher levels of information analysis are associated with the possibility of reduction of attention levels (Situation Awareness) because pilots are expecting the system to alert them on certain events. <u>(Human Error)</u>	▪ <u>Issue 1:</u> If the pilots are given the option to suppress alerts in the application, it should be evident for them the current status of the system (active or not); ▪ <u>Issue 1:</u> If the alerting function of the application has a malfunction the pilot should have the means to quickly identify the situation in order to act on it.

Decision and Action Selection (C)	1. Higher levels of automation in this function can support to the pilot in high pressure contexts and contributed to the reduction of pilot workload. (Workload)	1. Over trust in the decision proposals by the system might decrease pilots' attention levels and miss to consider other critical information. (Trust) 2. Higher levels of automation in decision-making processes may lead to loss of skill and proficiency in the activities performed over time. (Skill) 3. Lack of conspicuous and clear action proposals can leave pilot out-of-the-loop in the process he is following. (Situation Awareness)	▪ Issue 1: Adequate training and knowledge on the applications' use and limitations will support pilots on managing their expectation levels and actions. ▪ Issue 2: The choice of lower levels of automation in decision making lead to better user engagement and control on the process (minimizing complacency levels). ▪ Issue 3: If the automated function needs the user input to decide or implement a critical automated step, then it should be clear (good feedback) that the system requires his input.
Action Implementation (D)	1. Higher levels of automation in this function can support to the pilot in high pressure contexts and contributed to the reduction of pilot workload. (Workload)	1. Over trust in the actions implemented by the system might reduce pilots' attention level and miss critical information to detect a system failure. (Trust) 2. If an automated action is not being executed correctly, the might experience high workload to be able to reverse the situation.	▪ Issue 1: Pilots should be able to take back control and operate manual flight if they are expected to revert to more basic and less automated modes of operations. ▪ Issue 1: Adequate training and knowledge on the applications' use and limitations will support

		(Workload; Situation Awareness) 3. Higher automation levels in action implementation are associated to loss of skill and proficiency over time. (Skill)	pilots in managing their expectation levels and actions. ▪ Issue 2: The automated function must constantly provide the user with appropriate and clear feedback on the status of the processes being carried out (independently on the level of automation). ▪ Issue 2: Pilots should be able to operate in manual or less automated flight modes if they are expected to revert to more basic and less automated modes of operation. ▪ Issue 3: The choice of lower action implementation automation levels lead to better user engagement and control on the process. In case of system malfunction, the probability that the problem can be detected in due time is higher and the complacency effect can be reduced. ▪ Issue 3: When an automated function has different stages or working modes, the HMI must insure that the user is

			informed on the current mode engaged and anytime there is a mode change. This will help prevent the risk of mode errors that consist in the user mistaking or forgetting the mode the system is on.

Chapter 7. Conclusions

The main aim of the present work was to develop a mediation classification capable of supporting the understanding of the impact of a system or function on Human Performance.

Through the adopted approach, the research started from the literature review to identify the categories that better defined the mediated support, going through a basis of classifications of augmented reality, artificiality and automation. From the review of the several taxonomies resulted a set of categories that combined defined the mediated support classification: (1) Rendering modalities; (2) Type of visual display; (3) Visual display frame of reference; (4) Augmented perception; (5) Control-display (C/D) congruence; and finally (6) Level of Automation.

In order to understand if the defined taxonomy was actually able to identify the extent to which a task is being mediated and to relate those parameters to actual human performance issues and benefits, the taxonomy was applied within two different case studies. The two case studies represented two different contexts, the first on flight deck solutions for extended aircraft operations in degraded weather conditions (ALICIA) and the second, on Remotely Piloted Aircraft Systems solutions for unsegregated airspace integration. The applications and functionalities that were included in the present work from those two R&D projects supported aircraft flight path management and navigation in different flight phases.

The application of the Mediated Support Taxonomy in the two case studies, ALICIA and RAID, served two distinct purposes: (1) to understand if categories and scales that were defined in the Mediated Support Taxonomy were adequate to actually classify the applications developed in within the two different contexts; (2) to associate the mediated support categories with the human performance benefits and issues that were assessed in the projects' applications validation activities.

