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A Quantitative Framework to Assess Pilot Workload during Applications of Airborne Separation Assistance

by

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Doctor of Philosophy

All aspects of the work presented herein are original in concept except where indicated

"It is possible to fail in many ways...

while to succeed is possible only one way."

Aristotle

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Abstract

One of the principal concerns with the introduction of Airborne Separation Assistance System (ASAS) Work Package 1 is the operational flexibility of delegating to pilots responsibility for maintaining separation as in keeping with applications of Limited, Extended and Full Delegation [183]. This operational flexibility, among other things, includes identification of potential problems, generation of solutions to resolve them, and implementation and monitoring of the chosen solution. It has also been predicted that this will introduce new performance issues and present implications that will reflect significant changes in the way pilots and air traffic controllers will perform their respective tasks [4], [174], [175], [176] and [177]. As human performance considerations are expected to be central to the performance of advanced cockpit and Air Traffic Management (ATM) system [11] there is the need to address concerns which arise [11] pertaining to the possibility of adverse changes, impact and implementation on the cognitive and behaviour processes of pilots and air traffic controllers.

Against this background, the work in this thesis presents the development of an eighty-five factor task index and self–assessment performance framework for the determination of cognitive and performance challenges of pilots during applications of Limited, Extended and Full Delegation of Airborne Separation Assistance. The quantitative framework is developed using the technique of Critical Task Analysis (CTA) and is based on tasks which are inherent to dynamic situations during each respective application.

The performance framework was then incorporated into an existing decision support tool, Multi-criteria Analysis for Concept Evaluation (MACE) [9] whose operating and performance utilities were extensively expanded and modified from forty factors to eighty five factors to present the novel approach of this thesis. This novel approach is the development of another decision support tool, Multi-criteria Analysis for Pilot Evaluation, (MpE).

The objectives of MpE are:

1. To obtain quantitative measures of the workload of pilots during the ASAS applications already identified.

2. To clearly delineate the functions of pilot from those of ATC during the respective applications.

3. To predict the effects of change in the tasks environment on the workload of both human operators, pilots and controllers.

To illustrate the functionality and capabilities of MpE two thousand hypothetical ASAS applications conducted by pilots were simulated. No statistical methods were employed for arriving at this number of 2000, however it was deemed that the number adequately covered the various combinations of the scenarios within the ASAS applications. To achieve objective three above, three hundred and fifty hypothetical ASAS applications conducted by air traffic controllers were simulations using the programme in its original form of (MACE). Whereas Situation Awareness may not be deemed as an ASAS application it was however included as an ASAS application during both simulations to provide insight into the cognitive processes involved in dimension of regulation and to confirm whether CDTI would enable a better representation of the traffic situation.

In this thesis workload is defined as a comparison between *Heaven* and *Hell* where the closer to *Heaven* the workload is seen as easier and the closer to *Hell* the more difficult. To arrive at the workload measurements for pilots during each respective application the eighty-five factors served as indicators. Then, using a specific value scale provided by the programme these indicators were related to one or several *Criteria,* (a list provided by the programme expressing human dimensions) through linear regression. A quadratic solution where a positive result indicates the strength of the influence (*Heaven*) and a negative the weakness of the influence (*Hell*) provides the final outcome.

Of the 2000 ASAS application simulations conducted for pilots, the overall *regression coefficient* ρ, (where ρ indicates the effect of change) derived from the coefficient α_i produced a value of $\rho = 0.956$. As this value is nearer to 1 it indicates a positive representation of the distance to *Heaven,* where the closer to *Heaven* the workload is seen as easier. Accordingly, from this result one can deduce that the work of pilots during the four ASAS applications will be easier.

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List of Acronyms

AAO	Autonomous Aircraft Operations
ACAS	Airborne Collision Avoidance System
ACC	Area Control Centre
ACT-R	Adaptive Control Of Thought Rational
ADS	Automatic Dependent Surveillance
ADS-B	Automatic Dependent Surveillance - Broadcast
ARTCC	Air Route Traffic Control Centre
ASAS	Airborne Separation Assistance System
ASCII	American Standard Code for Information Interchange
ASRS	Aviation Safety reporting System
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATN	Aeronautical Telecommunications Network
CDM	Collaborative Decision Making
CDR	Conflict Detection and Resolution
CDTI	Cockpit Display of Traffic Information
CENA	Centre d'Études de la Navigation Aérienne
CFIT	Cost-effective Controlled Flight Into Terrain
CFMU	Central Flow Management Unit
CNS	Communications, Navigation and Surveillance
CTA	Critical Task Analysis
EATMS	European Air Traffic Management System
ECAC	European Civil Aviation Conference
ENR	En-route
EPIC	Executive Process Interactive Control

EUROCONTROL	European Organisation for the Safety of Air Navigation
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FFAS	Free Flight Airspace
FFP1	Free Flight Phase One
FIR	Flight Information Region
FL	Flight Level
FMS	Flight Management System
GNSS	Global Navigation Satellite System
HCI	Human Computer Interface
HF	Human Factors
HITL	Human in the Loop
HMI	Human Machine Interface
HPM	Human Performance Modelling
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
ILS	Instrument Landing System
MACE	Multi-criteria Analysis for Concept Evaluation
MAS	Managed Airspace
MpE	Multi-criteria Analysis for Pilot Evaluation
MIDAS	Man-Machine Integration Design & Analysis System
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATS	National Air Traffic Services
NLR	National Aerospace Laboratory (The Netherlands)
NRC	National Research Council
NUP	North European ADS-B Network Update Programme
OCA	Oceanic Control Area
OCC	Oceanic Control Centre
OCD	Operational Concept Document

PFAST	Passive Final Approach Spacing Tool
PHARE	Programme for Harmonised ATM Research in EUROCONTROL
RHEA	Role of the Human in the Evaluation for ATM Systems
RTCA	Radio Technical Commission for Aeronautics
SAGAT	Situation Awareness Global Assessment Technique
SICAS	SSR Improvements and Collision Avoidance Systems
SID	Standard Instrument Departure
SMA	Surface Movement Advisor
SSR	Secondary Surveillance Radar
STA	Scheduled Time of Arrival
STAR	Standard Terminal Arrival Route
TATM	Terminal Area Traffic Management
TCAS	Traffic Alert and Collision Avoidance System
TIS	Traffic Information Service
TIS-B	Traffic Information System - Broadcast
TMA	Terminal Manoeuvring Area
TWR	Tower
UK	United Kingdom
UMAS	Unmanaged Airspace
US	United States
WME	Working Memory Elements

Chapter 1

Introduction

1.1 Applying Human Factors to the ATM System

According to ICAO [14], the current system of Air Traffic Management (ATM) is under pressure, as traffic levels increase. To fulfil the growth of air traffic demand and in response to the shortcomings of the present system, since the early 1980s, a wide range of organisations and companies across the world have been pursuing the development of new ATM concepts and procedures. Many ATM systems are currently being upgraded and developed into "next generation" systems, which include computerised display with new functionality and computerised tools introducing a system evolution in human/system integration. As a result, a new system of ATM is evolving which is expected to take advantage of advanced communications, navigation and surveillance (CNS) technologies to cope with the increasing traffic demand and provide more flexibility to the airspace users while meeting agreed levels of safety. These developments suggest that the ATM system is at the beginning of a long period of significant change and evolution, a period that will possibly see major shifts in work practices particularly in the transition period when new systems and practices are introduced.

Three themes of development, namely, Airborne Separation Assistance Systems, Automation and Autonomous Aircraft Operation, concepts fully explained in sections 1.3.1 – 1.4 identify areas where shifts in work practices and responsibility will occur. The Operational Concept Document of European Air Traffic Management [1] and the ATM 2000+ Strategy of EUROCONTROL [2] have allowed for some elements of all three themes of development.

The introduction of Airborne Separation Assistance System (ASAS) Work Package 1 identifies three levels of control delegation these being:

- Limited Delegation
- Extended Delegation
- Full Delegation.

In Limited Delegation the controller is in charge of both problem and solution identification and only implementation of solutions and monitoring are delegated to the pilot. During the process of Extended Delegation the controller is in charge of identification of the problems, and delegates to the pilot the identification and implementation of the solution and the monitoring. Full Delegation allows onboard separation without controller intervention thereby devolving to the pilots more responsibility for maintaining separation. This includes identification of potential problems, generation of solutions to resolve them, and implementation and monitoring of the chosen solution. The delegation processes of the four applications all have implications that reflect a significant change in the way that pilots and air traffic controllers will perform their respective tasks. As human performance considerations are expected to be central to the performance of advanced cockpit and Air Traffic Management (ATM) systems [11] one of the principal challenges for human factors is to determine the adverse changes on the cognitive and behaviour process of the air traffic controllers and pilots as a result of reversionary roles. Sheridan et al [154] predicted that the role transfer will involve the controller being placed to an increasing extent into a role of monitor, a role Wicken et al [4] state is not a strong role for humans. Since the late 1940s, the conception of vigilance or monitoring tasks was that they were boring and poorly performed because of the low level of cognitive and sensory demand that they placed on the individual [174]. This perception changed when a new view of vigilance revealed operator vigilance is limited and proposed that enforced, prolonged monitoring is in fact a highly stressful situation [175, 176, 177].

This concern with regards the reversionary roles of the pilots and controllers can be attributed to the transition from a simple operating environment to a potentially more viable, complex and less safe operating environment. In the present system where procedures stem from the airborne operations of the Second World War where radar has been used to monitor the traffic situation, pilots are in charge of the efficient navigation and control of the aircraft and they rely on the information provided by the air traffic controllers. The present airspace, route structure and operating environment is simple and static and the techniques used are based on following instructions, modelling cognitive processes and mental representation of changing situations.

The present restrictions that are imposed on the aviation system have been made in order to assure a controlled regimented environment which has been deemed safe. Aircraft are equipped with a transponder that broadcast extra information to the radar such as an identification code (squawk) and the altitude (mode C) for the air traffic controller. The result is a complete overview of the three-dimensional traffic situation. Trailing blips even provide an impression of the direction and magnitude of the ground speed. On the basis of different sources of information air traffic controllers control complex dynamic, and time constraint traffic situations to diagnose risky relationships between aircraft and to solve potential conflicts.

As a result of the fixed routes of the current air traffic control (ATC) system there is substantial repeatability from one day to the next and with practice air traffic controllers learn the pattern of traffic, this consistency facilitates the cognitive processing required for information acquisition, decision-making and response planning. Within the air traffic control domain, the term picture describes the idea of a global mental representation of the current and future traffic situation in working memory. Air traffic controllers express with the term picture [4], [5], what is often described as situation awareness [6], [7]. However, once ASAS applications are introduced, whether shared or in the extreme case of where it is completely relinquished, it becomes more difficult for either of the operators to acquire and maintain the mental representations or picture needed. Corker et al [8] have confirmed the potential risks and consequences of loss of mental picture. Increased variability has also been confirmed for pilots in computer simulations of traffic flow with free flight [172], [173] where traffic patterns through sectors were also found to be less uniform and less predictable.

This raises the concern that the absence of the cognitive factor of situation awareness would reduce the regularity and predictability of both controllers and pilots, making it more difficult to acquire and maintain the mental representations needed to safely manage sector traffic [3], [175]. A reduction in traffic regularity would be realised as a decrease in the organisation of information on the controller's visual display of traffic. Strong display organisation has been shown to enhance the efficiency of allocating attention [177], [178].

In the case of pilots it is also predicted that airborne separation assistance will afford aircraft the opportunity to fly individual optimised paths, and hence the fixed routes which controllers have become familiar would be replaced by a much larger number of opportunistic flight path thus reducing the regularity and predictability of which they are accustomed. Hence, as a side effect of ASAS applications, the availability of unoccupied airspace occupancy would also decrease as regimented control decrease, and no gain in capacity, efficiency or safety could be expected as controllers now have to monitor these large number of optimistic flight path. Scientific literature [169], [174] on stress and performance documented a phenomenon, called *attention narrowing*, whereby humans under acute stress tend to experience a narrowing of focusing of their attention on only the central part (s) of a task while ignoring more peripheral aspects.

The main issue arising as a result of shifts in responsibility pertains to the level of workload. In devolving to pilots more responsibility for maintaining safe separation it will be necessary to ensure that the changes do not increase pilots' workload demand beyond their human performance limit, hence, a first step in the process is to understand the cognitive demands associated with the delegation processes of ASAS applications. Whereas the applications suggest higher potential workload savings for the ground environment they also have the potential to increase the overall demands on the flight crew as they may be given more active control responsibilities [3]. Fatigue is a risk factor for any extended, repetitive tasks and research [184] suggests that tired workers are most likely to respond more slowly to or even overlook obvious threats. Similarly, as mentioned above, *attention narrowing* can also develop and operator's vigilance can be limited [171, 172 and 173]. As in all aviation operations, constant attention to safety must govern all aspects of operation and in this regard such a phenomenon as described above can be ill afforded.

In the context of this thesis, workload refers to the impact and difficulty of changes incurred by the pilots and controllers as a result of the reversionary roles. It is insufficient just to know that the tasks of the human operators may be more difficult given the future changing roles, however, it is also critical to quantify the increase in difficulty, determine how it scales and assess which problems are most critical. This information should prove helpful not only in assessing the overall feasibility of the concept, but also in determining details of its implementation from a human factors perspective.

The domain of aviation human factors has stressed the importance of the human element in ensuring the safety and performance of aviation personnel operating in complex, dynamic systems [11], [184]. Previous research and literature [26] and [27] have all hypothesized that the introduction of several automated functions accessible through radar image would affect working methods, including information processing strategies and cooperation and increase workload. Accordingly, the work in this thesis presents a quantitative framework and computational model of a task index and self-assessment performance tool for the determination of cognitive and performance challenges of pilots during ASAS applications of Limited, Extended and Full Delegation.

Whereas it is essential to evaluate the future ATM concepts using objective criteria such as the impact on safety, ATC capacity, cost benefit and technical feasibility, given the human role in the future ATM, it is also essential to assess the difficulty the human operators will encounter adjusting to the ASAS applications of Limited, Extended and Full Delegation. This is necessary as it ensures that allocation of functions and actions required are operationally feasible. When one transitions from a simple operating environment to a potentially more viable, complex and less safe operating environment as envisaged in the context of separation assistance, due to a decrease in regimented control, it is then that a concern arises. This concern is further heightened when consideration is given to the consequences of an unsafe aviation system or concept.

The remainder of the introductory chapter is organised as follows. Section 1.2 will describe in detail the international efforts towards the implementation of a new ATM system with emphasis on the EUROCONTROL proposed operational methods for 2000+. Sections 1.3 review the concepts and procedures for the future ATM and outline the concepts of Airborne Separation Assistance System (ASAS) and its applications. Autonomous Aircraft Operation (AAO) one of two concepts central to achieving the goals of the new ATM system is outlined in section 1.4. The research topic is introduced in Section 1.5 providing a description of work and contribution of this thesis. Section 1.6 defines human factors and cognitive task analysis and section 1.7 presents previous related work in human factors and cognitive task analysis. A literature review is given in Section 1.8 and the chapter concludes with Section 1.9 which outlines the remainder of the thesis.

1.2 International Efforts Towards the Implementation of a New ATM System

The goal of Air Traffic Management (ATM), as defined in 1991 by the International Civil Aviation Organisation (ICAO), special committee on Future Air Navigation Systems (FANS), is "to enable aircraft operators to meet their planned time of departure and arrival and adhere to their preferred flight profiles with minimum constraints without compromising agreed levels of safety"[10]. This goal is achieved by two-principle ground based activities; Air traffic control (ATC) and Air Traffic Flow Management (ATFM). ATC is responsible for preventing conflict between aircraft, thereby providing a separation minima, whereas, ATFM strategically allocates air traffic flows to scarce capacity resources by adapting departures and arrivals to airports and airspace constraints. The process of ATC is the tactical safety separation service, the function of which is to prevent collision between aircraft and aircraft in the air; and between aircraft and obstructions on the manoeuvring area. The objective of this service, provided by air traffic controllers is " to maintain a safe, orderly an expeditious flow of air traffic both in the air and on the ground".

The ATM system is also part of a larger system which, in accordance with description of EATMP [11], is composed of three major elements, namely:

1. ATM System
2. Communications, Navigation, Surveillance Systems
3. Aeronautical Environment System

In response to the increasing traffic demand and the need to provide a more flexible system a new ATM system aim at taking advantage of advanced communications, navigation and surveillance (CNS) technologies and providing more flexibility to the airspace users while meeting agreed levels of safety is being proposed. This new system is the "gate-to-gate" concept, in which flights are treated as a continuum, from the first interaction with ATM until post -flight activities.

The main innovations proposed by Eurocontrol to realise this new ATM system are presented in the Operational Concept Document (OCD) [12]. To quote from the recent ATM Strategy for2000+,

" *New ATM concepts will require greater inter-operability between the systems of aircraft, aircraft operators, airport operators and ATM service providers both in the air and on the ground . These systems will evolve at different rates and be replaced or upgraded at different times, but will need to progressively support increasing traffic levels.*"

In response to the shortcomings of the current ATM, a wide range of organisations across the world have been pursuing the development of new ATM concepts and procedures. The new ATM is expected to take advantage of advanced communications, navigation and surveillance technologies to cope with the increasing air traffic demand and provide more flexibility to the airspace users while meeting agreed levels of safety.

1.2.1 International Civil Aviation Organisation (ICAO)

In 1983 the International Civil Aviation Organisation (ICAO), which is the United Nations agency regulating international air transport, established a Special Committee on Future Air Navigation Systems (FANS Committee). The FANS Committee considered the steady growth of air transport preceeding 1983 and identified the shortcomings inherent in the communications, navigation and surveillance systems and in the operational procedures supporting civil aviation at the time. The Committee determined that those systems and procedures were incapable of coping with the future needs of international air transport. In its final report presented to the President of the ICAO Council in 1988, the FANS Committee highlighted the need to develop new systems and procedures that overcome the limitations and allow ATM to evolve in a global scale. The Committee also recognised that the final achievement of a world-wide ATM system would require sovereign nations to change the way in which they deal with the implementation of civil aviation systems. Thus, they would have to make a compromise between their political and military interests and the international air transport needs.

In 1989 ICAO created the Special Committee for the Monitoring and Co-ordination of Development and Transition planning for the Future Air Navigation Systems (FANS Phase II Committee), which would continue the work of the FANS Committee. The FANS II Committee determined that the goals of the future global ATM should include the enhancement of safety, a more flexible and efficient use of the airspace, and the creation, to the extent possible, of a single continuum airspace, whose boundaries would be transparent to the users. The Committee finished its work in 1993 and by that time the FANS concept had come to be known as Communications, Navigation, Surveillance/Air Traffic Management systems (CNS/ATM systems). The concept of CNS/ATM systems involved a complex set of existing and emerging interrelated technologies, which were expected to enhance the performance of the existing ATM practises around the world by enabling a global ATM.

As a result of the conclusions and recommendations of the two FANS Committees, ICAO initiated the development of a plan for a global implementation of the CNS/ATM systems. This development culminated with the presentation of the Global Air Navigation Plan for CNS/ATM Systems [13] to the world-wide CNS/ATM Systems Implementation Conference, held in Rio de Janeiro in 1998. This Global Plan describes ICAO's approach to the implementation of CNS/ATM at the global, regional and national levels, with the aim of unifying diverse local needs into a coherent strategy. In addition, the Global Plan presents a broad ATM operational concept developed by ICAO, which reflects the CNS/ATM latest information available at the time.

Thus, the Plan was developed as an evolving document comprising technical, operational, economic, financial, legal and institutional elements, and offering practical guidance and advice to regional planning groups and States on implementation and funding strategies. According to the Global Plan, aeronautical communications will increasingly take place via digital data-link, whilst satellite voice and data communications providing global coverage will be added to the existing communications channels. An Aeronautical Telecommunications Network (ATN) is expected to support the interchange of digital data between airspace users and between users and managers over air-air, air-ground and ground-ground interconnected sub-networks. It is envisaged that the implementation of a global ATN will radically improve the current level of information sharing in ATM. The following air traffic forecast (Table 1.1) highlights the projected growth of international air transport between 1995 and 2005 and was used by ICAO to support the implementation of the Global Plan.

Regarding navigation, ICAO's Global Plan considers the progressive introduction of a Global Navigation Satellite System (GNSS) together with the widespread use of Area Navigation (RNAV), which release aircraft from flying along fixed airways referenced to ground navigation aids. These projected improvements are expected to provide global navigation support and allow airlines to fly more efficient routes.

The Global Plan predicts a major breakthrough in surveillance with the implementation of Automatic Dependent Surveillance (ADS). ADS enable aircraft to automatically transmit their position and other additional information contained in the Flight Management System (FMS) to the ATC, via satellite or other communication channel. ADS is anticipated to be applied in airborne surveillance through the concept of ADS-Broadcast (ADS-B). Aircraft equipped with ADS-B will broadcast their position and other flight related data to the ground ATC and to the surrounding aircraft. ADS and ADS-B are anticipated to support enhanced traffic situation awareness and conflict detection and resolution. In addition to these new technologies, conventional Secondary Surveillance Radar (SSR) modes will continue to be extensively used, along with the gradual introduction of Mode S.