The final part of the work consisted in the consolidation of the Mediated Support Taxonomy according to the result of its application to the functionalities from both case studies.

The results obtained from the association of the classification of applications resulted in high-level trends and recommendations for the different categories of the taxonomy according to their level of support. Those recommendations were provided in the form of operational benefits, issues and also respective strategies to mitigate those issues identified.

The rendering modalities of the applications explored in both case studies were exclusively visual due to the relatively low maturity level (reaching up to a pre-industrial maturity phase). This negatively impacted the comparison of benefits and issues between the different rendering categories (visual, auditory and tactile) and it was not possible to extract much human performance information on this category.

The types of displays from the analysed application covered Head Up Displays, Hand Held Displays, Head Down Displays and Forward Facing Displays. The HDD placed between PF and the PM allowed easy access to the same information, facilitating a shared situation awareness and interaction between pilots. The HUD improved local navigation guidance and situation awareness in degraded visual conditions and flight phases that the pilot should be monitoring outside information. Both the HUD and the HDD have the down side of promoting a bad shared situation awareness between the flight crew members if they are not provided with the same displays and information. It was not possible to identify human performance benefits and issues related to FFD from the human performance assessment results.

The visual frame of reference categories that were analysed covered the 3D Egocentric Display, the 2D map display, the 2D coplanar display and the combination of more than 2 types of displays. Generally speaking, the visual frame of reference impacted human performance mainly in terms of situation awareness and workload. The 3D visual frame of reference supported the pilot in tasks that require immediate surrounding awareness and local guidance. The 2D map displays and multiple displays are able provide a better global awareness of surrounding hazards and allowing a strategic view over the flight path. The visual scanning cost for pilots can be higher in applications that use a higher number of displays, this can negatively impact workload levels.

The results gathered on augmented perception were limited due to the level of detail of the human performance assessment results. Virtual and modelled rendering of real world features in the studied applications helped simplifying and optimizing the way information is provided to the user.

The results on automation were gathered by cognitive function (information acquisition; information analysis; decision and action selection; and action implementation). In general, the higher levels of automation in applications were associated to issues of over trust in the system, reduction of pilots' attention levels and ultimately reduction of the operator skill over time.

The coverage and the degree of detail on benefits and issues gathered on the different categories and sub-categories that compose the taxonomy were not homogeneous. This was associated with the application of the taxonomy to classify and organize a body of results that had been collected in a previous human performance assessment phase. Therefore, the human performance results gathered previously on an application impacted the results obtained for each of the taxonomy categories.

The application of the proposed taxonomy to a wider sample of applications would have allowed to gather a more reliable body of information in terms of human-machine interaction recommendations.

It should also be highlighted that the results gathered in this study in terms of human performance (benefits and issues) related to the Mediated support categories warrant caution in generalizing to a wider range of flight environments. This limitation is associated to the fact that the studied applications were not evaluated for all the different flight phases and that for some applications sample size was limited.

It can be concluded that the Mediated Support Taxonomy was useful to perform the comparison of different applications providing different types of mediated support. The classification supported the identification of human performance benefits and issues related to the categories that compose it. This is helpful to understand the source of some of the issues and to consider how to they can be mitigated.

The taxonomy also proved to be a useful tool to organize and analyse human performance results that have previously been collected. This can be particularly relevant to bring together and compare results from separate human performance assessments of different solutions to support pilots. This is something that usually happens in large R&D projects, where several applications and solution are developed and validated separately, but should provide a consistent support to human performance.

The methodological limitation of this study was that an actual validation of the Mediated Support Taxonomy was not performed. The results on the application of the present taxonomy by a third party to flight path management applications would have allowed greater insight and confidence on the support provided in classifying the mediated support and its usefulness.

The taxonomy allowed a meaningful classification in terms of mediated support of commercial flight decks application and RPAS applications. It could be interesting to apply the developed taxonomy in other contexts in future research, like the Air traffic Control Domain. The taxonomy could be useful to consider in a human performance assessment on the Remote Tower concept in Air Traffic Control, which will drastically increase the mediation between the operator and its usual physical work environment by means of new applications.

In future research, this taxonomy also could be used in earlier phases of applications' design and development process. It could be used as a basis to support the development of metrics and assessment materials for the evaluation activities e.g. basis to build customised questionnaires. This would allow the collection of more detailed and reliable data in terms of mediated support.