TOTAL SCHEDULED SERVICES

	Actual	Actual	Forecast	Average annual growth rate (%)	
	1985	1995	2005	1985-1995	1995-2005
Total number of passengers carried (millions)	899	1285	2010	3.6	4.5
Total Passenger-kilometres (billions)	1367	2228	3807	5.0	5.5
Passenger-kilometres (billions)					
By region of airline registration					
Africa	36.7	51.0	77	3.3	4.0
Asia-Pacific	222.3	549.7	1260	9.5	8.5
Europe	428.2	549.3	870	2.5	4.5
Middle East	42.7	67.0	115	4.6	5.5
North America	569.2	902.7	1310	4.7	4.0
Latin America and Caribbean	68.3	107.9	175	4.7	5.0

Table 1.1 Summary of the ICAO Air Traffic Forecasts for the year 2005 [14].

Communications	Navigation	Surveillance
• More direct and efficient air-ground linkages • Improved data handling • Reduced channel congestion • Reduced communication errors • Interoperability across applications • Reduced workload	• High-integrity, high reliability, all weather navigation services world-wide • Improved for-dimensional navigation accuracy • Cost savings from reduction or non-implementation of ground-based navigation aids • Better airport and runway utilisation • Reduced pilot workload	• Reduced error in position reports • Surveillance in non-radar airspace • Cost savings • Higher degree of controller responsiveness to flight profile changes • Conformance monitoring • Improved emergency assistance

Air Traffic Management
• Enhanced safety • Improved system capacity; optimised use of airport capacity • Reduced delays and flight operation costs • More efficient use of airspace; more flexibility; reduced separations • More dynamic flight planning; better accommodation of optimum flight profiles • Reduced controller workload; increased productivity

Table 1.2 High-level View of the Overall ICAO CNS/ATM Systems Expected Benefits [15].

The Global Plan proposes a global integrated approach to the implementation of the future ATM. The ATM-related activities will evolve as advancements in CNS technologies are incorporated into the current operations. This evolution of the ATM practises aims to enabling aircraft operators to meet their planned schedules and fly efficient routes without compromising agreed levels of safety. The expected benefits derived from the new ATM are depicted in Table 1.2 above.

In addition to the general benefits listed, the new approach to communications, navigation and surveillance proposed by ICAO is expected to be able to foster the growth of air transport in developing regions [16]. While many developing states cannot afford the implementation and maintenance of existing ground-based ATM technology, the ICAO's CNS/ATM systems concept could be achieved in those countries by taking advantage of shared investment provided by service providers. Thus, ADS is anticipated to make possible low cost air traffic control centres affordable to all nations. Furthermore, GNSS, ADS-B and air-to-air data-link communications might make possible safe navigation and airborne-based separation assurance in remote or inaccessible areas, where the installation of radar and ground control centres is impossible or unaffordable. Therefore, new technology as being proposed is expected to allow for communications, navigation and surveillance systems which can open the way to affordable, safe and efficient ATM in developing countries.

1.2.2 Federal Aviation Administration (FAA)

The Federal Aviation Administration (FAA) is the United States governmental organisation in charge of managing the National Airspace System (NAS). The NAS encompasses the whole civil aviation infrastructure in the United States and includes among other things, airports, air traffic control equipment and services, rules, regulations and procedures. The FAA approach to the ICAO CNS/ATM systems concept is embodied in the notion of Free Flight. In 1995, following the advice of the Radio Technical Commission for Aeronautics (RTCA), which is a United States-based non-profit private corporation that addresses requirements and technical concepts for aviation, the FAA endorsed Free Flight as its guiding concept and future ATM operational framework.

Earlier that year, the RTCA had been requested by the FAA to constitute a Free Flight Implementation Task Force and in the final report defined Free Flight as:

"...a safe and efficient flight operating capability under instrument flight rules (IFR) in which the operators have the freedom to select their path and speed in real time. Air traffic restrictions are only imposed to ensure separation, to preclude exceeding airport capacity, to prevent unauthorised flight through Special Use Airspace (SUA), and to

ensure safety of flight. Any activity which removes restrictions represents a move toward Free Flight." [17].

In that Final Report, the RTCA also proposed an incremental evolution towards the implementation of Free Flight and this is outlined in Table 1.3 below. In mature Free Flight operations, communications, navigation and surveillance technologies together with new ATM procedures would make possible an increase in the airspace capacity by reducing separation standards and would allow the airspace users to fly their preferred routes while guaranteeing adequate levels of safety. To achieve these objectives, Free Fight is anticipated to rely on extensive dynamic collaboration between the airspace users and all the establishments involved in ATM.

Depending on the traffic density and the complexity of the traffic flow, Free Flight will range from total route freedom and flexibility to four-dimensional flight plan contracts. Within Free Flight, it is anticipated that, in agreed and appropriate circumstances, the task of maintaining safe separation between aircraft could be shared between ATC and the flight crew and even fully transferred to the cockpit. This partial or total delegation of the responsibility for separation assurance to the flight crew is expected to deliver efficiency gains and more flexibility for the airspace users. Besides, given the appropriate situational displays and decision aid tools in the cockpit, full delegation of separation assurance to the flight crew could improve safety and efficiency in remote areas with no ground ATC coverage.

FUTURE ATM

- Universal two-way data-link
- Satellite-based Navigation and Surveillance
- Automatic Dependent Surveillance
- Collaborative Decision Support

FREE FLIGHT (All domains)
RVSM IN DOMESTIC AIRSPACE
DYNAMIC/ADAPTIVE SECTORS
DYNAMIC USE OF SPECIAL USE AIRSPACE
REDUCTION OF SEPARATION STANDARDS
CONFLICT PROBE/COLLABORATIVE CONFLICT RESOLUTION
FREE FLIGHT IN LOW DENSITY AREAS
PROCEDURES FOR RANDOM ROUTE NAVIGATION (RNAV)
COLLABORATIVE DECISION MAKING
REDUCED VERTICAL SEPARATION MINIMA (RVSM) IN OCEANIC AIRSPACE
EXPANSION OF THE FANS CONCEPT
LIMITED EN-ROUTE FREE FLIGHT
REQUIRED NAVIGATION PERFORMANCE EXPANSION AND IMPROVEMENT

- Ground-based Navigation and Surveillance
- Radar
- Radio Navigation Aids
- Limited Decision Support

CURRENT ATM

Table 1.3 Free Flight and the path to the future ATM according to RTCA [17].

In 1998 the FAA launched Free Flight Phase 1 (FFP1) as the first step in the evolutionary process towards Free Flight [18]. The aim of FFP1 is the limited deployment of a set of new systems and operational tools to evaluate their performance and the early benefits achieved as a result of their implementation. These new capabilities are expected to be available for a more widespread deployment and are consequently under review.

The five new capabilities being assessed within FFP1 are outlined as follows:

- Collaborative Decision-Making (CDM): The aim of CDM is to foster collaboration between airspace users and air traffic managers whereby they will achieve a more efficient utilisation of the airspace. CDM provides airlines and the FAA with real-time access to NAS-related information such as weather, delays.

- The User Request Evaluation Tool (URET): This enables controllers to manage pilot requests in en-route airspace by identifying potential conflicts up to 20 minutes ahead.

- The Traffic Management Advisor (TMA): Provides computer automation to support arrival sequence planning in the extended terminal airspace surrounding major airports in the United States. TMA is expected to increase the operational efficiency in the airspace between en–route and final approach.

- The passive Final Approach Spacing Tool (pFAST): The aims of pFAST is to maximise runway arrival throughput by providing the controller with an aircraft landing sequence and runway assignments according to user preferences and system constrains.

- The Surface Movement Advisor (SMA): Provides airlines with aircraft arrival information to enhance gate and ramp operations and reduce taxi delays.

In addition to the ground-based capabilities being evaluated in FFP1, the FAA is also involved in the operational evaluation of new cockpit-based tools and procedures within the program Safe Flight 21 [19]. Safe Flight 21 is a FAA and industry collaborative project aimed to assess operational enhancements that address the needs of the aviation industry and contribute towards the implementation of the Free Flight concept. The program encompasses a series of flight trials to be performed between 1999 and 2002.

The aim of these trials is to demonstrate and validate the following nine new operational enhancements in a real-world environment.

- Weather and Other Information in the Cockpit.

- Cost-effective Controlled Flight Into Terrain (CFIT) Avoidance.

- Improved Terminal Operations in Low Visibility.

- Enhanced See and Avoid.

- Enhanced En Route Air-to-Air Operations.
- Improved Surface Navigation for the Pilot.
- Enhanced Surface Surveillance for the Controller.
- ADS-B Surveillance in Non-Radar Airspace.
- ADS-B Separation Standards.

The main enabling technologies for these operational enhancements are Automatic Dependent Surveillance-Broadcast (ADS-B) and Traffic Information Service-Broadcast (TIS-B). The former provides the means for aircraft to transmit and receive, through, among other things, a broadcast-mode data-link, and information regarding aircraft identity, position and velocity. The latter allows for traffic and other data available on the ground to be transmitted to the cockpit via a broadcast-mode data-link. ADS-B and TIS-B information is displayed to the pilot on an advanced multifunction display, the Cockpit Display for Traffic Information (CDTI).

Through the analysis of the flight trials, Safe Flight 21 will address safety, capacity, efficiency, pilot and controller situation awareness, human factors, and certification and affordability issues concerning the nine operational enhancements considered in the program. Free Flight Phase 1 and Safe Flight 21 are the main projects concerning Free Flight being carried out under the auspices of the FAA. In spite of these efforts, the implementation of the Free Flight concept is an evolving process and many issues remain to be satisfactorily addressed. These issues range from where the authority for air traffic control will be, or can safely be placed, in the diverse traffic situations arising with the Free Flight concept, to the role of the automation tools and their interaction with the human operators.

1.2.3 European Organisation for the Safety of Air Navigation (EUROCONTROL)

Eurocontrol was founded in 1960 by six European countries with the mission of overseeing air traffic control in their upper airspace. Currently Eurocontrol has a membership of twenty-nine states and its main objective is to organise co-operation in ATM between the respective national administrations [20]. Eurocontrol's importance grew from 1990, as it thereafter implemented and managed the strategy of the European Civil Aviation Conference for the 1990's.

The European Civil Aviation Conference (ECAC) was established in 1955 by nineteen European States with the active support of ICAO. ECAC is an intergovernmental organisation with the objective of promoting the continued development of a safe, efficient and sustainable European Air Transport System [21]. Currently ECAC comprises thirty-eight member states and seeks to harmonise their civil aviation practices and to promote understanding in aviation policy matters between the member states and other parts of the world. Eurocontrol's major initiatives have been the establishment in 1996 of the Central Flow Management Unit (CFMU) in Brussels together with programmes to optimise, harmonise and integrate air traffic control at centres and airports across Europe [20]. Most recently, Eurocontrol has developed the ATM Strategy for the years 2000+ [22], which lays down a framework for improvements in European ATM in terms of airspace organisation, infrastructure and procedures. The Strategy provides the guidelines to meet the projected demand for air traffic in Europe during the period 2000-2015. ATM 2000+ was developed at the request of the ECAC Member States' Ministers of Transport, who endorsed it in January 2000. ATM 2000+ emphasises the need to create a single airspace for Europe, which, for ATM purposes, shall not be constrained by national boundaries [22].

The main innovations regarding ATM operational methods proposed by Eurocontrol to realise the objectives of the ATM Strategy for 2000+ are presented in the Operational Concept Document (OCD) [12]. The OCD provides a high-level description of the target operational concept for the European airspace in the year 2015. According to the OCD, the ECAC airspace in 2015 will comprise three different types of airspace regimes: Unmanaged Airspace (UMAS), Managed Airspace (MAS) and Free Flight Airspace (FFAS). The airspace regime indicates the method of managing a volume of airspace, including the way in which separation assurance is accomplished. The three airspace regimes proposed in the OCD are briefly described below:

- *Unmanaged Airspace (UMAS):*

  UMAS will basically be the airspace currently referred to as "Outside of Controlled Airspace", and will be subject to the same rules applied today, the Rules of the Air [23]. Aircraft operating in UMAS will not interact with ATM unless they wish to do so by filing a flight plan or by broadcasting their position and possibly their intentions through ADS or a similar electronic means. Traffic Information Service may be provided to aircraft flying in UMAS on request.

- *Managed Airspace (MAS):*

  In MAS the ground-based ATM provider will be responsible for separation assurance. MAS will encompass en-route airspace as well as volumes of airspace around airfields. These volumes will be dedicated to manage terminal area operations, as today's TMA (Terminal Management Area). Traffic within MAS in busy areas at peak times will be organised in the form of a route network. This route structure will change dynamically and will be optimised to increase flight efficiency. The routes will be designed taking into account the new airborne and ground-based CNS capabilities. These new capabilities are expected to support the reduction of the current separation minima and the definition of more closely spaced routes. This traffic organisation is referred to as Structured Routes and is anticipated to enable air traffic managers to achieve high levels of capacity in busy areas while meeting agreed levels of safety. In determined volumes within MAS and possibly in busy MAS areas outside peak times, aircraft will be allowed to operate user-preferred routes. Aircraft flying user-preferred routes are referred to as operating in Free-Routing. During Free-Routing operations, ATM retains the responsibility for separation assurance but it will collaborate with the flight crew to establish the best course of action to solve a conflict. User-preferred routes may change from day to day due to weather conditions, traffic restrictions, criteria of the airline, etc. Thus, collaboration between ATM providers and operators together with efficient information sharing will enable air traffic managers to meet the demands of the airspace users.

- *Free Flight Airspace (FFAS):*

While flying in FFAS, suitably equipped aircraft will be allowed to dynamically choose their preferred trajectories. Aircraft operating in FFAS are anticipated to modify their routes according to their long-term and short-term preferences through a collaborative interaction with the ATM provider. The responsibility for separation assurance from the other aircraft operating in FFAS will rest on the cockpit, although the ground-based ATM provider would intervene in non-nominal situations.

The volumes of airspace in which FFAS regime is envisaged to be applied will be periodically designated according to the expected traffic demand by an airspace planning service within ATM. In principle, access to FFAS will only be granted to suitably equipped aircraft. This limited access to FFAS, an airspace regime design to maximise user flexibility, is expected to encourage aircraft operators with less capable aircraft to upgrade their avionics.

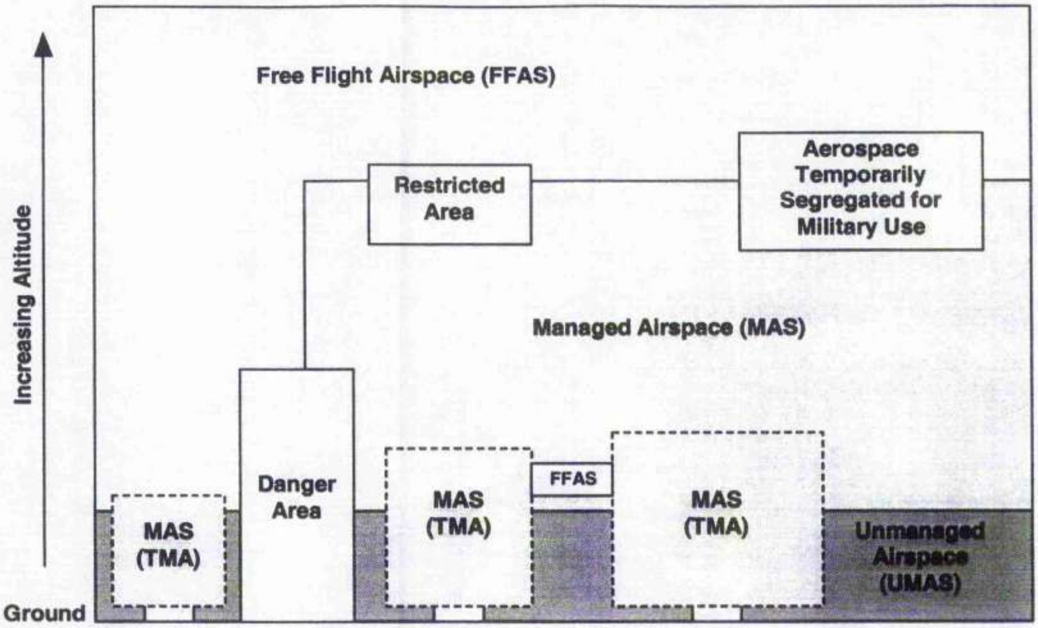

Figure 1.1 Vertical view of the predicted European airspace structure for 2015 [12].

1.3 Concepts and Procedures for the Future ATM

The following are the future concepts and procedure of the future ATM.

1.3.1 The Airborne Separation Assistance System (ASAS)

The ASAS concept embodies the response of ICAO to the diverse emerging tools and procedures being developed to support a further engagement of the flight crew in separation assistance under the future ATM. The ASAS concept, which was first introduced in 1995 by the ICAO Secondary Surveillance Radar Improvements and Collision Avoidance Systems Panel (SICAS Panel) [15] is defined as:

- *'The equipment, protocols and other aircraft state data, flight crew and ATC procedures which enable the pilot to exercise responsibility, in agreed and appropriate circumstances, for separation of his aircraft from one or more aircraft'* [13]

The ASAS concept encompasses two broad categories of proposed applications [14], which are briefly described below:

- *Traffic Situational Awareness Applications*: Provision of information to the flight crew regarding position, identity, flight status and intentions of proximate aircraft.

- *Co-operative Separation Applications*: The pilot uses ASAS equipment to perform an operational procedure that involves complying with defined separation minima with proximate aircraft.

Thus, the ASAS applications range from the mere enhancement of the flight crew's awareness of the surrounding traffic to the transfer of the responsibility for separation assistance from the ground-based control to the cockpit in the appropriate circumstances. Although the ASAS applications are still in the research and development stage, they are foreseen as cornerstones of the future ATM.

ICAO is committed to the elaboration of international technical requirements and operational standards for the envisaged ASA application. With this effort, ICAO strives to provide a standard framework for the development of cockpit based separation assistance tools. The main benefits expected to be delivered by the ASAS applications have been anticipated by the SICASP Panel [15] and are outlined below:

- Improvement of the pilot's situational awareness. Operational safety is expected to improve with the provision of information regarding identity, status, position and intentions of the proximate aircraft.

- Increase in the capacity and improvement of the efficiency of ATC through the active involvement of the aircraft crew in the separation assistance process. The delegation of the responsibility for separation assistance to the cockpit is expected to reduce the controllers' workload.

- Increase in the airspace capacity by enabling a more accurate compliance to separation minima. Ultimately, ASAS is expected to contribute to the reduction of these separation minima.

1.3.1.1 Enabling Technologies of ASAS

- *Automatic Dependent Surveillance-Broadcast (ADS-B)*

ASAS applications are expected to rely on information provided by an onboard surveillance system such as Automatic Dependent Surveillance-Broadcast (ADS-B). According to the ICAO Automatic Dependent Surveillance Panel (ADSP), ADS-B can be defined as a function that enables aircraft to periodically broadcast their state vector, which contains the aircraft position and velocity, together with other information [17]. ADS-B is automatic because no external stimulus is required to trigger a transmission; it is dependent because it relies on data from the on-board navigation systems and on-board transmission equipment to provide surveillance to surrounding aircraft. In principle, any user within the surveillance range, either aircraft or ground-based, may use and process ADS-B surveillance information.

Although in 1998 the RTCA issued a document containing the minimum performance requirements for ADS-B [18], ADS-B is still in the development stage and there is no international agreement on which data-link technology will finally enable the broadcasting of ADS-B data. Currently three different data-link technologies presumably capable of supporting the ADS-B function are being examined: Mode-S Extended Squitter, VHF Data Link Mode 4 (VDL Mode 4) and Universal Access Transceiver (UAT). The level of operational performance of the ADS-B function will depend on the final characteristics and capabilities of the chosen data-link. However, regardless of the favoured data-link, the ADS-B function will have to comply with international minimum operational standards. Thus, it is possible that more than one data-link technologies are approved to support ADS-B as long as the ADS-B function displays the appropriate operational performance levels.

- *Air-to-air data-link*

Advanced ASAS applications may also require the use of a point-to-point data-link, which would enable aircraft to address specific aircraft in the vicinity. In addition to the broadcasting ADS-B function, this data-link capability would allow aircraft to interchange data with selected proximate aircraft. This high-performance inter-aircraft data communications capability is anticipated to make possible co-ordination of separation assurance manoeuvres between aircraft [20]. However, this service is still in the research phase and its technical and operational requirements have not been established.

- *Cockpit Display of Traffic Information (CDTI)*

A crucial issue concerning the implementation of ASAS applications is the satisfactory interaction between the pilot and the ASAS equipment. Thus, it is anticipated that the Cockpit Display of Traffic Information (CDTI) will be an essential component of the interface between the pilot and the ASAS applications. The CDTI will display to the pilot the identities and relative positions of the proximate aircraft based on ADS-B surveillance data.

Other data received through ADS-B, such as aircraft intent, together with weather data acquired by the weather radar and information received from the ground-based ATM service are also subjects to be presented to the pilot in the CDTI, either automatically or by pilot's request as it is expected to be the core element of the traffic situational awareness ASAS applications. Besides, the ASAS co-operative separation applications are also anticipated to rely on the use of the CDTI, which will be a key element in the process of interaction between the pilot and the ASAS equipment.

- *Traffic Information System-Broadcast (TIS-B)*

It is expected that mixed-equipage traffic situations involving aircraft with and without ADS-B will occur in the future. In these situations, the information related to the proximate traffic displayed on the CDTI and used by the ASAS equipment will be based on both ADS-B surveillance data and radar data uploaded from a ground-based station through TIS-B (Traffic Information System-Broadcast). Thus, TIS-B consists of the broadcasting of radar information via data-link to provide aircraft with surveillance information concerning their proximate traffic. Thus, TIS-B will complete the picture of the traffic surrounding an ADS-B equipped aircraft by providing surveillance data for the proximate aircraft not equipped with ADS-B.