References

Ahlstrom, V., & Longo, K. (2003). Human Factors Design Standard (HF-STD-001). Atlantic City International Airport, NJ: Federal Aviation Administration William J. Hughes Technical Center.

Åhsberg, E., Garnberale, F., & Kjellberg, A. (1997). Perceived quality of fatigue during different occupational tasks development of a questionnaire. International Journal of Industrial Ergonomics, 20(2), 121-135.

Alexander, A. L., & Wickens, C. D. (2005). 3D navigation and integrated hazard display in advanced avionics: Performance, situation awareness, and workload (Technical Report AHFD-05-10/NASA-05-2). Savoy, IL: University of Illinois, Aviation Human Factors Division.

Benford, S., Brown, C., Reynard, G., & Greenhalgh, C. (1996). Shared spaces: transportation, artificiality, and spatiality. Proceedings of the 1996 ACM conference on Computer supported cooperative work, 77-86.

Billings, C. (1997). Aviation Automation: The Search for a Human-Centered Approach. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Borghi, A. M., & Cimatti, F. (2010). Neuropsychologia Embodied cognition and beyond: Acting and sensing the body, 48, 763–773. doi:10.1016/j.neuropsychologia.2009.10.029.

Cain, B. (2007). A review of the mental workload literature. NATO Report No. RTO-TRHFM- 121-Part-II. Toronto, Canada: Defence Research and Development.

Cardosi, K. M., & Murphy, E. D. (1995). Human Factors for Flight Deck Certification Personnel (DOT/FAA/RD-93/5). Cambridge, MA: U.S. Department of Transportation.

Carr, N. (2014). The Glass Cage: Automation and Us. Norton: New York.

Cathelain, S. (2005). Contribution à la conception de systèmes coopératifs. Application au domaine du contrôle de trafic aérien. Thèse de l'Université de Valenciennes, Février 2005.

Comerford, D., Brandt, S. L., Lachter, J., Wu, S-C., Mogford, R., Battiste, V. & Johnson, W., W. (2013). NASA's Single-Pilot Operations Technical Exchange Meeting: Proceedings and Findings. In NASA/CP–2013–216513, National Aeronautics and Space Administration. Ames Research Center: Moffett Field, (CA).

Cummings, M.L., Mastracchio, C., Thornburg, K.M., & Mkrtchyan, A. (2013). Boredom and distraction in multiple unmanned vehicle supervisory control. Interacting with Computers, 25(1), 34-47.

Dekker, S. W. A., & Woods, D. D. (2002). MABA-MABA or abracadabra? Progress on human automation coordination. Cognition, Technology, and Work, 4, 240–244.

Deutsch, R. & Pew, W. (2005). Single pilot commercial aircraft operation, BBN Report. 8436. Cambridge, MA: BBN Technologies.

Edwards, E. (1972). Man and machine: Systems for safety. Proc. of British Airline Pilots Associations Technical Symposium (p. 21-36). London: British Airline Pilots Associations.

Edwards, E. (1988). Human Factors in Aviation. Academic Press: San Diego, CA.

Endsley, M. R. (1995). Measurement of situation awareness in dynamic systems. Human Factors, 37,65–84.

EUROCONTROL (2007). The Human Factors Case: Guidance for Human Factors Integration. Edition 2.0. Ref.nr. 07/06/22-35. Brussels, Belgium.

FAA/EUROCONTROL (2010). Human Performance in Air Traffic Management Safety. Action Plan 15 White Paper.

Gopher, D., & Donchin, E. (1986). Workload – An examination of the concept. Handbook of Perception and Human Performance. Volume 2. Cognitive Processes and Performance. K.R. Boff, L. Kaufman and J.P. Thomas, John Wiley and Sons, Inc: 41-1:41-49.

Grandjean, E.P. (1970) Fatigue. American Industrial Hygiene Association Journal, (31) 401-11.

Hawkins, F. H. (1993). Human Factors in Flight (2nd Edition). Gower Technical Press: Hants, UK.

Hoc J.M. (1996) Supervision et contrôle de processus: La cognition en situation dynamique, Grenoble: Presses Universitaires de Grenoble (PUG).