1.3.2 ASAS Applications

- *Traffic Situational Awareness Applications*

The aim of the Traffic Situational Awareness (TSA) applications is to provide the pilot with an accurate picture of the surrounding traffic. The provision of TSA does not involve the transfer of responsibility for separation assistance from the ground-based ATC to the cockpit, thus, TSA does not constitute separation assistance in itself and is considered as the first stage to co-operative separation ASAS applications. It is expected that TSA will be accomplished through the display of ADS-B and TIS-B data on a CDTI where the use of the CDTI for separation purposes shall be identified as a Co-operative ASAS application.

- *Co-operative ASAS applications*

In the current ATC system, pilots are in charge of the efficient navigation and control of their aircraft, and air traffic controllers are responsible for maintaining aircraft separation. Thus, in controlled airspace pilots have to follow controllers' directions to ensure safe separation from the proximate aircraft. Separation minima are in place and controllers issue instructions to the pilots to comply with them and therefore achieve safe and efficient air traffic operations. Pilots themselves have no separation minima to maintain, other than avoid imminent collisions and wake turbulence [19]. However, co-operative ASAS applications will involve a new definition of the responsibilities of the ground ATC and the flight crew in the separation assistance tasks. Under determined circumstances, the flight crew could assume the responsibility for maintaining safe separation with other traffic when provided with the adequate tools and procedures. Thus, the flight crew would co-operate with the ATC in the task of separation assistance.

The Review of the General Concept of Separation (RGCS) Panel of ICAO distinguishes two levels of transfer of responsibility for co-operative ASAS applications [19]:

- *Limited transfer of responsibility:* ATC remains responsible for separation assistance, except in determined circumstances defined in a period of time, a volume of airspace and a level of complexity of traffic. In such circumstances, the flight crew would assume the responsibility for separation within an ATC clearance. In general, a clearance is an authorisation for an aircraft to proceed under conditions specified by ATC [20]. Limited transfer of responsibility is anticipated to make possible an increase in ATC capacity through a reduction of the controllers' workload, an accurate compliance with the separation minima and a possible reduction of those minima. An example of a co-operative separation application involving Limited Delegation is station keeping, where an aircraft flying behind another one in en-route or terminal airspace is cleared by the controller to follow the leading aircraft and maintain a certain longitudinal separation from it.

- *Extended transfer of responsibility:* The responsibility for separation assistance is fully assumed by the flight crew. The ground ATM authority would be responsible for monitoring the traffic complexity and maintaining it at a level compatible with the airborne separation assurance capabilities. An example of a co-operative separation application is Autonomous Aircraft, where aircraft flying in specially allocated volumes of airspace dynamically re-plan their routes according to their preferences and to the constrains of the environment, including weather and possible conflicts with other proximate Autonomous Aircraft. Thus, Autonomous Aircraft are fully responsible for separation assistance. Besides the expected benefits of limited transfer of responsibility, extended transfer is envisaged to bring about more freedom and flexibility for airlines together with an increase in safety of flight operations in areas with no ground based ATC.

In addition to defining the two different levels of transfer of responsibility for separation assistance in co-operative separation applications, the ICAO RGCS Panel also establishes three different levels of delegation of separation assistance to the flight crew in such ASAS applications. The delegation of separation assistance is an operational concept and involves the assignation of specific separation assistance tasks to the flight crew. The RGCS Panel describes the separation assistance process as consisting of four consecutive tasks, regardless of where the responsibility for this process is placed [30]:

Task 1.- Conflict Detection: It involves the analysis of a traffic situation and the detection of possible violations of the established separation minima between the aircraft considered. Conflict detection can be performed either by a human operator or by an automated conflict detection tool.

Task 2.- Conflict Resolution: It involves the determination of a strategy to avoid the predicted conflicts. This solution is created with the possible assistance of conflict resolution tools.

Task 3.- Implementation of the Conflict Solution: The flight crew manoeuvres the aircraft according to the strategy elaborated to solve the conflicts.

Task 4.- Monitoring of the Conflict Resolution: A human operator observes the aircraft trajectory to establish that the conflict resolution manoeuvre achieves its objective. If the objective is anticipated to be unattainable through the current manoeuvre, the separation assistance process restarts in task 1.

Depending on which of these tasks are assigned to the cockpit during the separation assistance process, the RGCS Panel distinguishes three levels of delegation of separation assistance in ASAS co-operative separation applications [18].

Limited delegation: Tasks 1 and 2 (Conflict detection and resolution) are performed by ATC. The tasks of implementing and monitoring the solution manoeuvres are allocated to the flight crew.

Extended delegation: Conflict detection is performed by ATC. The remaining tasks are assigned to the cockpit.

Full delegation: All the separation assistance tasks are assigned to the cockpit.

Limited delegation and extended delegation are associated with limited transfer of responsibility for separation assistance, while full delegation of separation requires an extended transfer of responsibility for separation assistance.

1.4 Autonomous Aircraft Operations (AAO)

The concept of Autonomous Aircraft Operations (AAO) refers to an envisaged co-operative separation ASAS application involving extended transfer of responsibility for separation assurance and full delegation of separation assurance. The flight crews of the Autonomous Aircraft will be granted responsibility for exercising separation assurance within designated airspace [21]. The type of airspace allocated for AAO will be the Free Flight Airspace (FFAS) regime, defined by Eurocontrol in its Operational Concept Document for the future European ATM [12]. FFAS will be operative in some volumes of European upper airspace under the future European ATM. Autonomous Aircraft will be required to be fitted with a minimum standard of CNS and ASAS equipment, which will be mandatory to enter FFAS.

As mentioned in Section 1.2.2, AAO are also being considered under the Free Flight initiative of the Federal Aviation Organisation in the United States. Besides, Autonomous Aircraft will probably be allowed to operate elsewhere over oceanic and remote areas with no ground-based ATC coverage, in volumes of airspace allocated to aircraft flying user-preferred routes and exercising responsibility for separation assistance from each other.

Once an Autonomous Aircraft enters a volume of airspace designated for AAO, it is granted responsibility for separation assistance from the surrounding aircraft, which are also Autonomous Aircraft, and ATC delegates the four tasks which separation assurance consists of to its flight crew. These four tasks are conflict detection, conflict resolution, and implementation of the conflict resolution and monitoring of the conflict resolution. Thus, the flight crews of the Autonomous Aircraft will hold extended transfer of responsibility for separation assurance. It is expected that Autonomous Aircraft will rely on ADS-B to acquire the position and intentions of the proximate traffic. Adequate conflict detection and resolution decision support tools for the pilot will have to be developed and an air-to-air communications data-link may also be necessary.

Autonomous Aircraft will not have to fly along established airways. They will be allowed to dynamically choose their preferred routes within FFAS, while avoiding conflicts with proximate Autonomous Aircraft. This capability to operate user-preferred routes will enable airlines to fly optimal trajectories and to avoid weather hazards within FFAS. Thus, operations in FFAS are expected to bring substantial benefits to airlines, such as a reduction of both fuel consumption and flight time and an increase in passengers' comfort. In addition, this flexible routing capability would add volume of airspace available to the current fixed route network. Despite the fact that ATC may perform a monitoring role in some operations in FFAS, Autonomous Aircraft will function without ground-based redundancy [21].

ASAS will be the primary means for separation for Autonomous Aircraft and ACAS will keep its role as a safety net. A fundamental requirement of the AAO concept is that the air traffic density must be kept below an established limit by the ATM services [21]. Within FFAS, traffic density should be such that Autonomous Aircraft are able to resolve the possible conflicts they will encounter without having to perform conflict avoidance manoeuvres too often, since these deviate the aircraft from their preferred routes. However, adequate separation minima for AAO remain to be established. However, it is anticipated that the use of advanced CNS technologies to implement these operations will allow for a reduction of the current separation minima, particularly in areas with no radar coverage. In these areas, currently with no ATC available and with separation assurance procedures based on pilots' voice position reports and large separation minima, AAO together with reduced separation minima will bring about an increase in safety and capacity.

1.5 Description of work and contribution

International organisations have all identified an understanding of human factors as a research priority and an integral part of any new concepts and procedures [11]. This is a position that has been discussed and exhorted for several decades [24], [25] and more so recently with the introduction of Airborne Separation Assistance System (ASAS) Work Package 1. One of the principal concerns with its introduction is the operational flexibility of delegating to pilots responsibility for maintaining separation as in keeping with applications of Limited, Extended and Full Delegation [183]. This operational flexibility, among other things, includes identification of potential problems, generation of solutions to resolve them, and implementation and monitoring of the chosen solution.

It has also been predicted that by the execution of these applications this will introduce new performance issues and present implications that will reflect significant changes in the way pilots and air traffic controllers will perform their respective tasks [4], [174], [175], [176] and [177].

As human performance considerations are expected to be central to the performance of advanced cockpit and Air Traffic Management (ATM) system [11] the work in this thesis addresses the implications and impact on the cognitive and behaviour processes of pilots and air traffic controllers during applications of Airborne Separation Assistance System (ASAS) Work Package 1, namely Limited, Extended and Full Delegation. It presents the development of a quantitative framework of eighty-five task-index and self –assessment performance factors which are incorporated into a decision support tool called, **Multi-criteria Analysis for Pilot Evaluation, MpE**. The quantitative framework is developed using the technique of Critical Task Analysis (CTA) addressing primarily issues concerning problems such as mental representation of the changing situations and the context-dependent flexible coordination of concurrent cognitive tasks, which are inherent to dynamic situations during the ASAS applications identified.

The decision support tool MpE is presented in the form of a Microsoft computer programme and represents an expansion of the operating and performance utilities, also called *Determinants,* of an already developed decision-support tool, Multi-criteria Analysis for Concept Evaluation MACE [9]. MACE is one of many packages of tools, software and documents developed specifically for air traffic controllers by EUROCONTROL scientist and experts to analyse and access changes, seen from a human factors perspective, of future ATM systems. The new *Determinants* (performance factors) now increased from forty factors to eighty-five factors represent the novel approach of this thesis.

Using the method of cognitive task analysis the *Determinants* were extensively modified and expanded from their original forty factors to eighty five factors, incorporating the tasks required for cockpit environment during ASAS applications of Limited, Extended and Full delegation. The focus of the expansion has been on issues concerning problems such as mental representation of the changing situations and the context-dependent flexible coordination of concurrent cognitive tasks, which are inherent to dynamic situations during the respective applications. The following cognitive tasks thought to be essential in performing delegation tasks were identified:

- Sensing and perceiving
- Visual functioning
- Perceptual functioning
- Information processing
- Reasoning/decision making/planning
- Spatial processing

The option of the operational processes of Limited, Extended or Full delegation will be determined by the appropriate combination of the above cognitive tasks.

To accomplish the workload analysis, representative tasks that fully exercise operation within the current system of operation and functions for each delegation level provide a basis for comparing workload levels. The following tasks were identified:

- Communication
- Navigation
- Engine & system performance monitoring
- System Status
- Emergency Tasks

MpE was constructed with the following three goals in mind:

1. To obtain a quantitative measures of the workload of pilots during ASAS applications of Limited, Extended and Full Delegation.

2. As a decision support tool to clearly delineate the cognitive tasks of pilots from those of air traffic controllers.

3. To predict the effects of change in the task environment of the pilot on the workload of the other human operators.

To illustrate the functionality and capabilities of the MpE two thousand hypothetical ASAS applications conducted by pilots were simulated. No statistical methods were employed for arriving at this number of 2000, however it was deemed that the number adequately covered the various combinations of the scenarios within the ASAS applications. To achieve objective three above, three hundred and fifty hypothetical ASAS applications conducted by air traffic controllers were simulations using the programme in its original form of (MACE). Whereas Situation Awareness may not be deemed as an ASAS application it was however included as an ASAS application during both simulations. The concept of situation Awareness application is intended to give the traffic crew information through a CDTI. Its inclusion as an application is intended to provide insight into the cognitive processes involved confirm whether its use enable a better representation of the traffic situation. The addition of Traffic Situation Awareness as an application resulted in four applications being simulated.

To arrive at workload measurements for the respective concepts the changes that each concept induced were first quantified. In the simulations for the pilot the new expanded eighty-five factors served as indicators. Using a specific value scale provided by the programme, these indicators were then related to one or several criteria, (a list provided by the programme expressing human dimensions) through linear or quadratic relationships where a positive result indicates the strength of the influence. Similarly the programme's original forty factors were used as indicators. The workload measurement took into account the relationship between the indicators of change and the criteria; and the interdependencies between the criteria.

The workload results for each application is a relationship between the programme's provided *Criteria* and the expanded eighty-five performance factors/*Determinants*. It is the result of a computation using multi-criteria analysis techniques, linear regression and quadratic calculations and is defined as a comparison between *Heaven* and *Hell*, where the closer to *Heaven* the workload is seen as easier and the closer to *Hell* the more difficult.

Using the Equation at 1.1 below the values of the acceptance levels and the abilities of the pilots with regard their new roles as they related to each respective application were determined.

$$\delta^{heaven}_{projectP} = f(criteria) = f[g(determinants)] = f \circ g(determinants) \qquad 1.1$$

To determine which *Determinant* score has a strong impact, either positive or negative, a direct relationship called h, between *Determinants* and $\delta^{heaven}_{projectP}$ was derived using equation 1.2.;

$$\delta^{heaven}_{projectP} = f \circ g(determinants) = h(determinants) \Leftrightarrow h = f \circ g \qquad 1.2$$

Then, using *linear regression algorithm* based on best square difference minimisation, a model as shown at Equation 1.3 of the following shape was established:

The *Linear regression models* at Figures 1.2 and 1.3 were developed based on best square difference minimisation, for the ATC and pilot.

$$\delta^{heaven}_{projectP} = Cste + \alpha_1.D_1 + \alpha_2.D_2 + ... + \alpha_{40}.D_{40} = \sum_{i=1}^{40} \alpha_i.D_i \text{ avec } D_0 = 0$$

$$\delta_{projectP}^{heaven} = Cste + \alpha_1.D_1 + \alpha_2.D_2 + ... + \alpha_{85}.D_{85} = \sum_{i=1}^{85} \alpha_i.D_i \text{ avec } D_0 = 0$$

Of the 2000 ASAS application simulations conducted for pilots, the overall *regression coefficient* ρ, (where ρ indicates the effect of change in the pilot's environment) derived from the coefficient α_i produced a value of:

$$\rho = 0.956$$

As this value is nearer to 1 it indicates a positive representation of the distance to *Heaven,* where the closer to *Heaven* the workload is seen as easier. Accordingly, from this result one can deduce that the work of pilots during the four ASAS applications will be easier.

As a research contribution, the eighty five performance factors identified as a result of the cognitive task analysis provide pilots with situation awareness and control schemes to facilitate operational effectiveness and workload management during ASAS applications of Limited, Extended and Full Delegation. Secondly, the development of the computational decision support tool MpE, highlights the viability and flexibility of the original MACE programme. As the programme was designed specifically to assess and measure the impact and consequential changes in the job of air traffic controllers, the development of MpE shows that with further human-in the loop validation it can be used within the ATM environment.

The research in this thesis is timely, as it has contributed to the aviation community, most notably cognitive engineering. This field of engineering in recent times has seek to identify what make the task difficult for human operators and how such difficulty impairs human performance [31]. It also addresses concerns raised at [185] as it identifies what is important in a particular domain from the user's perspective, given the goals and constraints of the user, the environment and the tools available.

One of the principal concerns with the introduction of ASAS applications is the adverse change on pilot's cognitive and behaviour processes from devolving to them more responsibility for maintaining separation. As role transfer between pilots and controllers becomes inevitable as pointed out in sections 1.2 – 1.3, accordingly the work in thesis has achieved its objective to develop preliminary understanding of pilot performance demands associated with conducting particular complex ASAS applications, particularly those of Limited, Extended and Full Delegation. It also provides the foundation for ongoing research in the area of human factors as the findings can be used in deciding and determining how the concept of delegation levels should be implemented to mitigate human performance issues and in the process ensuring human factors requirements are met. The work in thesis, by so doing accords well with the aim of the " ATM Strategy for 2000+" (EATCHIP, 1998a) which states:

"*...Consideration of human factors issues must be part of the technology design and certification process and of the development of operating procedures, and be completed before technology is used operationally to avoid flawed human-technology interfaces which may cause operating problems and additional costs throughout the system life cycle.*"

1.6 Human Factors and Cognitive Task Analysis Defined

Human factors is the study of human's interaction with products, environmental events, and equipment in performing a series of tasks or activities in completing a goal-directed behaviour with a focus on the human-system interaction [33]. As a discipline it applies knowledge of human capabilities and limitations to the design of technological systems and concepts. This human-system interaction encompasses not only physical behaviour but also the cognitive aspects of human behaviour.

The root of human factors lies in the Greek term ergonomics where "ergos" refers to the work itself and "nomos" refers to the rules in completing the work. Like most coherent activities, human factors combine features of other disciplines; for example, information is drawn from psychology to understand how people process information and make decisions. An understanding of the sensory processes as the means of detecting and transmitting on the world about us is obtained from psychology and physiology. The measures and movement of the body-essential in optimising the design and layout of controls, and other workplace characteristics of the flight deck, cabin and air traffic control environment call upon anthropometry and biomechanics.

Weiner et al, [31] reiterating the above definition declared; "human factors is concerned to optimise the relationship between people and their activities, by the systematic application of human science, integrated within the framework of systems engineering". The object of human factors, from Weiner's definition, can be seen as effectiveness of the system, which includes safety and efficiency, and the well being of the individuals. Andriole [34] in his contribution to the importance of human factors, noted that it is impossible to successfully design unless a multidisciplinary approach is used, embracing behavioural science and human factors on equal footing with peer disciplines. Smolensky et al [35] commented that human factors have not always been considered when new systems or concepts were conceived, developed or procedures were changed. He further illustrated the affects of this absence of human factors consideration on safety by sighting as examples aircraft accidents which all revealed that efficiency of the ATM system is also influenced by the lack of human factors knowledge as its absence or neglect can be expected to cause less than optimum performance of tasks.

Incorporating human factors into the design, development, and insertion of new technologies, issues of usability, ease of implementation, procedures, training, roles and responsibilities, and more can be resolved quickly while hardware capabilities are engineered and new regulations are crafted and approved. The work in this thesis has employed two principles of human factors, human performance modelling (HPM) and Cognitive task analysis (CTA). These principles are outlined as follows.

Human performance modelling (HPM) is the process of computer-based simulation where human characteristics are embedded, within a computer software structure in order to represent the human operator interacting with computer generated representations of the human's operating environment [36]. Many human factors researchers have proposed human performance modelling as a method of upholding the guiding human factors and ergonomics principles. The computer- generated human performance representation possesses many advantages to studying human-in-the-loop (HITL) performance especially when dealing with advanced, complex systems or concepts [36]. One of the advantages is the ability to model critical events that cannot be studied fully with HITL subjects due to safety concerns and subsequent cost.

Cognitive task analysis is a knowledge elicitation and representation method derived from the domain of instructional and cognitive psychology associated with operating in dynamic, complex, high-information environments [78]. CTA seeks to identify what is important in a particular domain from the user's perspective, give the goals and constraints of the user, the environment, the organisation, and the tools available. CTA focuses on making expert knowledge explicit and can provide information on expertise that is typically difficult to capture by other knowledge elicitation methods [79], [80].

CTA has been successfully used in numerous operational domains that are characterised by complexity, high information load, automation, time pressure, uncertainty, risk and continually changing information. In this thesis the intrinsic task requirements imposed on pilots during ASAS applications of Limited, Extended and Full Delegation were identified, paying particular attention to factors such as information processing, decision making, problem solving, cognitive workload, judgement, situation assessment, short and long-term memory, and attentional focusing.

1.7 Previous Related Work

Work on the impact of shifts in separation authority between pilots and controllers have been examined, however most of this have been conducted during the investigation of free flight operations. Endsley et al [37,38] reported that controllers acting as passive monitors during free flight might show a decrease in situation awareness, an increase in workload due to different responsibilities, and have problems making timely interventions. They indicated that communications might significantly increase under free flight conditions due to the need to obtain pilot intent information.

Glater et al [39] reported a free flight study in which traffic densities and presence of self-separating aircraft were varied. It was shown that it was difficult for controllers to notice the self-separating maneuvers of pilots. While controllers detected nearly 100% of conflict under moderate traffic, their conflict detection performance dropped to only

50% under high-density traffic. Metzger et al [40] performed a study manipulating traffic densities and locus of control that is active or passive. Passive control consisted of the controller detecting the conflict, but refraining from providing a resolution strategy. In the active control locus, controllers detected conflicts and provided resolution strategies. In the high-density condition, controllers took twice as long to detect conflicts in the passive compared to the active control condition.

Corker et al [41] have also investigated the impact of shifts in separation authority. In their study, the Jacksonville Air Route Traffic Control Centre (ARTCC) controller participants worked traffic from four different conditions: current traffic, trafficing directly to their feeder fix close to their destination airport, 20% of traffic self-separating, and 80% of traffic self-separating. The controllers were instructed that in the cases of self-separation, they had authority to cancel free flight whenever they felt safety was compromised. Results indicated that controller subjective workload was affected by the free flight conditions. They also reported that when the majority of the aircraft were managing their own separation, the subjective workload rating for the controller was higher. It was also reported that increase in workload appeared to be directly related to the increase in communication requirements necessary to accomplish the controllers' management of airspace. The controllers reported that they needed to communicate with the aircraft to determine its intent knowledge they felt was vital to accomplishing their tasks. Finally, the data from this investigation revealed that the controllers cancelled free flight for an average of about 20% of the aircraft in conditions where 20% were self-separating, while 9% of the aircraft were cancelled in the condition with 80% of the aircraft self-separating.