Hofer, E. F., Braune, R. J., Boucek, G. P., & Pfaff, T. A. (2000). Attention switching between near and far domains: An exploratory study of pilots' attention switching with head-up and head-down tactical displays in simulated flight operations (D6-36668). Seattle, WA: The Boeing Commercial Airplane Co.

http://ec.europa.eu/transport/sites/transport/files/modes/air/sesar/doc/eu-atm-master-plan-2015.pdf

Hugues, O., Fuchs,P., & Nannipieri, O. (2011). New Augmented Reality Taxonomy: Technologies and Features of Augmented Environment. In: Furht, Borko. Handbook of Augmented Reality (pp.850). Springer: Berlin.

ICAO Circular 216-AN31. (1989). Human factors Digest No 1.

ICAO. (2011). Cir 328/AN/190 on Unmanned Aircraft Systems (UAS).

Kahneman, D. (1973). Attention and effort. Englewood Cliffs, NJ: Prentice-Hall.

Karray, F., Alemzadeh, M., Saleh, J.A. and Arab, M.N. (2008) Human-Computer Interaction: Overview on State of the Art. International Journal on Smart Sensing and Intelligent Systems.

Lee, J., & Moray, N. (1992). Trust, control strategies and allocation of function in human machine systems. Ergonomics, 35(10), 1243–1270.

Martinussen, M., & Hunter, D. R. (2010). Aviation psychology and human factors. Boca Raton, FL: CRC Press.

Milgram, P., & Colquhoun, H. J. (1999). A taxonomy of real and virtual world display integration. In: Ohta, Y. and Tamura, H. Mixed Reality – Merging Real and Virtual Worlds, (ch. 1, 1–16). Ohmsha: Tokyo and Springer Verlag: Berlin.

Moray, N. (1967). Where is capacity limited? A survey and a model. In: Sanders, A. (Ed.) Attention and performance. Amsterdam: North-Holland.

Moray, N., Inagaki, T., & Itoh, M. (2000). Adaptive automation, trust, and self-confidence in fault management of time-critical tasks. Journal of Experimental Psychology–Applied, 6, 44–58.

Muir, B. M. (1987). Trust between humans and machines, and the design of decision aids. International Journal of Man-Machine Studies, 27(5-6), 527–539.

Normand, J., Servières, M., Moreau, G. (2012). A new typology of augmented reality applications. In AH 2012 Proceedings of the 3rd Augmented Human International Conference, pp. 18:1-18:8. ACM.

Nullmeyer, R., & Montijo, G. (2009). Training interventions to reduce Air Force predator mishaps. In: Proceedings of the 15th International Symposium on Aviation Psychology. Dayton, OH.

Parasuraman, R., & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. Human Factors, 39, 230-253.

Parasuraman, R., Sheridan, T.B., & Wickens, C.D. (2000). A model for types and levels of human interaction with automation. IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems and Humans, 30, 286–297.

PARC/CAST. (2013). Operational Use of Flight Path Management Systems, Final Report. Performance-based operations Aviation Rulemaking Committee/Commercial Aviation Safety Team, Flight Deck Automation Working Group.

Rasmussen, J. (1986). Information Processing and Human-Machine Interaction. An approach to cognitive engineering. New York: Elsevier Science Publishing Co., Inc.

Reason, J.T. (1993). L'erreur Humaine. Presses Universitaires de France: Paris. ISBN 2-13-04517.

Save, L., & Feuerberg, B. (2012). Designing Human-Automation Interaction: a new level of Automation Taxonomy. In D. de Waard, K. Brookhuis, F. Dehais, C. Weikert, S. Rottger, D. Manzey, S. Biede, Reuzeau, F., & P. Terrier (Eds.). Proceedings HFES Europe Chapter Conference Toulouse.

SESAR Joint Undertaking. (2016). SESAR European Drones Outlook Study.

Sheridan, T.B., & Verplank, W. (1978). Human and Computer Control of Undersea Teleoperators. Cambridge, MA: Man-Machine Systems Laboratory, Department of Mechanical Engineering, MIT.