Similar work of shared separation conditions was conducted at [42] detailed a real-time simulation with pseudo-pilot systems which were linked to NASA ARC Boeing 747 400 flight simulator. The work addressed earlier findings of Hollnagel Contextual Control Model [43, 44, and 45]. In the experiment controllers monitored many aircraft and attended to conflict to see whether pilots resolved them satisfactorily. Some results of Dimeo et al [42] were similar to Corker et al [41] as they both showed discomfort for the controllers when separation authority was shared with the flight deck. Dimeo et al reported that the pilots preferred the shared separation conditions and they were safer, even though they reported their workload was higher and there was little evidence that significant new cognitive problems were being posed to pilots when control was delegated to them.

Earlier work conducted in this area has been performed at NASA Ames Research Centre (ARC) where efforts were made to provide quantitative description of the airspace complexity dynamic similar to those provided here in this thesis. [46], studied dynamic density as an ATM metric of controller activity level characterising the measures of airspace complexity that are based on the flow characteristics of the airspace. The dynamic density was developed based on interviews and survey techniques with input from sixty (65) qualified air traffic controllers. The controllers were presented with questionnaires which contained preference for factors affecting their performance. In addition to the traffic density, the numbers of aircraft undergoing trajectory change and requiring close monitoring due to reduced separation were also studied. These were also identified by controllers as significant contribution to workload and an activity catalogue tool was developed to measured controller activity which was then correlated to dynamic density.

Another effort to provide quantitative and computational results on air traffic complexity as a result of new concepts is one undertaken at Wyndemere, Inc.,[47] which described a method for evaluating and measuring the complexity of airspace. The framework was designed to evaluate a model of the perceived complexity of an air traffic situation, with specific emphasis on the traffic and airspace characteristics that impact on the cognitive and physical demands placed on the air traffic controller. An attempt was made to include the level of knowledge about the intent of aircraft. The Federal Aviation Authority (FAA) William J, Hughes Technical Centre [48] has also conducted a study to identify a set of dynamic metric variables and to quantify their contribution towards controller workload. The intent of the study was to evaluate validity and utility of the identified metrics for air traffic management.

Notwithstanding the work of [47] and [48], the work in this thesis offers a novel approach as it has presented an extended framework which identifies what is important from the pilot's perspective, given the goals, constraints, environment and tools available during ASAS applications of Limited, Extended and Full Delegation. A literature search using BIDS and inserting aviation/aerospace and ATM, using key word such as pilot/controller role transfer, role reversal measurements and workload resulted in less than ten articles being identified.

1.8 Literature Review

Although historically the emergence of human factors as a distinct discipline cannot be traced to any single event or year, the application of human factors to ATM can be said with some certainty to have started in 1951 and since its origins, the literature on human factors in ATM has grown tremendously although much of it, as noted by [81] remains diffused and rather inaccessible. In 1951 a National Research Council (NRC) report was published, concerned with the planning of a "long range research program on human factors in air navigation and air traffic control" [49]. The list of topics considered in that report were:

- The role of the human operator (manual vs. automatic)
- The division of responsibility between humans and machine
- Human performance characteristic
- The division of responsibility between human operators
- Manpower and personnel problems
- Economic issues.

These topics still remain as relevant as ever with a more recent NRC report [50] covering very similar subjects such as task in ATC; performance assessment, selection and training; workload and vigilance, teamwork and communications; and automation. Similarly, literature produced by ICAO [51, 52]; EATCHIP [53] and EATMP [11] is further increasing awareness of human factors in ATM as have produced human factors guidance material on the following topic which this thesis addresses:

- A wide variety of workload measures have been developed [54], [55] as mental workload of the human operators remains a key human factors consideration.

- As the human operator will remain in the loop for the foreseeable future, the impact of automation on the human operators has received much research focus – flight deck [31], [56]; ground-based ATC/ATM systems [57], [2].

- Safety is also receiving attention [58], [59].

- As controlling and navigating are both highly cognitive activities and as such both the controller's mental picture and the pilot's situation awareness (SA) have been topics of research – [60, 61, 62].

- Teamwork between controllers, between pilots, and between controllers and pilots which is critically important for the safety and efficiency of the ATM systems has also received research attention [10, 51].

- Human Factors Integration [1].

The amount of human factor knowledge which has been accumulated over the years is quite enormous, as evidenced by such seminal texts as *"Human Factors Design Handbook"* [63], *"Engineering Data Compendium"* [64], and *"International Encyclopaedia of Ergonomics and Human Factors"* [66] each of which cites hundreds of references. In addition, there are now many sources of human factors information available on the Internet as highlighted at Appendix 1 where some of the sources used in this research are highlighted.

A number of human factors design guides have been produced in recent years, primarily in the United States under the auspices of the FAA. These documents basically build upon existing human factors material with some tailoring of information specifically for ATM systems. The Federal Aviation Authority's (FAA) *Human Factors Design Guide* [66] provides human factors guideline covering the following topics: automation, maintenance, human-equipment interfaces, human-computer interfaces, workplace design, user documentation, system security, personnel safety, environment and anthropometry. A related FAA report by Cardosi and Murphy [67] provides extensive literature review and guideline on the following major topics as they relate to future and present ATM: human capabilities such as visual and auditory perception and speech; human information processing paying great detail to the cognitive processes; issues in ATM automation; human computer interface (HCI); workload and performance measurement; workstation and facility design and evaluation and lastly human testing and evaluation. In addition, the report includes a section on human factors in system and concept acquisition which discusses at some length the development of a "human factors plan". The United States National Research Council, Committee on Human Factors carried out a wide-ranging study of the human factors issues of ATC systems and technology, focusing particularly on automation [50]. The impetus of the study was the concern that:

"*Efforts to modernise and further automate the air traffic control system should not compromise safety by marginalising the human controller's ability to effectively monitor the process, intervene as spot failures in the software or environmental disturbances require, or assume manual control if the automation becomes untrustworthy*".

Similarly, though not to the magnitude of those produced the USA, specific human factors guidance documents on the design of human machine interface (HMI) has been produced for the United Kingdom and Europe by EUROCONTROL and some national authorities notably, [68, 69, 70 and 81]. In the case of EUROCONTROL one such document is a description of a "state-of-the-art" graphical interface for en-route ATC [60].

The effects of automation on the future role of the controller is also a topic of particular concern of the Programme for Harmonised Air Traffic Management Research in EUROCONTROL (PHARE)" [71] and the European Commission's "Role of the Human in the Evaluation of ATM systems [72].

The automation for the future ATM, which raises a host of human factors issues, i.e., stress, situation awareness, workload, vigilance, etc has seen much research devoted to aviation issues and particularly automation of aircraft cockpits and the flight decks of commercial airliners [31, 32, 56, 73 and 83]. The automation of ATM system, and particularly the ATC systems has, also received significant attention over several decades [74, 75, 76 and 104], although perhaps less than for other domains.

1.9 Outline of Thesis

The remainder of the thesis is organised as follows:

Chapter 2 expands on the human factors of the Airborne Separation Assistance with emphasis on the delegation levels. The general architecture of multi-criteria analysis concept evaluation (MACE) is introduced and the reason for its selection for the development for MpE. This section concludes with a comparison analysis of the utilities of MACE to those other decision tools.

Chapter 3 introduces the research topic and also expands on the development of the concept. This chapter also highlights the incorporation of CTA results and the amendments made to the original tool.

Chapter 4 presents results based on the applications of M-pE.

Chapter 5 provides a discussion on the results developed in chapter 4 using MACE for Pilots Extension (M-pE) simulation. The aim is to test their functionality and how well they realized their desired goals. This chapter also provides a comparison analysis of results obtained from the programme in it original format, for air traffic controls and those obtained with the M-pE, for pilots.

Chapter 6 includes additional discussion not covered in previous chapters and also outlines areas of future work.

Chapter 2

Delegation and Air Traffic Control

2.1 Introduction

In the previous chapter the technical developments and operational procedures envisaged for the future ATM were highlighted. It was also pointed out that the changes as a result of the future ATM, specifically ASAS applications would affect the tasks and roles of the human operators. As the objective of the work presented in this thesis centres around human factors in the air traffic environment and the effect of change with respect to new operating procedures it is only fitting that before expanding on these proposed changes, particularly those this thesis addresses, to first takes an in-depth look into the present process of air traffic control. Accordingly, section 2.2 details the development of air traffic control (ATC) while section 2.3 illustrates the role and tasks of the three classes of controllers through the description of a typical flight operation by a civil aircraft in controlled airspace where typical European control techniques. Section 2.4 introduces and discusses in detail the research topic highlighting the human factors issues arising as a result of ASAS applications, notably the processes of delegation. This section also details the need to evaluate the effects of the applications process. Section 2.5 introduces the general architecture of the decision support tool developed, **Multi-criteria Analysis for Pilot concept Evaluation (MpE)**. The chapter concludes with a critical review of other decision support tools.

2.2 Development of Air Traffic Control

Air traffic control continues to pose human factors problems of a type and complexity seldom encountered elsewhere in other disciplines [74], however this was not always the case for in the early formative days the tools at the disposal of the controller and tasks performed were very simple. The tools consisted essentially of a means of communication, sometimes indirect, between pilot and controller and between controller and the point of departure and arrival. A simple display on which the controller could list the traffic under their care and amend essential data derived from position reports sent by pilots was used. Similarly, the task involved no serious strain as it depended basically on the skills of the controller, who took full responsibility for maintaining a safe, orderly and expeditious flow of traffic along the airways. This was achieved by studying progressive positional information transmitted at regular intervals by the pilots. Their ancillary tools and simple procedures raised no serious problem to justify evaluation of airspace or procedures and meant that little consideration had to be given to the human operators' capabilities, task, tools and environment.

Today, the task of ATC includes several phases [50] ground operations from gate to taxiway to the runway, takeoff and climb operations to reach a cruising altitude, cruise flight over land and/or sea to the destination, approach and landing operations at the destination, and finally, taxi back to the gate (or other point of unloading). The ATC service is usually organised into a number of specialist units where almost every ATC control position has different duties. Control is accomplished by three general classes of controllers, each resident in different kinds of control facilities. First, there are ground and local controllers who handle traffic on the taxiways and runways, through takeoffs and landings and are collectively referred to as tower (TWR) controllers. The second set are radar controllers who handle aircraft from takeoff to their cruising path origin along what are usually referred to as Standard Instrument Departure (SID) routes, and return them through their approach at the destination along Standard Terminal Arrival Routes (STARs). The former are known as departure controllers (DEP) and the latter as approach controllers (APP). Third, are en-route controllers working at the Area Control Centre (ACC) who manage the cross-country flow of traffic along the airways between TMAs. In the United States this is known as the Air Route Traffic Control Centre (ARTCC). Figure 2.1 is a generic representation of the specialist units within ATC.

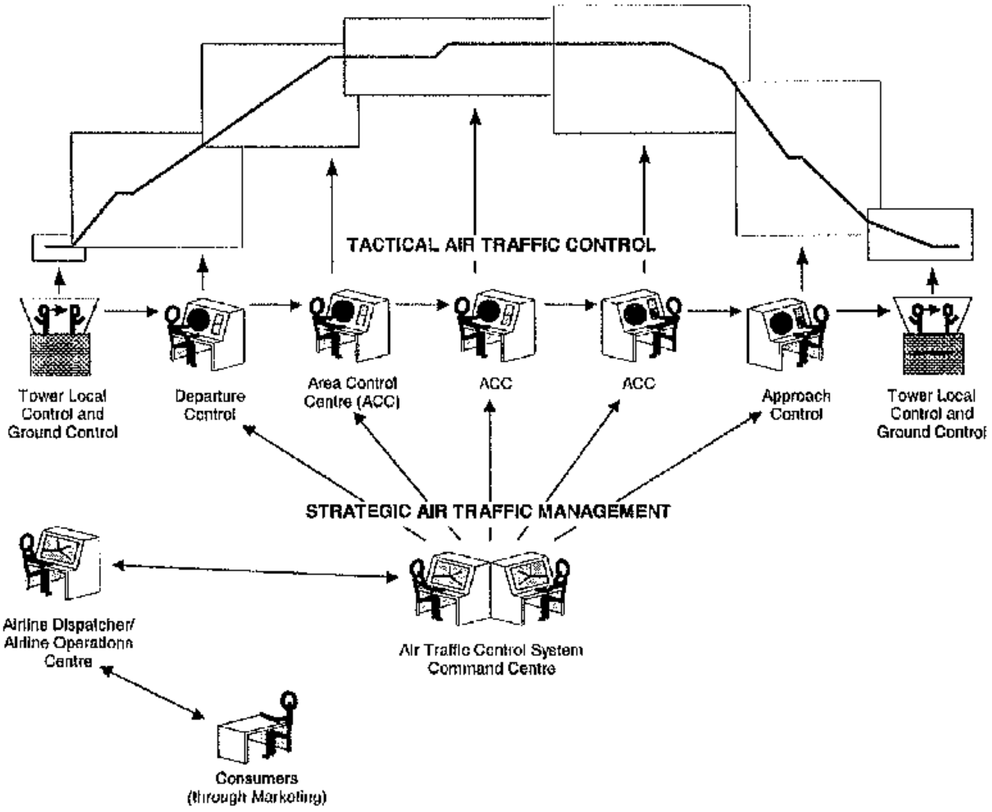

Figure 2.1 Phases in Air Traffic Control Operations [50].

2.2.1 The Airway System

The current system of airways was created in response to limited navigational technology [88] and was invented to segregate other traffic from "tame" aircraft capable of accurate navigation and having available the flight-deck manpower to make position reports and maintain a listening watch on an ATC frequency.

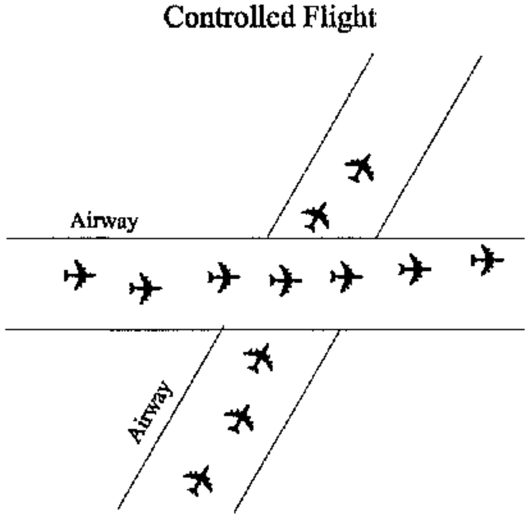

Figure 2.2 A Typical Airway System.

The system (Figure 2.2), a corridors of approximately 10 nautical miles wide, assumes that the aircraft is capable of navigating to acceptable accuracy, by reference to ground-based point-source radio navigation facilities such as high-frequency (HF) non-directional beacons or very high frequency (VHF) omni-ranges (VOR), the standard navigational aid adopted by international agreement.

Currently accepted overall VOR system performance gives an accuracy of ± 5 degrees at the 95% confidence level. To provide adequate track maintenance within the 10nm wide airways, VOR beacons must be established at intervals of not more than about 90 nm. Communication between controller and aircraft is by means of VHF radio-telephony (RTF). Almost invariably, the pilot speaks directly to the controller concerned and the aircraft is given control sector sharing a common RTF channel. In certain sectors where all aircraft cannot be within line-of –sight of a single VHF ground station, the "Climax" or offset-frequency-simplex technique allows a number of ground stations to co-operate in providing the controller with the necessary two-way coverage.

2.3 Air Traffic Control – Role and Task

The role of the air traffic controller is not to let the reserved airspace of two aircraft overlap [74] for if they do, a separation error occurs. Controllers use different techniques to ensure aircraft separation some of the most common are speed control, altitude change, radar vectors, holding patterns [83]. They must address the sometimes-conflicting goals of safety and efficiency through an integrated series of procedures, judgments, plans decisions, communications and co-ordinated activities [50].

Categories Of Coordination Behaviours	ATC POSITION				
	Control Delivery	Ground Controller	Local Controller	TRACON Controller	En Route Controller
Situational Awareness	♦	♦	♦	♦	♦
Leadership			♦	♦	
Communication	♦	♦	♦	♦	♦
Mission Analysis	♦	♦			
Assertiveness			♦	♦	♦
Decision Making	♦		♦	♦	
Adaptability	♦	♦	♦	♦	♦

Table 2.1 Categories of Coordination Behaviours that Contribute to ATC performance (Adapted from the definition of [10])

To illustrate the operating environment, roles and tasks of the three classes of controllers a typical flight operation by a civil aircraft in controlled airspace is demonstrated and reviewed. It is intended to illustrate some of the human factor constraints and limitations inherent in a contemporary ATC and navigation techniques where typical European techniques are used. The description concentrates on the environment as seen by the pilot and the coordinated behaviour of the air traffic controller as detailed in Table 2.1. Section 2.4 gives a more detailed discussion on the problems facing the air traffic controller.

2.3.1 Tower Controller

Before departure, ATC must be provided with a flight plan giving the destination and alternative aerodrome, the intended route, cruising speed, desired flight level, proposed time of departure and other details. Relevant portions of this plan are sent by **AFTN** network, by the command centre, to the departure aerodrome control, to all ATC centres concerned with the flight, and to the destination aerodrome.

At major airports, the pilot must request clearance to start engines prior to taxing out for takeoff. This is withheld if significant aerodrome congestion or en-route delays are anticipated. Such delays may be due to problems at the destination airport or to some other en-route flow-control restriction. The pilot may be told that his aircraft must not reach the **Flight Information Region (FIR) boundary,** which often corresponds to the national border, in advance of a specific time, or that his desired flight- level/route combination is not acceptable at the requested time. These circumstances may result in a change of route, of cruise level, and/or delayed start-up clearance.

On receipt of start-up and taxi clearance from Departure Control, the TWR or Aerodrome Controller as referred to in some countries, clears the aircraft to the appropriate runway holding area, where the pilot must obtain airways clearance before takeoff. This originates in **the Air Traffic Control Centre (ACC)** and must be related to previously cleared traffic, to over-flying traffic, to traffic cleared from other aerodromes in the vicinity and to traffic inbound to the departure aerodrome. If all is well the aircraft is then cleared for take-off and given a change of frequency and instructed to contact the radar controller. It should be noted that the ATC unit at the aerodrome is responsible for separation from other aircraft within its local sphere of influence. All this requires co-ordination between the ATC agencies concerned.

2.3.2 Radar Controllers

The area of airspace in which radar controllers operate is known as a Terminal Manoeuvring Area (TMA) and usually surround one airport, but where two or more airports are geographically in close proximity, it is usual for a single TMA to encompass all. The radar controllers operate from what is called a Terminal Radar Approach Control Area (TRACON) which resembles an upside-down wedding cake centred on the airport, extending outwards to a radius of up to 40 or 50 nautical miles and covering an altitude range of ground to upwards of 10,000 feet.

On receipt of the aircraft from TWR, the aircraft is normally given a **Standard Instrument Departure (SID)** route through the Terminal Control Area (TMA), as well as an en-route clearance, although procedures vary. The aircraft is also given a return route clearance, through its approach at the destination along Standard Terminal Arrival Routes (STARS). The SID often includes a minimum noise route. Following take-off, the climb-out on departure routes within the TMA may have to be limited so that departing aircraft pass beneath arrival traffic in the holding areas so as to ensure adequate vertical separation, at least 1000 ft, until such time as the TMA and, subsequently, en-route radar controllers co-ordinate its climb to cruising level. The outbound route must also avoid the inbound traffic between the holding area and their destination airports. The departure radar controller monitors and/or directs the aircraft through the initial phases of flight in the TMA, and starts the aircraft on its climb to cruising level after liaison with the appropriate en-route Sector controller(s), to whom control is then transferred.

2.3.3 En-Route Controllers

En-route (or ACC controlled) airspace is divided into zones called Flight Information Regions (FIRs) where each FIR is strategically divided into sectors. In turn, each sector may be sub-divided into low-altitude sectors extending from the floor of controlled airspace to an altitude of 18,000 feet above mean sea level with high-altitude sectors extending from Flight Level (FL) 180 to FL350, and super-high-altitude sectors from FL350 to FL600. The associate or planning controller receives the flight-plan information anywhere from five to 30 minutes prior to an aircraft entering that sector. The radar controller is in charge of all air-to-ground communication, maintains safe separation of aircraft within the sector and coordinates activities with other sectors and/or ACCs.

Normally two controllers usually command each individual sector and one of them gives heading and altitude instructions to keep the aircraft separated from other traffic which may include opposing direction traffic, possibly in descent. During this phase, the sector controller passes precise time and level information to the sector next due to receive the aircraft. This sector has previously been notified of the flight and, typically, is part of another ATCC. As the aircraft approaches the appropriate transfer point, control responsibility is handed over to the adjacent sector. As the aircraft approaches its destination, the Sector controller clears the aircraft to commence descent, through its approach at the destination along Standard Terminal Arrival Routes (STARS), in effect reversing the technique used in the initial climb.

For outbound aircraft, the pilot may be told that that his aircraft must not reach the Flight Information Region (FIR) boundary, which often corresponds to the national border, in advance of a specific time, or that his desire flight level/route combination is not acceptable at the requested time. These circumstances may result in a change of route, of cruise level and/or delay start-up clearance.

For in-bound aircraft, the aircraft is supplied with the inbound routing and runway in use at the destination aerodrome, liasing with the TMA arrival controller to ensure that the descent is arrested, if necessary, at the flight level required at the TMA "stack". Control is then transferred to the TMA arrival controller who gives the pilot a warning of any likely landing delay greater than twenty (20) minutes.

2.3.4 Approach Controller

Where the numbers and rates of arrival into the TMA from a number of converging airways exceed the acceptance rate of the landing runway, arriving aircraft will have to queue. Normally they are required to fly a racetrack-shape holding pattern based on a VOR. Successive aircraft are assigned flight levels differing by 1000ft starting at a level of 500ft or so. Control of the arriving traffic, in the bottom levels of this "stack", at least, is normally transferred to the Approach Control Unit for the airport concerned who will have received advanced notification of the traffic from the TMA controller.

Approach Control is often sited at a major airport rather than in the ATCC. Its task is to choose an efficient strategy for merging the traffic from the stacks, by adjusting their path to ensure a safe separation between successive aircraft bound to the same or different runways, with allowance, if necessary, for vortex wakes, and to deliver a stream of inbound aircraft to the landing runway threshold(s) with close adherence to the desired spacing. Normally the task is shared between the Radar Directors and the Approach Controllers. The approach controller co-ordinates with the TMA sectors in the ATCC, and usually takes over traffic from the ATCCC as it enters the lower level of the stack. Approach controllers withdraw the aircraft from the stack using radar control. As levels are vacated at the bottom of the stack, the remaining aircraft are "laddered down" to refill these levels, always maintaining the 1000ft separation. They adjust the length of the path flown by each aircraft until the point where they intercept the ILS localiser, usually at 2000 – 3000ft at a point some 8-12 nm from the runway threshold. The aircraft then descend on the glide path to the landing runway.

A conventional airport has a single runway or a pair of parallel runways aligned with the prevailing wind, with "stacks" established 10-20nm from the runways and off set from the centre-line. This distance is the minimum required to accomplish descent from the bottom of the stack whilst reducing to approach speed. No.1 Radar Director identifies the aircraft on the radar on its departure from the stack and commences the path-stretch manoeuvres necessary to obtain an accurate spacing, and controls the further decent from the level of the bottom of the holding pattern. When traffic from more than one holding pattern is to be merged into a single airport, there may be more than one radar director concerned with this task. There may, for instance, be respectively concerned with traffic from the North or South. As the aircraft approaches the extended runway centre line, control is passed to No 2 Radar Director, who is normally concerned with single runway operation. If more than one runway is being simultaneously used for landing, the No2 Director position is similarly duplicated. When the aircraft is established on the glide slope and the path –stretching manoeuvre is complete, control is handed over to the air traffic control position concerned with both arrival and departure on a given runway.

The main areas of controlled airspace described above are illustrated in the sample real-world airspaces of Figures 2.3. The four UK TMAs are:

- Scottish TMA which covers Glasgow, Edinburgh and Prestwick airports
- Belfast TMA which covers Belfast City and Aldergrove airports
- Manchester TMA which covers Manchester and Liverpool airports
- London TMA which covers Heathrow, Gatwick, Stansted, Luton and London City airports (as well as some military airfields)

Also included are airports outside these areas which are controlled by local TRACONs (or control zones). The principal low-level airways that are generally used for internal flights within the UK are also drawn in the figure, as are the boundaries of the two UK and other surrounding FIRs.

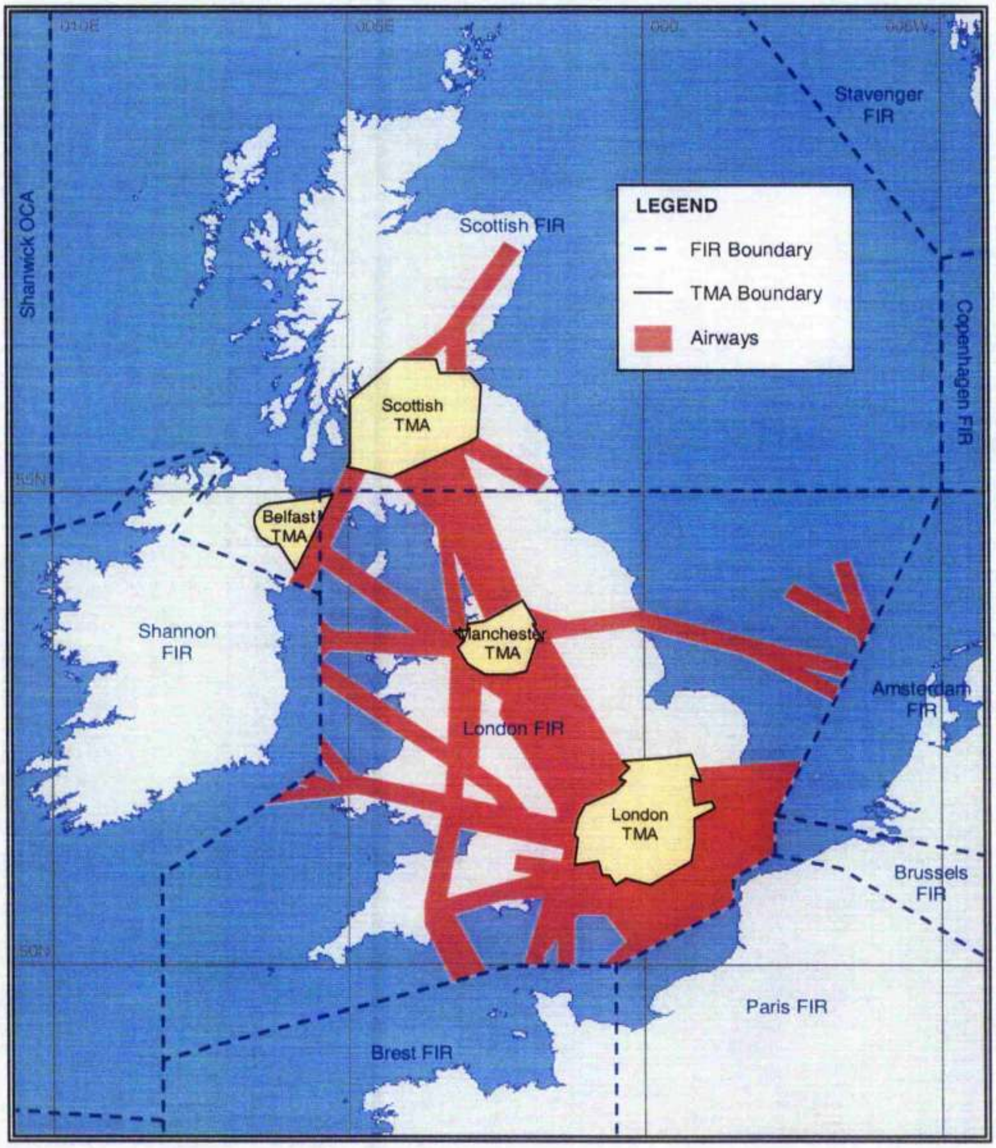

Figure 2.3 UK FIRs, TMAs and Lower Airways [84].

2.4 Functions of the Air Traffic Control Process

There are four (4) different processes in ATC namely:

1. *Monitoring* which refers to the continuous or intermittent comparison between the anticipated traffic situation and the actual system state.

2. *Controlling* the process of intervention, which tries to change the traffic situation actively according to the principles of ATC. According to Nelson's [85] description of control, it includes:

   (a) Selection of a strategy

   (b) Allocation of time

   (c) The decision to terminate.

3. *Checking* is the process of situational scanning and takes place intermittently or as a consequence of unexpected events.

4. *Diagnosing and decision-making* is an active process of information search which tries to explain unexpected or new traffic situations.

These four processes are depicted below in Table 2.2. below.

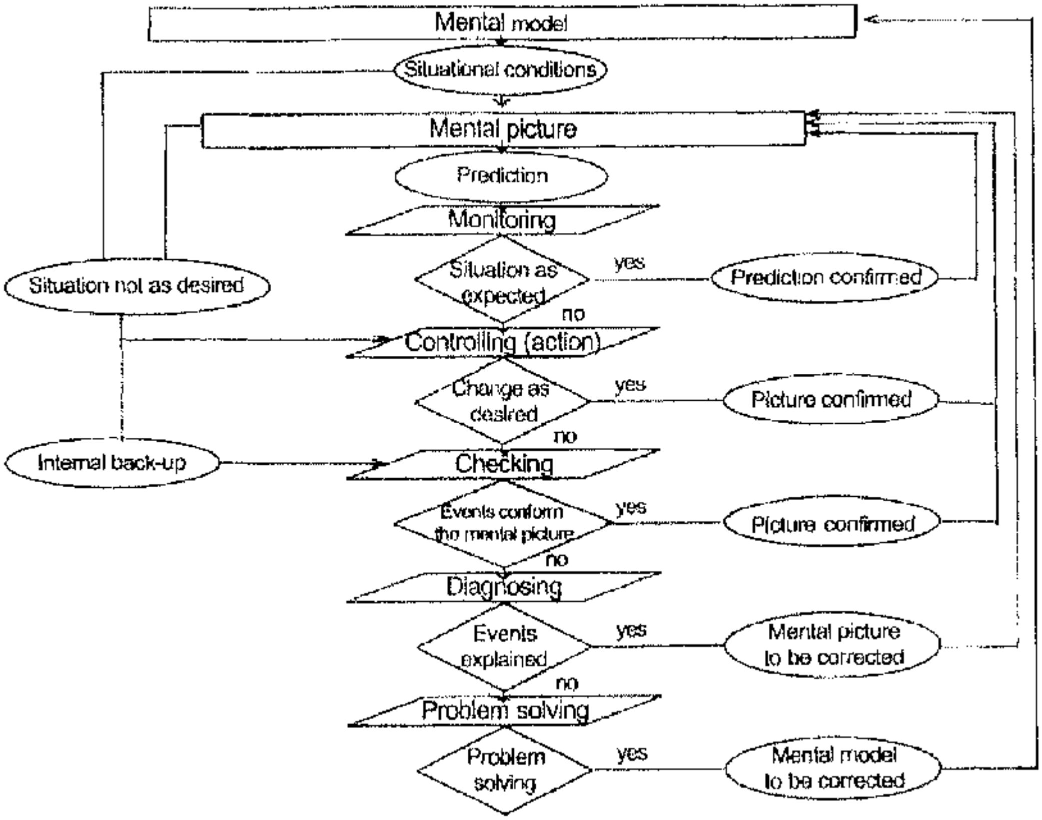

Table 2.2 Functional steps of Air Traffic Control (Adapted from EUROCONTROL, HUM.ET1.ST01.1000-REP-02)

As long as the traffic situation develops as anticipated and planned, the controller either has to monitor the situation or has to execute control actions creating a form of open-loop activity which is directed towards future states of the system. Similarly, once the situational conditions remain normal, i.e. as expected, and the control actions result in the expected changes, the mental picture corresponds to the subjective reality and the mental model is confirmed. From time to time the controller has to reaffirm that the situational conditions really are as expected by checking the whole situation including the less attended areas. A comparatively low rate of checking activity in comparison to monitoring activity will be observable in a well-controlled situation. In the case of unexpected events, as in the case of full and limited delegation, which present new stimuli or a misfit between planned and observed situation, the mode of action changes from monitoring and controlling to checking and diagnosing. Control is no longer conducted in an anticipatory proactive way but in a more situational determined reactive way. The cause of unexpected events has to be inferred from the mental model or the knowledge base of the controller. Where there is no obvious explanation, further checks have to be conducted to re-establish an adequate picture of the situation.

After the mental picture or traffic picture as sometime referred has been established monitoring takes place as long as no active intervention is necessary. If the traffic situation is not as desired and action is necessary the next step "controlling" is initiated. Monitoring and controlling are continued as long as no unexpected events occur and the controller needs no internal backup of the mental picture. In case of internal backup or unexpected information, checking of the whole situation takes place. If checking confirms the mental picture, the process steps back to monitoring and control. Otherwise active information search and active retrieval from the long-term memory starts to diagnose the situation. If the mental model does not allow explanation of the current situation, the controller starts active problem solving. Each of these basic functions includes more fundamental cognitive functions like perception and decision-making where decision-making takes place between the different steps. The mental model of the controller drives monitoring and controlling whereas checking and diagnosing as a process are geared by events. As diagnosing is directed to re-establish the mental picture therefore this process has to be interactive, as it will allow the reactive activity to be switched to proactive control.

2.5 Human Factors issues in Separation Assistance

The work in this thesis addresses the following applications of Airborne Separation Assistance, namely:

- Limited Delegation
- Extended Delegation
- Full Delegation.

ASAS applications involve a transfer of task of traffic separation from controlled-based systems to the pilot in the cockpit [2]. The delegation processes of these applications have implications that reflect a significant change in the way that pilots and controllers will perform their respective tasks in the future. The main issue arising out of the implementation of these applications, particularly in managed airspace, is the possibility of adverse changes and the implications and impact of these changes on the cognitive and behaviour processes of pilots and air traffic controllers.

In the present operating environment pilots are observed to have an aircraft-centric view and are primarily concerned with traffic which impact on their current or planned trajectories. Conversely, as pointed out in Section 2.4 above, the controllers have a more system centred, "big picture" view and are concerned with how the trajectories and overall flows will interact. [86], [87]. The selection of a particular application may have a strong impact on the predictability of pilot's possible future action and trajectories. Similarly so on the availability and situation awareness of the controllers. On one hand a very limited delegation would maintain a high level of predictability of aircraft behaviours and trajectories from a controller's point of view, with a counter part of limited gain in controller's workload. In which case, a more extended delegation leaves more autonomy to the pilot to manage the solution, with a risk of a possible reduction of predictability for the controllers.

In the case of Limited Delegation, RTCA [99] has proposed a list of possible applications such as station keeping, in-trail climb and descent. Information required on traffic is initially limited to flight state, either position or velocity, along with CDTI indicating velocity and closure rate of a target aircraft. A typical example of this form of delegation can be seen in visual crossing report clearance where the encounter between two aircraft is identified and announced by the controller. During this delegation process, the pilot is in charge of reporting an estimate-completed time of crossing and possible resumption of flight plan. The "ASAS crossing procedure" proposed by CENA is an example of Extended Delegation, using a CDI with relative track information. [89], [90]. This application is intended for used in an en-route and managed airspace. First the controller identifies a conflict and the aircraft and lets the pilot decide which solution to use. The delegation relies on the controllers' initiative and uses a specific phraseology to communicate the instructions of delegation.

All the autonomous aircraft, self-separation and free flight applications fall into the category of Full Delegation [91], [8], [92], [38], [93], [94], [95]. This type of application is intended for en-route airspace where there are two possible operations – managed airspace with mixed equipage [8], [95] or dedicated airspace with all aircraft equipped [92] such as the Free Flight Airspace proposed at [1]. In the context of managed airspace, the role of the controller could consist of providing separation for non-equipped aircraft while permitting equipped aircraft self-separation [8], [38]. A proposal such as "transition zones" [96] affords some filtering to reduce the possible interaction s between equipped and non-equipped aircraft. In this zone all aircraft will have the responsibility of self-separating. In such an environment the role of the controller will drastically change from traffic control to service regulatory, search and rescue, and possibly to flow manager. Sheridan et all [154] predicted that the role transfer will involve the controller being placed to an increasing extent into a role of a monitor.

Hoffman et al [45], in his proposal for limited delegation divided the general tasks of separation assistance into the following three (3) sub tasks:

1. Identification of problems, mainly detecting potential losses of separation of conflict between aircraft.

2. Identification of a solution when a problem has been detected, typically identifying which aircraft has to manoeuvre and type of manoeuvre to be executed.

3. Implementation of solution and monitoring of the implementation.

It was pointed out that the level of delegation would significantly affect the controller's ability to predict the aircraft's trajectory and maintaining an adequate mental model of the situation. Noting that in general, the delegation of separation tasks and responsibilities should be structured so that controllers can remain in appropriate control. Hoffman et al went on to suggest controllers could attain appropriate control if they can delegate a separation task.

2.5.1 Cognitive and Behaviour Processes of the Human Operator

As a result of the differences in operational impact on both the pilot and air traffic controller, there are six cognitive factors which are of particular interest to the Airborne Separation Assistance applications, namely:

1. Situation awareness and assessment
2. Workload,
3. Task load
4. Sector complexity
5. Decision-making
6. Performance.

Situation awareness is defined as :

"The perception of the elements in the environment within a volume of time and space, the comprehension on their meaning and the projection of their status in near future." [97]

This basic definition has been extended by Dominguez et al. [98], who state that SA needs to include the following four specific pieces of information, namely:

a. Exacting information from the environment
b. Integrating this information with relevant internal knowledge to create a mental picture of the current situation.
c. Using this picture to direct further perceptual explorations in a continual perceptual cycle.

d. Anticipating future events.

Taking these four elements into account, SA can be considered as:

"The continuous extraction of environmental information, the integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in directing further perception and anticipating future events". [98]

The predictive component of situation awareness is heavily dependent on spatial working memory to compute likely trajectories based on current aircraft state, intended plans, and individual aircraft dynamics. Hence, this predictive component is highly vulnerable to competing demands of attention. Usually, aircraft move routinely and predictively through the airspace, and so prediction is not demanding. However, when multiple aircraft move in three dimensions and varying speed such that their predicted position at a future time is not a constant distance separation on the radar display, then such prediction on multiple aircraft taxes the controller's processing capabilities to the utmost and limits the resolutions with which the future state of the aircraft in the airspace can be visualized.

Situation awareness may be more vulnerable and more difficult to achieve when operating procedures are inconsistent with the prescribed set of circumstances envisaged with Limited and Full Delegation. In such circumstances information must be translated from symbolic (verbal) formats into spatial mental pictures and with the human operator operating under conditions of high workload or distraction. Recent research in aviation [100] has revealed the wide difference in pilots' apparent ability to maintain situation awareness of aircraft and its automation systems. Such difficulty was also seen in maintaining situation awareness of the surrounding airspace. Such differences undoubtedly relate to differences in the vulnerability of several processing components, related to the fundamental processes of selective attention, perception, comprehension and prediction.

The term workload when used in the context of air traffic control refers to mental workload. This is due to the fact that the ATC process is primarily cognitive and information-intensive rather than physical and labour-intensive.

Workload is defined as "*the physical and mental effort an individual exerts to perform a task.*" Smolensky et al [35], further defined it as *quantitative* – if the amount of work exceeds the ability of an individual to meet the demand over a given period of time; or *qualitative* – if the requirements of the work exceed the skills, knowledge, and abilities of the individual. In the case of ASAS applications, mental workload is important, as effective processing skills are required both to monitor different sources of information and to integrate or manipulate the information in order to diagnose, and rectify faults or to make crucial control decisions.

The advanced technology and operating procedures proposed intended for use during the application processes are intended to reduce or regulate the workload of both the pilot and air traffic controller, however there is evidence to suggest that the successful reduction of workload is not necessarily a positive, and in some respects it may not be desirable [100], [101], [102]. In particular, if the reduction of workload is attained by the full or partial automation of a few functions, which in ATC is usually the simplest way of attaining reduction of workload, a consequence can be that the controller has to process less information or process the same information at less depth. As a result, the controller experiences a reduction or loss in understanding of the full air traffic picture.

During the delegation processes ATC workload may be differentiated from task load in that task load refers to "*air traffic events to which the controller is exposed*" whereas workload describes the effort expended by the controller to manage the events. Theory predicts that controllers may expand attention resources in response to an increase in task load [103]. The controller may experience increased mental workload, but performance is maintained. Increase in task load may also increase controller mental workload but not change performance because of the use of compensatory or regulatory methods [106].

Sector complexity describes the static and dynamic characteristics of the air traffic environment that combines with the task load to produce a given level of workload [107]. In this sense, complexity can mediate the relationship between task load and workload.

Decision-making which is greatly influence by situation awareness [35] is the process of choosing a course of action and occurs in the context of both controller's and pilot's plan for sector management. Decision-making is vulnerable when information is incomplete, conflicting, or unreliable or when goals conflict. One concern of the *Panel on Human Factors in Air Traffic Control* [3] is that automated decision aids as proposed for use to facilitate delegation, relying on incorrect models of the human decision making, may result in systems and concepts that are less efficient than the human alone [108], [109] [110].

2.6 Multi-criteria Analysis for Concept Evaluation (MACE)

A successful air traffic control decision-support tool must offer direct benefits the operator who will be using it [108]. Therefore, to access the impact as a result of the adverse changes brought about as a result of ASAS applications requires a decision-support tool which can create an air traffic control environment that allows pilots and controllers to behave realistically in a realistic setting. This tool not only must be capable of creating and understanding present and future operational tasks for which they will be responsible, but must also be capable of creating the cognitive aspects of their behaviour. Hollnagel [111], argues that cognitive modelling, a component within human performance modelling (HPM) and on whose principles decision-support tools are based, should attempt to reproduce key phenomena of a task in practical terms rather than attempting to replicate specific theories of mechanistic behaviour. In order to accomplish this, cognitive modelling should emphasis appropriate goals for the respective human role within the concept being analysed, in this case ASAS applications.

By virtue of its operational principals of human performance and cognitive modelling the decision support tool Multi-criteria Analysis for Concept Evaluation (MACE) [9], lends itself to easy manipulation for the design of other effective decision aids and in this regard provides the background for development of such a tool for the analysis of the pilots during ASAS applications. Human performance modelling was introduced over fifty (50) years ago with quasi-linear and manual control models [113], [114] and was related to modelling human tracking behaviour in a closed-loop person-machine system [113]. Craik's work provided three legacies; firstly, his work describe human and machines in collaboration in the same mathematical terms, in the same structure terms and in the same dynamical terms. Secondly, it provides an analytical capability to define the information that should be displayed to the human operator in the human system as a consequence of the sensory/perceptual and cognitive characteristic in control. Thirdly, it is a fundamental paradigm shift in which man-machine systems could be conceptualised as a single entity linked/coupled to perform a specific task or set of tasks.