Shively, R.J., Hobbs, A., Rorie, C., & Lyall, B. (2015). Human Performance Considerations for Remotely Piloted Aircraft Systems (RPAS). Remotely Piloted Aircraft Systems Panel (RPASP) Second Meeting (RPASP/2), Montréal.

Sperandio, J. C. (1971). Variation of operator's strategies and regulating effects on workload. In: Ergonomics, 14(5), 571-577.

Sperandio, J. C. (1977). La régulation des modes opératoires en fonction de la charge de travail chez les contrôleurs de trafic aérien. Le Travail Humain, 40, 249-256.

Stone, R. J. (1991). Advanced Human-System Interfaces for Telerobotics Using Virtual Reality and Telepresence Technologies. Proceedings of the Fifth International Conference on Advanced Robotics in Unstructured Environments (ICAR'91).

Van Krevelen, D. & Poelman, R. (2010). A Survey of Augmented Reality Technologies, Applications and Limitations. The International Journal of Virtual Reality 9, 1-20.

Ververs P. M., & Wickens, C. D. (1998). Head-up displays: Effects of clutter, display intensity, and display location on pilot performance. The International Journal of Aviation Psychology, 8(4) 377-403.

Wickens, C.D. (1999). Frames of reference for navigation. In D. Gopher & A. Koriat (Eds.), Attention and performance (Vol. 16). Cambridge, MA: MIT Press.

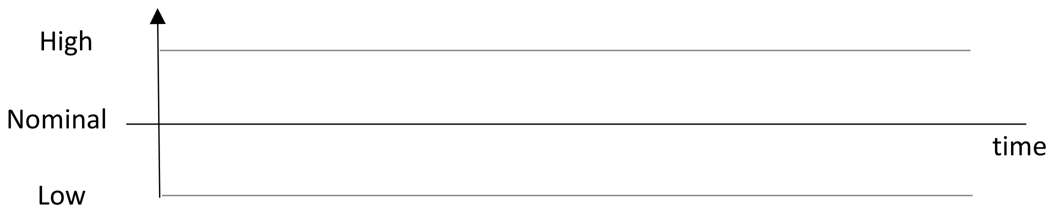
Wilson, M. (2002). Six views of embodied cognition. Psychonomic Bulletin & Review, 9(4), 625–636.

Appendix A

A1. RAID HUMAN PERFORMANCE REMOTE PILOT POST-FLIGHT QUESTIONNAIRE

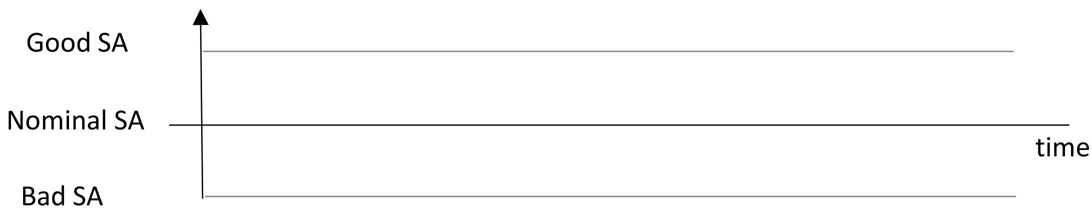
Flight Scenario: ____

1	Can you sketch the **workload** level you experienced during the flight?



Please elaborate:

2	Can you sketch the **situation awareness** level you experienced during the flight?



Please elaborate:

3	Can you provide a subjective assessment on your own **level of stress** during the flight?					
Stressed	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	**Relaxed**

Please elaborate:

4	Can you provide a subjective assessment on your own **level of performance** during the flight?					
Frustrated	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	**Satisfied**
Please elaborate:						
5	Can you provide a subjective assessment on the **time pressure** you had to perform your tasks?					
Rushed	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	**Calm**
Please elaborate:						
6	Can you provide a subjective assessment on the **quality of the interaction** with the ground station?					
Poor	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	**Good**
Please elaborate:						
7	Can you provide a subjective assessment on the quality of **communication** with the ATC (clarity, timeliness)?					
Not Adequate	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	**Adequate**
Please elaborate:						
8	Did you perform any unwanted action during the flight?					
8a	If so, were you able to recover from the unwanted action quickly?					
9	Did you experience any delay in the reaction of the RPA during a manoeuvre?					