A new level of abstraction was introduced and systematised by Craik and subsequent developers of operator control models. In this paradigm, the description of the operator in the man-machine system could be used to guide the machine design. On the other hand cognitive modelling concepts were integrated into the engineering models' philosophy in order to assist in predicting complex human operations. The overall philosophy behind the use of cognitive modelling was to provide engineering-based models of human performance which permit a priori predictions of human behaviour of a very restricted set of behaviours in response to specific task.

2.6.1 Historical Background

Multi-criteria Analysis for Concept Evaluation (MACE) forms part of the IMPACT Project [112] a package of tools, software and documents conceived and produced by EUROCONTROL scientists and experts. It proposes a generic life cycle that identifies the main activities for projects dealing with new air traffic management concepts, including their training implementation and needs.

The stages of the IMPACT methodology comprise:

- Definition of the operational scenarios where an analysis and formularisation of the needs are conducted.
- Evaluation of the new system
- Validation of the new system.

- Enrichment of the impact analysis knowledge base.

IMPACT aims to identify processes and activities hence to identify an IMAPCT is to manage the consequence of change in a predictive way. IMPACT's strength is the constitution of a generic theoretical view based on past particle air traffic management project experience. As an IMPACT tool, MACE is a decision support tool, with a Microsoft Excel application and its aim is to evaluate the "transformation cost" induced by a given concept before its implementation. To accomplish this, it acts in a predictive way and hence operates as a global risk management strategy in conducting new concepts studies. The transformation cost, which is seen from a human factors perspective is defined:

"How a given concept will change the controllers' activity and what are the difficulties the future system/concept will encounter to be taught and accepted by the controllers''.[9].

Designed specifically for air traffic controller, "*the transformation cost*" is derived from a list of sixteen inter-related criteria (Table 2.3) expressing all the human dimensions playing a role in the evaluation of a transition cost and deemed as having an influence on the future concept acceptance and training. As these criteria cannot be supplied directly, the programme provides a "questionnaire" which helps identify indicators of change by describing the concept to be implemented. There are forty indicators provided which are related to one or several criteria through linear or quadratic relationships and specific value scales are provided for each indicator, enabling the user to quantify the change the concept induces.

PSYCHO-PHYSICAL FACTORS	RELIABLE FACTORS
Job Motivation	Error Risk
Stress	Error Recovering Strategies
Confidence in System	
Physiological Workload	
Mental Workload	
COMMUNICATION FACTORS	**COGNITIVE FACTORS**
Controller/Pilot Interaction	Knowledge Evolution
Inter-sector Interaction	Cognitive Processes: information gathering solicitation and support
Controller/ Controller Interaction	Cognitive Processes: Working memory solicitation and support
Controller/System Interaction	Cognitive Processes: Planning and decision making
	Cognitive Processes: Checking

Table 2.3 Criteria List Expressing Human Dimensions [9]

A global score is provided for the concept being evaluated by taking into account the relationship between the indicators and the criteria and interdependencies between the criteria. The score is the result of a computation using multi-criteria analysis techniques and indicates potential difficulties that the concept may encounter for acceptance and learning. In addition, through this score, MACE identifies the dominant indicators in order to give the user valuable input for improving the concept.

2.6.2 Structural Framework

The basic structural framework of MACE is one made up of five subject sheets, namely:

- Project Description

- Evaluation Results
- Results Improvement
- Determinants Influence

There are also two macros. The programme provides a fix value rating scale which ranges from 0 to –4 representing no change/neutral for zero and increasing in increments of twenty five up to one hundred.

-4 = increase + 100%
-3 = increase + 75%
-2 = increase + 50%
-1 = increase + 25%
0 = neutral (no change)

Table 2.4 Value Scale Rating Scale [9]

The first subject sheet is *Project Description* which is used to identify and describe the concept. It is made up of the following four columns.

- *Determinants* – there are forty (40) and represent the definitions of the "indicators of change" and relate to the concept and its implication.
- *Help and comments* – provides an explanation for the use of the *Determinants.*
- *Value* – the inserted value represents each respective *Determinant* and is substantiated by the above column.
- *Justification* – self-explanatory.

The second sheet is the *Evaluation Result* and it presents, in the top left corner, the numerical values or score of the Distance to Heaven and to Hell. Two tables, the inter-dependencies between the *Criteria;* and the inter-dependencies between the *Criteria* illustrate the influences of the *Determinants*. The last row of the table shows the final value of each *Criteria.*

A set of typed relations linking *Determinants* and *Criteria* produce a global assessment called " *Distance to Heaven"*, where *Heaven*, the theoretical easiest to accept and learn, is derived by all the *Determinants* being quoted at their best values.

Result Improvement is the third sheet and here there are three tables:

- The *Determinants* sorted as in the *Project Description* sheet, and the coefficients of the linear regression corresponding to each single Determinant.
- The values of the *Determinants* and the product of value and correspondent coefficient of each *Determinant.*
- The list of *Determinants* with the corresponding real and absolute value which is now sorted in decreasing order of absolute value.

The real distance to *Heaven* and the distance computed using the linear regression are displayed at the bottom of the tables, together with the residual error committed using the regression.

The fourth sheet is *Determinants Influence* and it presents a table of the *Determinants* on the *Criteria*. The final sheet is *Simulation* and each column of the table represents a *Determinant* where allowable values for the corresponding *Determinant* can be inserted. The numbers are selected randomly inside specified ranges and the first column of the table contains the values of the distance to *Heaven* computed using the complete model. Every value in the first column is obtained by considering the numerical values of the same row as the *Determinants* values of a real project. In this sheet it is also possible to find all the numerical results of the linear regression parameters computation and the statistical analysis which will enable the user to conduct comparison analysis of the "true" results of the complete model.

2.6.3 Mathematical Structure & Computations

MACE use multi-criteria analysis techniques to compute the global score which is derived from the relationships between the indicators and the criteria and interdependencies between these criteria.

The interdependencies between the *Criteria* are typed and weighted:

- "↗" - a linear positive dependency
- "∩" - a parabolic dependency (increasing then decreasing)
- Number of "+" - strength of the influence.

The comparison is expressed as a distance, where;

- Each project is quoted through 16 *Criteria* (C_1 to C_{16}) and can be represented as a point in a hyperspace with 16 dimensions.
- *Heaven* has value (H_1 to H_{16}) for each *Criteria.*

It is possible to determine the value of the distance of each project to *Heaven* using the *Euclidean distance*:

$$\delta = \sqrt{(C_1 - H_1)^2 + (C_2 - H_2)^2 + \ldots (C_{16} - H_{16})^2} = \sqrt{\sum_{i=1}^{16} (C_i - H_i)^2}$$

Equation 2.1 Euclidean Distance [9]

Similarly, it is also possible to define the so-called "*distance to Hell*" – where the *Determinants* are quoted as their worst values.

The distance between *Hell* and *Heaven* is a constant and this results in the provision of only one location in the hyper-space leading to either *Hell* or *Heaven:*

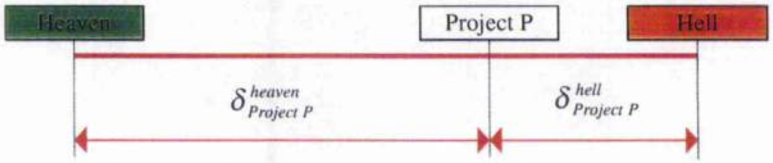

Table 2.5 Illustration of the distance of a given project to *Hell* and *Heaven* [9]

The comparison between $\delta^{hell}_{Project\ P}$ and $\delta^{heaven}_{Project\ P}$ will depend on the project P - the closer to *Heaven* the easier to be learned and accepted, the closer to *Hell* the more difficult.

The overall result gives no information on the most efficient way to obtain a better quotation and hence, to improve the acceptance and ability to be learnt of new concept. In order to do so, relationships between *Criteria* and *Determinants* have to be derived. The synthetic function to obtain *Criteria* values from *Determinants* and then overall result has the form:

$$\delta^{heaven}_{projectP} = f(criteria) = f[g(determinants)] = f \circ g(determinants)$$

Equation 2.2 Function to obtain Criteria values from Determinants [9]

A direct relationship, called h, between *Determinants* and $\delta^{heaven}_{projectP}$ identifies which *Determinant* scores have a strong impact, either positive or negative, on this value.

$$\delta^{heaven}_{projectP} = f \circ g(determinants) = h(determinants) \Leftrightarrow \ h = f \circ g$$

Equation 2.3 Relationship between *h* and Determinants [9]

2.7 MACE and other Tools

When the decision tool was compared to others it was revealed that it afforded the opportunity to focus on issues concerning problems inherent to dynamic situations where concentration is on modelling the cognitive abilities of both the pilot and air traffic controller, rather than perceptual and motor skills. The remainder of this section provides some oversight into other tools which were also considered highlighting their strengths and weakness.

Recently there have been some promising attempts to formulate cognitive architectures that deal with the specific demands of a dynamic task environment. One such model is Adaptive Control of Thought-Rational (ACT-R), [115]. ACT-R provides a suitable psychological framework of human cognition and it also describes an environment for implementation; it is based on explicit and very detailed assumptions about the cognitive architecture and unlike MACE is available in the public domain and has been applied to modelling a great number of problems solving tasks. ACT-R includes two kinds of knowledge representation: Declarative and Procedural knowledge.

The basic units in declarative memory are so-called working memory elements (WMEs), an object with identity and has named slots that can be filled with lisp objects or reference to other WMEs. Every WME has an activation level which is manipulated by the programming environment and references to other WMEs can be interpreted as relations, so that a semantic net with WMEs as nodes and references for relations is spread out. ATC-R defines an object-oriented structure for declarative memory where a special structure within the declarative part of the memory is the goal-stack. Every node in the net is an object of a certain class and a class is declared by naming all slots an object of this class will have.

The procedural knowledge is represented by the production rules which consist of a condition and an action. Conditions and actions refer to WMEs and the application of a production rule is realised by a simple pattern - matching mechanism. In order to support goal-directed performance, the first condition of every production rule must match the current goal. If all conditions of a production rule are true, then the action is executed. An ACT-R run consists of the continuous application of production rules. Additional features of ACT-R are learning mechanism to adjust WME and production parameters, partial matching, and the aggregation of production rules.

Like other models for adaptive control of complex task environments [115], [116] and [117], ACT-R concentrates on rather static tasks and on invariant goal structures. For example, the cognitive of Anderson's ACT-R [115] does not take into account that in dynamic situations the operator has to continuously update their mental representation and as such, its production systems are directed by a fixed goal hierarchy. In the case of the changing and complex situation requirements necessary for delegation, the controller has to coordinate the cognitive activities where such coordination is context-dependent and does not follow a pre-defined goal of hierarchy.

As an extension of ACT-R a new computational framework, the Executive-Process Interactive Control (EPIC) has been proposed for human performance [118], [119], whereby perceptual, cognitive, and motor processors have been built up for modelling cognitive processes during the performance of multiple concurrent tasks. The perceptual processor provides a continuously update of the task environment and within the cognitive processor, concurrent tasks can be scheduled by flexible executive processes that control relative task priorities. Recently there have been some promising attempts to formulate cognitive architectures that deal with the specific demands of a dynamic task environment As a programming environment, ACT-R includes a broad and detailed theoretical framework of human cognition and for the most part, is suitable for modelling the cognitive performance of en-route air traffic controllers, however research has shown, for some aspects of dynamic situations, it does not provide convincing solutions.

Man-Machine Integration, Design, and Analysis System (MIDAS) provides another modelling environment that provides an updateable mental representation of the task environment and flexible scheduling of multiple task performance [120]. However, MIDAS is a complex numerical simulation model of experimental computational tools for evaluating human factors and performance analysis of complex man machine systems. The model is made up of several modules that can be independently turned on or off according to the problem under consideration. Modules include models of human vision, attention, perception, internal representation of the world, decision rules and responses. Aircraft dynamics, guidance, environment, and terrain data may also be included. For a given problem, the user provides a model of the environment, events that are to occur, and probability distribution. Also provided are the decision rules the human uses in acting on the information being observed. Midas then runs through a simulation in 100 msec time increments, simulating the occurrence of events and the action taken by the human in response. Detailed representation of human perception, cognitive behavior and responses allow analysis of critical areas of human performance such as information management cognition and workload. MIDAS also allows for the inclusion of probabilistic events and error and is able to model interruption and resumption of tasks in single and multiple operator interaction.

Several adaptations of MIDAS to the commercial aviation domain have been developed, including Taxi-MIDAS and Air-MIDAS. In Air-MIDAS, input requirements include the mission and activities to be performed, including probability distribution when events occur; operator characteristics including knowledge bases and decision rules. Additional modules can be used, incorporating inputs such as anthropometrics models, vehicle dynamics, and perception/attention models. MIDAS has been used to examine where the effect of voice communications relative to data link and pilot ability to successfully initiate the descent before reaching the top of descent point.

Of all the tool investigated MIDAS would have been another alternative to MACE as it provides human factors analysis such as reach ability and visibility; visualization of future concepts, measurements, operator(s) performance and information requirements analysis, all based on the major assumption that the human operates according to a set of define rules which predict the future situation. The model has been used in the following research [121] and a summary of its use is also provided on its website: http://ccf.arc.nasa.gov:80./af/aff/midas/MIDAS_home_page.html.

However, as mentioned earlier it is a very complex model intended to simulate complex situation and human cognitive processes and as such has its limitations most notably: difficult to use; extremely data intensive, uninterrupted user interface; extremely slow speed of simulation; many undeveloped components.

Chapter 3

Concept Development and Implementation

3.1 Introduction

The use of computer-generated simulations can create an air traffic control environments that allows the pilot and air traffic controller to behave realistically in a realistic setting. Such a simulation approach allows for the provision of high levels of stimulus and response fidelity [122]. There has been some research and development efforts, [123] and [124] aimed at capturing the performance of air traffic controllers. These include full-scale dynamic simulations that allow controllers to direct the activities of a sample of simulated air traffic, performing characteristic functions such as ordering changes in aircraft speed or flight path, all within a relatively standardised work sample framework. Similarly, there have been a number of human-in-the loop simulations which also provided the pilot's perspective [125] and [126].

Experiments, [127] and [128] pertaining to delegation of separation were conducted, using mathematical simulations, to capture the essence of in-trail following in terminal areas from a systems dynamics perspective. Model-based simulations were also conducted to evaluate the impact of different control strategies on the inter-aircraft time dispersion at the runway threshold and in another study [129], the impact of traffic complexity on the application of delegation in en-route airspace was also undertaken. [130] provide details of one of many evaluations also conducted on the impact of delegation of sequencing operations on air traffic controllers' activities.

This chapter presents this thesis's contribution to computer-generated simulation as it introduces the research topic and approach used in developing, designing and creating the quantitative framework of Multi-criteria Analysis Concept Evaluation for Pilots (MpE). The development of the software Multi-criteria Analysis for Pilot Evaluation, (MpE) revolved around the expansion and modification of the *determinants* of Multi-criteria Analysis Concept Evaluation (MACE). However in so doing, all efforts were made to maintain the structure and the graphic appearance of the original version as hence assessments and programme applications were conducted using the dedicated scales, units and textual help as supplied and proposed under the original program.

As the functionality and capabilities of the developed MpE programme is examined against the original MACE programme it was necessary to provide a frame of reference for the *determinants* numeric values and rating scales used for the air traffic controllers simulation. To provide this frame of reference visits to Prestwick International Airport, Glasgow Scotland were made during the periods (March/April and Nov/Dec, 2002) to gain practical insight into controlling within a busy environment and to create a CTA. The CTA required both an interview and data analysis portion. The interview and observation portion, conducted with fifteen (15) controllers and three (3) traffic personnel resulted in the creation of a task list (Appendix 2). This list was then used to determine the extent and nature of how controllers perform strategic planning for separation and cognition. When direct observation was impossible controllers were interviewed to ascertain mainly how they perceive their roles to change during each application. They were also required to identify specific examples where they see MACE or MpE may not be applicable within the proposed simulations.

The exposure that this site visit and interview provided was necessary as it also afforded the opportunity to consult with and observe controllers working in a busy "heavy" traffic en-route environment and helped in eliminating the introduction of any biases into the research as a result of this author's work experience within a "light" traffic ATC environment. These visits highlighted the necessity for the provision of variability of each operator's performance (pilot and air traffic controller) and in this regard, the performance measures and by extension the numeric values used, took into account relevant activities that occurred during a segment of time of each particular application.

An assessment of today's en route operations was performed through a literature review, [35], [50], [132], [133] and [134] of current en-route operations to provide the data analysis portion. Extensive reviews of previous literature involving air traffic control, pilot performance, workload, task load and sector complexity were also conducted. Future free flight and autonomous concepts [1, 135 & 136] were researched given their potential impact on current operations. Emphasis was also placed on articles which dealt with evaluating performance in simulation, situation awareness, multi-task performance and sector load management.

An attachment at the Centre of Excellence, University of Zilina, Zlovak Republic during the period July – November 2003 afforded the opportunity of experiencing the pilot's working environment during a traffic situation awareness application through observation and participation in two training flights. The work of [131] which provided a comprehensive goal-direct task analysis for commercial airline pilots and the cockpit environment was referenced to provide further insight.

3.2 Research Approach

The cognitive process was taken into account with regards the objective of the framework development for each ASAS application. The core of the cognitive process is based on the cognitive activities, derived from the original MACE programme which are divided into the following five groups:

- Situational awareness, planning, and action.
- Knowledge, skills.
- Skills awareness, confidence and motivation.
- Workload, stress and fatigue.
- Human error.

A combination of the above produces a cognitive model, Figure 3.1, which is a relationship of three dimensions:

1. The basic cognitive process which is a continuous loop of Comprehension-Action-Evaluation.
2. Internal factors such as workload, stress, and fatigue which impact on the basic loop and provide regulation of the third dimension, resources allocation.
3. Allocation of resources to the different aspects of activities of each delegation (understanding, anticipation of action, execution, evaluation of the action outcomes).

The allocation of resources to the different aspects of activities is influenced by factors such as motivation, skill awareness and confidence. In this context confidence is deemed to include either of self, system or in the other operators in the system. All the factors are involved in the cognitive trade-off between the expected performance and the psychological cost.

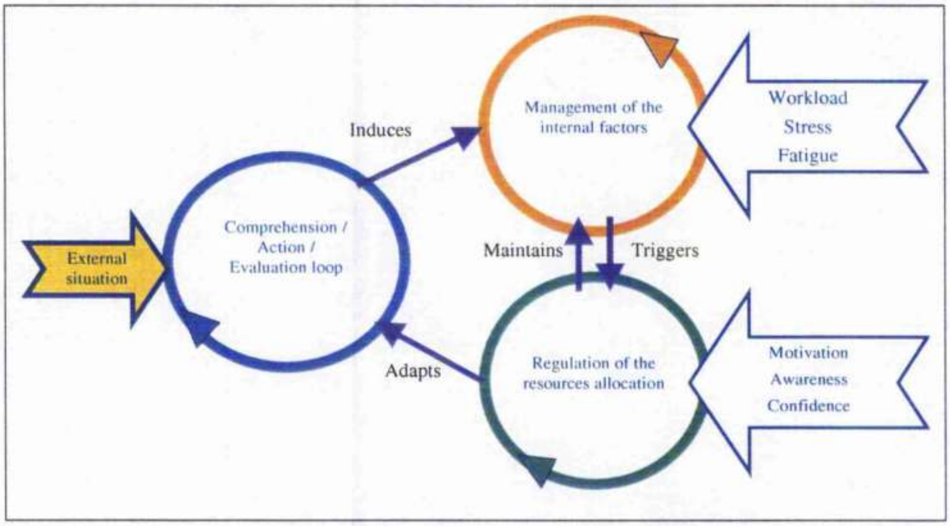

Figure 3.1 Three Dimensional Cognitive Model [9].

In addition to the three-dimensional cognitive model, Figure 3.1, above the following cognitive related abilities were also taken into account. These activities provide an understanding of how pilots make decisions and act to perform their tasks during each ASAS applications.

- Attention
- Reasoning
- Memory related
- Spatial processing-related

The objective in the development of the numeric values was the determination of four (4) key factors:

2. How pilots and air traffic controllers presently perform.
3. Tasks required of pilots to perform the application and delegation levels simulated.

4. Identification of the main factors affecting performance in the present and future en-route environment.

5. Identification of potential technological and procedural solutions that will enhance activities during the applications.

3.3 Experimental Design and Assumptions

The operational assumptions are consistent with the air traffic control rules of flight as outlined for (UMAS) and FFAS by Eurocontrol in the Operational Concept Document (OCD) [1]. International civil aviation guidelines have been adhered to form the execution of the scenarios for each level of delegation as defined in Table 3.1.

Whereas Situation Awareness may not be deemed as an ASAS application its inclusion is intended to provide insight into the cognitive processes involved in dimension regulation of the resources allocation. The concept is intended to give the traffic crew information through a CDTI to confirm whether that would enable a better representation of the situation.

APPLICATIONS	PROCEDURES
Traffic Situation Awareness Application	EUROCONTROL (OCD)
Limited Delegation	EUROCONTROL (OCD)
Extended Delegation	EUROCONTROL (OCD)
Full Delegation	EUROCONTROL (OCD)

Table 3.1. Delegation Levels and Applications.

The following four applications are examined and defined as used within this thesis:

1. Traffic Situation Awareness Applications - There is no transfer of responsibility for the provision of separation, as the pilot has to implement the instructions received by the controller who remains responsible for all separation tasks.

2. Limited Delegation - The controller is in charge of both problem and solution identifications. Only implementation and monitoring are delegated to the pilot.

3. Extended Delegation - The controller is in charge of the detection of problems and delegates to the pilot the identification, implementation, and monitoring of the solution with their responsibility.

4. Full Delegation – Pilots are responsible for all the tasks related to separation assurance - identification of problems and solutions, implementation and monitoring.

Each application is defined and represented by a letter (A-D) as shown in Table 3.2.below.

APPLICATIONS	VALUE DEFINITION
Traffic Situation Awareness Application	A
Limited Delegation	B
Extended Delegation	C
Full Delegation	D

Table 3.2 Application and Delegation Levels Defined.

As implementation of applications pertaining to applications 3 and 4 are most likely to include automated conflict detection probes the following principles as stated in ICAO circulation 249-AN/149, [52] formed the guidelines for the conflict detection, resolution and display:

1. The human must be in command.

2. To command effectively, the human must be involved.

3. To be involved the human must be informed.

4. Functions must be automated only if there is a good reason to do so.

5. The human must be able to monitor the automated system.

6. Automated systems must, therefore, be predictable.

7. Each element of the system must have knowledge of the other's intent.

8. Automated systems must be able to monitor the human operator.

9. Automation must be designed to be simple to learn and operate.

3.4 Concept Development - Pilots

The novel approach of this thesis is an increase of performance factors, termed *determinants* from forty to eighty five to produce a quantitative framework of a task index and self-assessment performance tool for the determination of cognitive and performance challenges of pilots during delegation applications of Limited, Extended and Full Delegation of Airborne Separation.

First an operational profile of pilots and air traffic controllers which highlighted their differences, Table 3.3, was developed. A pilot's performance profile was then created, Figure 3.2, from which representative tasks were identified that would fully represent pilot's operation during each ASAS application. The tasks identified were - communication, navigation, engine and system performance monitoring, system status and emergency. This also formed the basis of the workload analysis. The more cognitive task analyses conducted the more similarities in task activities across all applications were revealed.

The format of an Aviation Safety Reporting System (ASRS) incident report form was used to identify tasks accomplished by pilots during each application. The format of the report was so designed as to identify the various possible factors which determine the scenarios and the consequent appropriate level of delegation.

PILOT	AIR TRAFFIC CONTROL
Roles strictly defined – each member remains in their role until completion of flight. Each task design to complement each crewmember. Overall responsibility is designated to the captain. Size of active team remains unchanged.	Role is defined by the physical working position/workstation. Activation of positions depends on traffic situations. Each controller is responsible for all the traffic in their respective area – may work many positions. Team members work without over-the shoulder supervision.
Shared mental model required for job and good co-operation through adherence to company procedures and checklists.	Large differences in individual way of working methods – procedures (eg: hand over) checklist (emergency).
Recurrent training on high fidelity flight simulators.	Whereas few facilities own high-fidelity ATC simulators refresher training is however now mandatory for ACC.
Physical involvement; strong personal interest.	No physical danger hence more detached.
Trained to handle unexpected problems and provided with checklists to assist.	Conflict detection, resolution, implementation and monitoring are their exclusive tasks.

Table 3.3 Operational Differences between Pilots and Controllers.

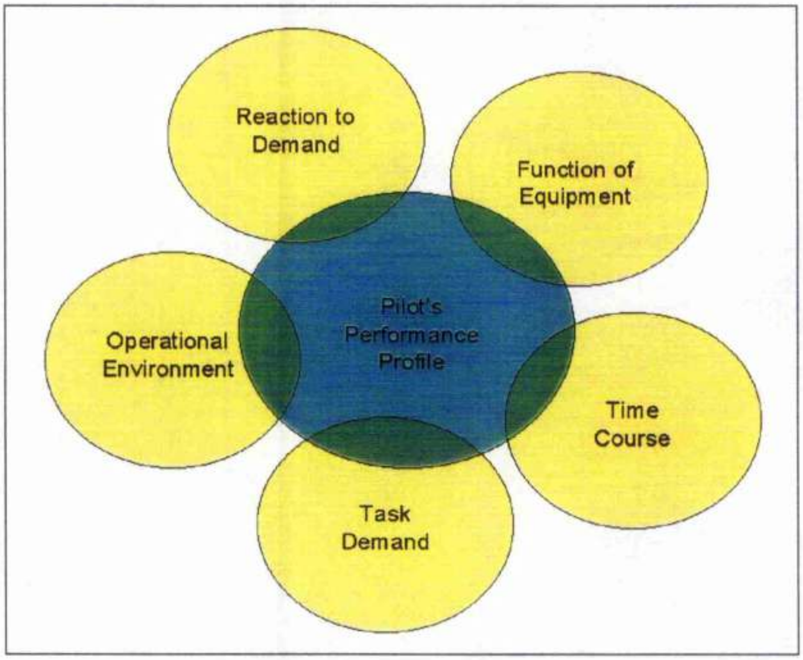

Figure 3.2 Performance Profile of Pilots.

The first step in the expansion was the reclassification of the two categories of the *determinants* lists, technical and activity related, as detailed in Tables 3.4 and 3.5. As some *determinants* were not deemed directly related to pilot's tasks, those not reclassified acted as external factors. The SHEL model interface [138] was used as guidance as the intension was to enable the programme to be as general and flexible as possible.

Aviation Tasks	Communication Tasks
Navigation Tasks	Systems Management Tasks

Table 3.4 Determinants Expansion – Technical.

Assisted Tasks	Executed Tasks
Decision Tasks	

Table 3.5 Determinant Expansion – Activity Related.

Whereas the sixteen interrelations of the *cognitive criteria* file remained unchanged it was necessary to amend the *criteria* list for the *communication factors* category, Table 3.6, to reflect the different subjects addressed by pilots.

COMMUNICATION FACTORS	
Air/Air Interaction	Pilot/Crew Interaction
Air/Ground Interaction	Pilot/System Interaction

Table 3.6 Criteria Expansion – Communication Factors.

Basic Human Information Processing

Automation has brought about more than just the configuration of the cockpit. It has greatly altered the nature of the pilot's task; notably, a decrease in physical activities and an increase in cognitive activities. As automatic systems proliferate in the cockpit, the role of monitoring and supervising becomes more and more prominent. As the performance capabilities of the aircraft expands, its mission capability increases and the complexity of pilot's planning and decision-making tasks increases correspondingly. Given the speed capabilities, not only have the amount of cognitive activities increased, there is less time to carry them out, thus heavily taxing the pilot's memory and attention systems. The following cognitive activities were deemed necessary for pilots during each application.

Monitoring

Monitoring is imperative for failure detection, fault diagnosis, and problem-solving in general. Based on a through review of models of monitoring behaviour of the past thirty years [Senders 1955], [Kvalseth, 1977] and [Moray et al, 1983]. Moray [1986] identified several factors that are found to influence monitoring strategy. These factors include endogenous uncertainty due to human's forgetting, the accuracy with which observation must be made, the correlation structure of the different source of information, the cost of making an observation

Decision Making

A pilot's decision making and judgement undoubtedly play a critical role in successful mission completion and safety in flight. Although the basic characteristics of decision making are actively studied in the psychological literature [143], [144],[145], and [146], research specific to pilot's decision making [147], [148] and [149] is relatively sparse. Some necessary decisions that are direct results of automation include determining causes of failures and deciding when to intervene and stop the automatic actions. There are also additional decisions due to increased aircraft capabilities that are made possible by automation.

The decision making process is considered to be attention demanding and susceptible to memory limit. Five major non-optimalities in human diagnosis and hypothesis testing have been identified [168]. First, [164] observed that a hypothesis is often chosen based on the representativeness of the environmental cues to those that would be generated if the chosen hypothesis were true. The non-optimality lies in the failure to take into account the prior probabilities of all possible hypotheses, a departure from the prescription of Bayes' Theorem [156]. Contrasting human performance with the optimum performance prescribed by the Bayes' Theorem, Edwards [155, 144] and others found the human to be generally conservative. In revising the odds of the hypotheses, human decision makers often do not extract as much information from each observation as they optimally should, they request more evidence than is necessary before coming to a decision, they are reluctant to make extreme probability estimates, and do not claim as much confidence as they optimally should.

Secondly, humans tend to treat all environmental clues "as if" they were of equal reliability [159, 167] further suggested that the insensitivity to differences in cue reliability make the human ill-suited for prediction task which lead [154] to suggest that the role of the human on prediction should be to identify the relevant predictor variables but computer aids should be provided to integrate information and derive the predicted value.

Third, as the number of information sources grow, the limitations of human attention and working memory may be so imposing that a selective filtering strategy would be employed to process multiple environmental cues [167]. Fourth, humans are strongly biased by evidence that occurs early in the sequence. The human confirmation bias is to seek only confirmatory evidence to the chosen hypothesis and to ignore information that disconfirms it [162, 165]. Sheridan [163] observed that the confirmation bias produces a "cognitive tunnel vision" by which information that is consistent with the initially formulated hypothesis is not processed, or remembered well [160]. Further, the tunnelling phenomenon typically worsens during high workload situations [163].

Fifth, human tend not to use negative information as evidence to disconfirm a particular hypothesis or support a competing hypothesis [165, 151]. Given the human's limits and biases in decision-making, decision aids can be designed specifically with these non-optimalities in mind.

Attention and Memory

Human information processing, and hence pilot information processing is largely limited by the capacity of human memory and attention. For example, an obvious attention limit in monitoring is the rate at which multiple sources of information can be assimilated. Another example, effective decision-making and fault diagnosis require maintaining several hypotheses and their corresponding prior possibilities in the working memory. Human working memory is characterised by strict capacity and temporial limits.

The major cause of forgetting from the working memory is interference [166]. In particular, there are two types of inferences: proactive inference caused by previously stored information and retroactive inference caused by most recently acquired information. These inferences can be minimised either by increasing the distinctiveness of the items to be stored [170, 157,] by distributing the items to be remembered over time [161] and by distributing the items to be stored over different processing codes[158].

There is little question that the working memory is attention or capacity limited. The effects of attention is purported to affect the whole gamut of information processing stages from perception to response selection and execution. Since attention is limited, performance deteriorates when processing demands exceed the available attentional resources. It is common assumption that the more difficult the task is, the more attention it demands in order to maintain a certain level of performance. Since all processing, other than automatic processing, requires attention, more tasks require more attention or processing resources.

3.4.2 Determinants and Criteria Expansion

The two most important factors of the software are the lists of *determinants* which provide the indicators of change and the list of *criteria* which express all the human dimensions playing a role in the evaluation of a transformation cost.

Amendments were also made to the *determinant Influence* file of the programme where the addition of two other files, *simulation results* and *statistical analysts* were created to display and analyse the results of the simulations. The *simulation results* displays the table of the simulation and results of the linear regression coefficients; and the *statistical analyst* file contains all the analysis made to demonstrate the quality of the approximation with the regression.

3.5 Software Spreadsheets Expansion

This section details the changes, and by extension the expansion of the programme, made to the five excel spreadsheets of the software - project description, evaluation results, results improvement, determinants influence and simulation results. It also details the expansion of the *determinants* list which perform the role of descriptors of change. *Criteria* valuations used for assessment within each file and the justification for such use is also provided within this section and the inter-dependence and relation between *criteria* and *determinants* is also defined.

3.5.1 Project Description File

Project Description is the first file of the programme. Table 9.1 of Appendix 3 displays the *determinants* valuations where consideration in the selection, among other things, took into account the heterogeneity of traffic flow such as the existence of crossing points and nodes in the airspace; and the heterogeneity of aircraft equipment. The appeal of the technical system and the intrinsic capability of the concept to demonstrate an explicit added value with regard the current situation and objective of the future have justified the psychophysical factor of job motivation.

Similarly, the *determinant/criteria* inter-relationship valuation in Table 9.2 of Appendix 3 took account of factors such as stress and mental workload as zones of poor technical navigations assistance on the ground, bad weather and greater density of flights will influence the overall performance of the pilot. Stress and mental workload are also the resulting factors in the consideration of responsibility and delegation.

3.5.2 Coverage of Assisted Tasks

Coverage of assisted tasks relates to level of assistance provided by a tool and is further expanded into the following eight (8) categories – activities pertaining to flight navigation, communication and system management, back-up procedures, tool complexity and its usability, new features and autonomy. Tables 9.2 –9.3 details the *determinants valuation* and *determinants/criteria interdependencies* of the eighty five (85) determinants used.

Factors such as heading, speed, altitude, were consideration in the *determinants/criteria inter-relationship valuation* for flight control. Cognitive factors such as monitoring, planning and checking were taken into account to define traffic separation and confidence in the system.

3.5.3 Role Modification – Activity Related Tasks

Tables 10.1 – 10.5 of Appendix 4 clearly detail the *determinants valuation* and *determinants/criteria inter-relationship* respectively within this category. Activities relating to two categories of tasks, Executed Tasks Tables 10.7 and 10.20 and Decision Tasks are detailed.

3.6 Interdependencies Relationship

Determination of the increase in difficulty, how such difficulty scales and an assessment of which problems are critical for pilots during the application and delegation levels was derived through comparison between $\delta^{hell}_{Project\,P}$ and $\delta^{heaven}_{Project\,P}$ where the closer to *Heaven* the easier to implement and accepted, the closer to *Hell* the more difficult. The interdependencies between the *criteria*, provided at Table 1 of Appendix 5 are typed and weighted where;

- "↗" means a linear positive dependency,
- "∩" means a parabolic dependency, i.e. increasing then decreasing,
- The number of "+" indicates the strength of the influence.

Secondly a relationship between *Criteria* and *Determinants* were derived to determine the acceptance level and the ability of the pilots with regard their new roles and as they relate to a respective application. This was derived through the equation:

$$\delta^{heaven}_{projectP} = f(criteria) = f[g(determinants)] = f \circ g(determinants) \qquad \textbf{3.1}$$

As the value of $\delta^{heaven}_{projectP}$, identifies which *Determinant* scores have a strong impact, either positive or negative, on this value. To obtain this value a direct relationship, called *h*, between *Determinants* and $\delta^{heaven}_{projectP}$ was derived using the equation;

$$\delta^{heaven}_{projectP} = f \circ g(determinants) = h(determinants) \Leftrightarrow h = f \circ g \qquad \textbf{3.2}$$

In the simulation of MpE the overall results of two thousand (2000) hypothetical applications were assessed for $\delta^{heaven}_{projectP}$. Then, using *linear regression algorithm* based on best square difference minimisation, a model of the following shape was established:

$$\delta_{projectP}^{heaven} = Cste + \alpha_1.D_1 + \alpha_2.D_2 + ... + \alpha_{40}.D_{40} = \sum_{i=1}^{40} \alpha_i.D_i \text{ avec } D_0 = 0 \qquad 3.3$$

The values of the coefficient α_i of the regression, as computed starting from the simulation, are detailed at Table 2 of Appendix 5. Examination of most of the coefficient shows α_i are negative, which complies with the model since it determines the distance to *Heaven,* which as a positive value of a given *determinant,* leads normally to shortening this distance.

The distance to *Heaven* and *Hell* along with the list of all the ordered *determinants* are the main results derived from the programme. Judgement is based upon the concept of the simulation following a Normal Law where the following can be deduced:

1. The future situation is very easy to accept and learn if the distance to *Heaven* is included in the 16% of the results which have a value smaller than the mean value – standard deviation.

2. The future situation is easy to accept and learn if the distance to *Heaven* is included in the 34% of the results which have a value comprised between the mean value – standard deviation and the mean value.

3. The future situation is difficult to accept and learn if the distance to *Heaven* is included in the 34% of the results which have a value comprised between the mean value and the mean value + standard deviation.

4. The future situation is very difficult to accept and learn if the distance to Heaven is included in the 16% of the results which have a value larger than the mean value + standard deviation.

From the 2000 simulations conducted for pilots, the *regression coefficient* ρ derived from the coefficient α_i produced a value of:

$$\rho = 0.956 \tag{3.4}$$

This value represents a really good indicator of the validity of such a model as its square value is nearer to 1.

3.7 Concept Development – Air Traffic Controllers

As the original programme MACE was designed specifically to assess and measure the impact and consequential changes in the job of the air traffic controller it was deemed necessary to ascertain whether the programme, as a predictive human performance tools, was capable of evaluating the impact and consequential changes in air traffic controller when analysed under similar operations as pilots. Accordingly, MACE was used to assess the effects of shift in authority on air traffic controllers during ASAS applications. Three hundred and fifty (350) simulations were conducted assessing the effects of shifts in authority and workload measurements for air traffic controllers during ASAS applications of Limited, Extended and Full Delegation. This number of simulations was conducted, as there were no significant changes to results when this amount was exceeded due to the subjective nature of the programme. Tables 3 and 3A of Appendix 5 clearly detail the *determinants valuation* and *determinants/criteria interdependencies* of the the forty (40) *determinants* used.

In chapter 2 the seven categories of coordination behaviors necessary for successful performance in air traffic control were defined through an example of a typical flight operation. The following captions expand on these behaviours by describing the general duties of the ATC positions and identifying the most characteristic behaviour of the positions involved in the applications.

En Route

En route controllers are responsible for maintaining safe traffic patterns in the sky and preventing collisions while aircraft are flying straight and level. Each controller monitors one sector of airspace and examines the traffic situation for separation, conformance, and flow restriction violations [132]. They respond to violations by adjusting flight paths to prevent separation conflicts and to accomplish these tasks, they synthesise flight altitudes, airspeds, times, routes and headings to develop a mental picture of each aircraft's current and future positions [132]. As mentioned in Chapter 2, this information is drawn from flight data strips, radar screens, and pilot communication.

Although aircraft are at a flight level while under en route guidance, air traffic continuously presents the controller with potential problems to resolve. For instance, en route controllers must excercise assertiveness in resolving aircraft conflicts [132]. First, the controller determines the validity of potential aircraft conflict indication or notices and perceivess the problem which is then communicated with other controllers whose areas will be involved. En route controllers also engage in mission analysis to create descent patterns for aircraft preparing to enter terminal areas. The task consists of integrating multiple convergent traffic patterns into ordely sequences of spaced aircraft with uniform airspeeds [191].

A close examination of the en route position reveals that, here also, efficient and effective communication plays a critical role on successful management. A major source of en route contollers information is displayed in a data block on the radar screen or on a flight strip and as each aircraft progresses along its route, computers update the data block., while the controllers manually update the flight strip information. If, during an update, a controller overlooks or omits data, other controllers will not have the information needed to create their mental projections of the aircraft's continuously changing position.

Spoken communication exchanges occur both between pilots and controllers and among the individual controllers. For instance, if an enroute controller arranges a descent pattern for aircraft, the en route center must telephone ahead to the receiving facility and consult with that facility before assigning an aircraft a lower altitude. Aside from managing traffic in their sector, the en route controller must also maintain situational awareness of the traffic as or near the sector boundaries. Thus, they must be aware of the neighboring traffic situation so that adjustments to aircraft routing and delaying handoffs will alleviate the workload of an overburdened contoller in a neighboring sector.

As an aircraft traverses from one sector into another, responsibility for that aircraft is handed from one controller to the other where the time during and immediately following each handoff is crucial.

Previous research [3] has indicated the necessarity to measure workload, taskload, complexity and performance in air traffic control to evaluate the effects of new systems and procedures on individual controllers and the system as a whole. It has been concluded that computing measures of taskload and performace on a system level, while accounting for sector complexity, may also contribute to better prediction of workload within the overal operating environment.

The use of the original programme within this thesis also provided the backdrop during simulation and also provided some priliminary information about the meaning of the MACE measurements.

The assessment of the controllers and the use of Multi-criteria Analysis for Concept Evaluation (MACE) in the process also provide another important aspect of this thesis. It illustrated the functionality and capabilities of the software which together with MpE act as a predictive human performance tool for the evaluation of the impact and consequential changes as a result of delegation applications.

3.8 Software Description

Two copies of the software are provided at cover. One provides the expanded computational model, **Multi-criteria Analysis for Pilot Evaluation, (MpE)** produced to determine the impact and consequential changes brought about as a result of pilot's role shifts during applications of Traffic Situation Awareness; Limited, Extended and Full Delegation. The other is the original programme **Multi-criteria Analysis for Concept Evaluation (MACE)** which is used to determine the same impact and changes for air traffic controllers.

Multi-criteria Analysis for Pilot Evaluation, (MpE), as a computer programme has been developed to operate as an Excel spreadsheet and is user friendly as only mouse and keyboard are needed. The development of the programme took the following into account:

1. Where possible all quantitative estimates of parameters be borne from subject matter experts.

2. The mental operations represented in the model be cognitively plausible and presents a true representation of operations in the airborne separation assistance application.

There are five operating panels of the programme. The first panel, *Project Description Sheet*, as shown in Figure 3.3 provides the new eighty-five determinants, and allows the user to select the appropriate number considering which of the four situations (traffic situation awareness; limited, extended and full delegation) need to be analysed.

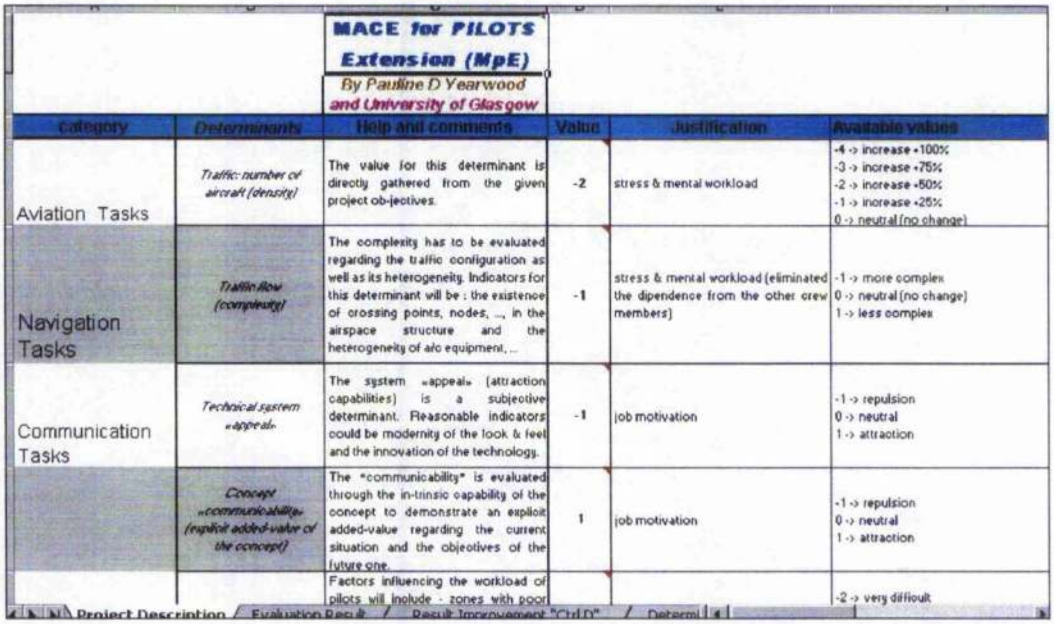

Figure 3.3 Project Description Display

The user inserts the chosen number in the value field for the respective *determinant* all the while observing the admitted range. Once completed press enter. This process is repeated for all the *determinants*. For MpE, two columns were inserted; 1.*Category* for identification of new *determinants* and 2. *Criteria Influence* for clear identification of which *ciriteria* are influenced by a single determinant and is an available value column.

The second panel provides the *evaluation sheet*, Figure 3.4 where the user checks, in the left top corner, the *distance to heaven* and the *hell values*. In MpE a small table was inserted at the top for the display of the numerical value of the *distance to heaven* and *the distance to hell* in the best possible combination of the respective *determinants*' value. This panel also provides the syntethic judgement of the quality of the situation being assesed and displays two tables. One table displays interdependencies between the *criteria* and the other the interdependencies between the *criteria* taking into account the influences of the *determinants*. The last row of this panel displays the final value of each criterion.

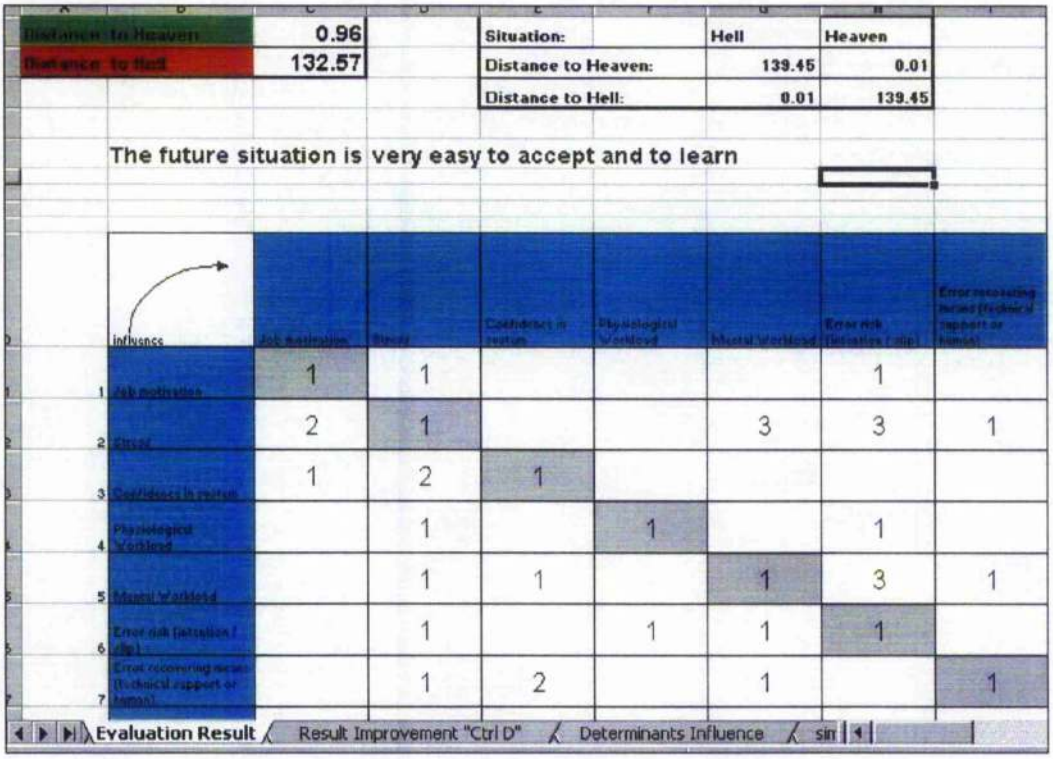

Figure 3.4 Evaluation Results Display.

To obtain the new order list of *determinants,* when using the programme for the controllers the user presses *Ctrl U* and for the pilot's programme the user presses *Ctrl D*.

The *results improvement* panel, Figure 3.5, allows the user to check the evaluated *determinants* list. Again, the structure used in the project description panel was repeated for the MpE programme and a new column, *determinants category,* added to help the user identify each *determinant* after it has been sorted in order of importance.

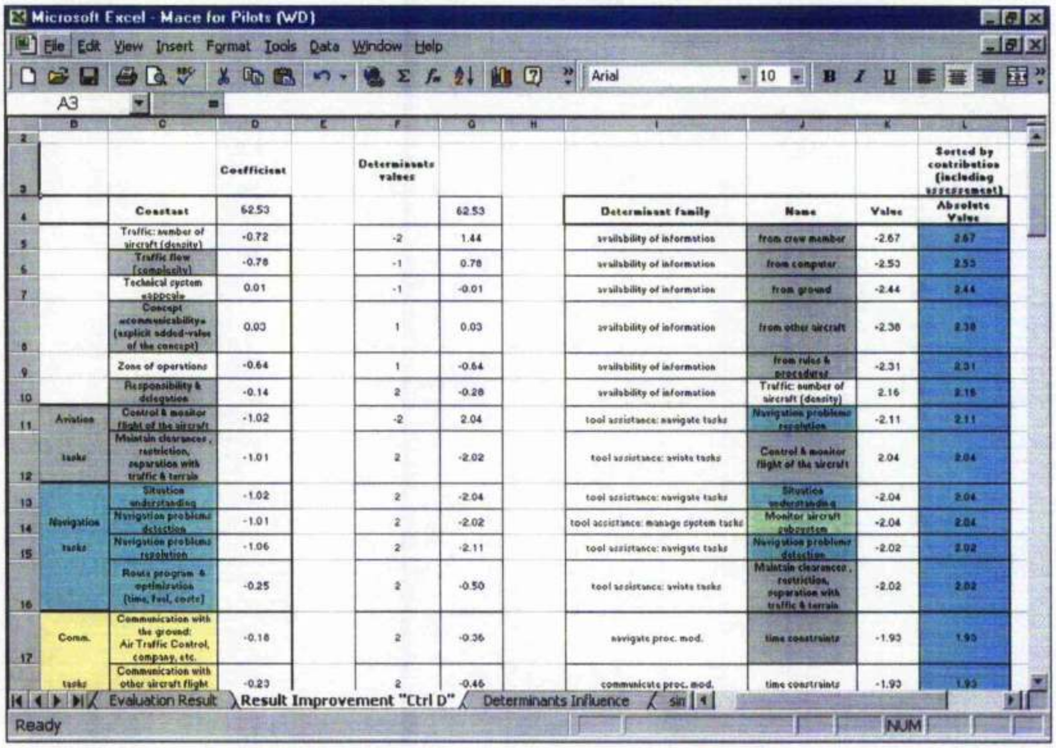

Figure 3.5 Results Improvement Display

Here there are three "blocks" of tables, the first one listing the *determinants* and the coefficients of the linear regression corresponding to each *determinant*, the second displays the value of the determinants and the product of value and correspondent coefficient of each determinant. The third table details the *determinants* with the corresponding real and absolute value. The real distance to heaven and the distance computed using linear regression are displayed at the bottom of the panel together with the residual error committed using the regression.

The *determinants influence* panel, Figure 3.6, displays the influence of the *determinants* on the *criteria*.

1											
2			quadratic relations in yellow								
3				Job motivation	Stress	Confidence in system	Physiological Workload	Mental Workload	Error risk	Error recovering	Interactio air/groun
4			Traffic: number of aircraft (density)		-2			-2			
5			Traffic flow (complexity)		-1			-1			
6			Technical system «appeal»	-1							
7			Concept «communicability» (explicit added-value of the concept)	1							
8			Zone of operations		1			1			
9			Responsibility & delegation	-2				2			
10		Aviation tasks	Control & monitor flight of the aircraft			-2					
11			Maintain clearances, restriction, separation with traffic & terrain			2					
12	coverage	Navigation tasks	Situation understanding			2					
13	of		Navigation problems detection			2					
14	assisted		Navigation problems resolution			2					
15	tasks		Route program & optimisation (time, fuel, costs)			2					
16	(assistance	Communication tasks	Communication with the ground: Air Traffic Control, company, etc.			2					2
17	provided		Communication with other aircraft flight crew			2					
18	by		Uplink & downlink data and information			2					2
19	a	System Management tasks	Manage & correct system faults			2					
20	tool)		Monitor aircraft subsystem			2					
21			Communication & co-ordination management with the crew			2					
22		Existence of back up procedures	autonoumus (Manual / on board)							1	
23			provided by the ground (Air Traffic Control, dispatchers, company, etc.)							1	
24			Automatic							1	
			Redundancy of human								

Determinants Influence / simulation result / Simulation

Figure 3.6 Determinants Influence Display.

	A	B	C	D	E	F	G	H	I	J	K
3	Distance to Heaven with the real model	Distance to Heaven with linear regression	Traffic: number of aircraft (density)	Traffic flow (complexity)	Technical system «appeal»	Concept «communicability» (explicit added-value of the concept)	Zone of operations	Responsibility & delegation	Control & monitor flight of the aircraft	Maintain clearances, restriction, separation with traffic & terrain	Situatio understan
4	Average values										
5	67.76		-1.96	0.00	-0.03	0.06	-0.46	-0.63	0.00	-0.01	-0.05
6	Min values										
7	42.71		-4	-1	-1	-1	-2	-3	-2	-2	-2
8	Max values										
9	93.53		0	1	1	1	1	2	2	2	2
10	Standard deviation										
11	7.27		1.44	0.81	0.81	0.82	1.12	1.68	1.43	1.44	1.42
12	Linear regression coefficients calculated with Minitab										
13	costant = a_0		a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
14	62.5281		-0.72	-0.78	0.01	0.03	-0.64	-0.14	-1.02	-1.01	-1.02
15	Simulation results										
16	76.05	75.24	0	-1	-1	1	-2	-1	-1	1	-1
17	72.31	72.80	-2	-1	1	0	-2	-3	0	1	0
18	61.85	64.19	-2	0	1	-1	1	1	-2	2	-1

Determinants Influence / simulation result / Simulation

Figure 3.7 Simulation Results Display

The fifth panel is *simulation results*, Figure 3.7. which displays the results of thee linear regression coefficients. Each column represents a *determinant* and the data is selected randomly inside specified ranges. The first column contains the values of the *distance to Heaven* computed using the complete model. Every value of the first column is obtained by considering the numerical values of the same row as the *determinants* values of the situation analysed. This panel also provides all the numerical results of the linear regression parameters computation and the statistical analysis. This comparative analysis is used to determine the "true" results of the complete simulation.

The final panel, *simulation valuation*, Figure 3.8, provides an analysis of the variable X1 and its 2000 random values. From this panel the average, standard deviation, minimum and maximum values are obtained.

SIMULATION VALUE

	Average	Standard deviation	Min	Max
Y	67.764	7.272	42.710	93.530
Variable X1	-1.956	1.438	-4	0
Variable X2	0.000	0.811	-1	1
Variable X3	-0.026	0.805	-1	1
Variable X4	0.055	0.817	-1	1
Variable X5	-0.457	1.118	-2	1
Variable X6	-0.631	1.677	-3	2
Variable X7	-0.002	1.432	-2	2
Variable X8	-0.006	1.440	-2	2
Variable X9	-0.048	1.416	-2	2
Variable X10	0.019	1.404	-2	2
Variable X11	0.010	1.401	-2	2
Variable X12	0.026	1.410	-2	2
Variable X13	-0.027	1.404	-2	2
Variable X14	0.018	1.418	-2	2
Variable X15	-0.024	1.392	-2	2
Variable X16	0.034	1.426	-2	2
Variable X17	0.037	1.397	-2	2
Variable X18	0.038	1.404	-2	2
Variable X19	-0.476	1.118	-2	1
Variable X20	-0.496	1.116	-2	1

Determinants Influence / simulation result / Simulation

Figure 3.7 Simulation Valuation Display.

Chapter 4

Calculations and Results

4.1 Introduction

This chapter provides the results of the pilot and controller simulations conducted using the developed quantitative framework Multi-criteria Analysis for Pilot Evaluation, MpE, and Multi-criteria Analysis for Concept Evaluation, MACE. These results were then used to determine increase in difficulty, how such difficulty scales and which problems are most critical for each respective human operator during applications of Traffic Situation Awareness, Limited, Extended and Full Delegation.

Section 4.2 presents the results of the pilots using MpE and follows through with a discussion on these results. Section 4.3 presents those of air traffic controllers using MACE and is also followed by a discussion of these results. The section concludes with a comparative analysis of the two programmes.

4.2 Results Using MpE

4.2.1 Pilots

TRAFFIC SITUATION AWARENESS APPLICATION		
DETERMINANT SUB-GROUP	DETERMINANTS	REAL VALUE
Tools Assistance: Navigation Tasks	Situation Understanding	-2.04
	Problem Detection	-1.01
Tools Assistance: Aviation Tasks	Clearance Restriction	-1.01
Sensory-motor Channel	Visual	1.43
	Voice	-0.78
	Auditory	-0.74
	Zone of Operation	1.28
Information Availability	Computer	-1.27
	Ground	-1.22
Technical System Function	Communication	0.74

Table 4.1 Determinants Values – Traffic Situation Awareness.

LIMITED DELEGATION		
DETERMINANT SUB-GROUP	DETERMINANTS	REAL VALUE
Tools Assistance: Navigation Tasks	Situation Understanding	-2.04
	Problems Resolution	-1.06
	Problems Detection	-1.01
Tools Assistance: Aviation Tasks	Traffic & Terrain	-2.02
Sensory-motor Channel	Visual	1.43
	Voice	-0.78
	Zone of Operation	1.28.
Information Availability	Computer	-1.27
	Ground	-1.22
	Other Aircraft	-1.19

Table 4.2 Determinants Values – Limited Delegation

EXTENDED DELEGATION		
DETERMINANT SUB-GROUP	DETERMINANTS	REAL VALUE
Tool Assistance: Navigate Tasks	Situation Understanding	-2.04
	Problem Detection	-1.01
	Problem Resolution	2.11
Tool Assistance: Aviation Tasks	Clearance Restriction	-2.02
	Traffic Density: Number of aircraft	1.44
Sensory-motor Channel	Visual	1.43
	Zone of Operation	1.28
Information Availability	Computer	-1.27
	Ground	-1.22
	Other Aircraft	1.19

Table 4.3 Determinants Values – Limited Delegation

FULL DELEGATION		
DETERMINANT SUB-GROUP	DETERMINANTS	REAL VALUE
Tool Assistance: Navigate Tasks	Situation Understanding	-2.04
	Problem Detection	-2.02
	Problem Resolution	-2.11
Tool Assistance: Aviation Tasks	Clearance Restriction	-2.02
	Traffic Density: Number of aircraft	1.44
Sensory-motor Channel	Visual	1.43
	Zone of operation	1.28
Information Availability	Computer	-1.27
	Ground	-1.22
	Other Aircraft	1.19

Table 4.4 Determinants Values – Full Delegation.

DELEGATION APPLICATION	DISTANCE TO HEAVEN	DISTANCE TO HELL	INTERPRETATION
Present Situation	63.52	77.37	Easy to accept and learn
Traffic SA Application	60.34	80.69	Very easy to accept and learn
Limited Delegation	58.29	82.79	Very easy to accept and learn
Extended Delegation	63.05	77.69	Easy to accept and learn
Full Delegation	64.45	76.27	Easy to accept and learn

Table 4.5 Overall Results Pilots

4.2.2. Pilot Results Analysis – Results Discussion

The results from the simulation are quite intriguing. Tables 4.1 – 4.4 detail the ten most relevant *determinants* analyses and the contribution of each to the formation of *the distance to Heaven*. The absolute value of each *determinant* contribute to the determinantion of the global result. The workload results are provided at Table 4.5.

Results for Traffic Situation Awareness and Limited Delegation both revealed that these concepts will be very easy to learn and accept. Whereas the result, (60.34) for traffic situation can be attributed to the fact that core roles remain unmodified. The result of (58.29) for Limited Delegation, through indicating very easy acceptance, however indicates that such acceptance should be facilitated by the concept of flexible use of delegation where the levels of delegation correspond to incremental steps of practice, yielding to gradual confidence building. In addition this low rating suggests that pilots will very well tolerate Limited Delegation, a view supported by previous research.

An examination of the positive values of the *determinants* factors *zone of operation* (1.28, 1.28, 1.28) *and visual channel use* (1.43, 1.44,1.44) revealed pilot's difficulty in all three delegation applications and support the view for the need of on board assistance tools such as autopilot target values or flight management system (FMS) trajectories for conflict detection and resolution, along with intent information about other traffic to reduce pilot workload

Although the overall results indicated an easy acceptance level for extended delegation results from the simulation revealed that aircraft density at (1.44) will be a major problem for pilots. This is further substantiated by the noted increase in *distance to Heaven*, 63.05 from 58.29 as was recorded.

Again the software revealed that implementation is possible and not too complicated for the application of full delegation, however, the positive real values of 1.44 and 1.19 detailed in Table 4.4 highlight the problem of traffic density. Conversely very positive influences (–2.02 and –2.11) are expected from navigational tools.

4.3 Results Using MACE

4.3.1 Air Traffic Controllers

TRAFFIC SITUATION AWARENESS	
DETERMINANTS	REAL VALUE
Task Procedure modification: Availability of Information - Assumed Complete & Relevant	-3.00
ATC Tools Complexity: Usability	-2.91
Conflict Resolution	-2.04
Situation Understanding	-2.03
Traffic Load	1.39
Technical System Functionality	0.70
HMI Information	0.70
Communication Management	-0.56
	-0.48
Concept - (Explicit added-value)	0.01

Table 4.6 Determinants Values – Traffic Situation Awareness.

LIMITED DELEGATION	
DETERMINANTS	REAL VALUE
Task Procedure modification: Availability of Information - Assumed Complete & Relevant	-3.00
ATC Tools Complexity: Usability	-2.91
Conflict Resolution	-2.04
Situation Understanding	-2.03
Traffic Load	1.39
Technical System Functionality	0.07
HMI Information	0.70
Autonomy	1.15
Airspace Management Information	0.72
Redundancy of Human Competencies and Action	-0.68

Table 4.7 Determinants Values – Limited Delegation

EXTENDED DELEGATION	
DETERMINANTS	REAL VALUE
Task Procedure modification: Availability of Information - Assumed Complete & Relevant	-3.00
ATC Tools Complexity: Usability	-2.91
Conflict Resolution	-2.04
Situation Understanding	-2.03
Traffic Load	2.79
Technical System Functionality	0.07
HMI Information	0.70
Autonomy	1.15
Airspace Management Information	1.44
Traffic Flow Complexity	1.64

Table 4.8 Extended Delegation

FULL DELEGATION	
DETERMINANTS	**REAL VALUE**
Task Procedure modification: Availability of Information - Assumed Complete & Relevant	-3.00
ATC Tools Complexity: Usability	-2.91
Conflict Resolution	-2.04
Situation Understanding	-2.03
Traffic Load	2.79
Technical System Functionality	0.07
HMI Information	0.70
Autonomy	2.29
Airspace Management Information	1.44
Traffic Flow Complexity	1.64

Table 4.9 Determinants Values – Full Delegation.

DELEGATION APPLICATION	DISTANCE TO HEAVEN	DISTANCE TO HELL	INTERPRETATION
Present Situation	56.19	76.68	Easy to accept and learn
Traffic SA Application	49.94	82.95	Very easy to accept and learn
Limited Delegation	50.07	82.67	Very easy to accept and learn
Extended Delegation	51.30	81.34	Very easy to accept and learn
Full Delegation	52.07	80.29	Very easy to accept and learn

Table 4.10 Overall Results of Delegation Levels – Air Traffic Controller

4.3.2 ATC Results Analysis - Results Discussion

Using the original software MACE an assessment of the impact of the delegation levels on the tactical controller was conducted. The main results, Table 4.10 ranging from easy to very easy to accept and learn and with a mean decrease *distance to Heaven* of 5, forecasted an improvement in controllers' job with the inplementation of applications traffic situation awareness, limited, extended and full delegation. These results, by suggesting that the global effect will be positive, indeed alleviate industry's concerns of loss of motivation skills and increase of time constrict on controllers.

For the three delegation levels the simulation revealed the first two *deteminants* the same for – *availability of information* and *usability of ATC tools*, -3.00 and –2.91 respectively which, in the context of the sofware represents a positive effect on controllers. *Conflict resolution* with a real value of –2.04 is also seen to present a positive effect. The positive effects of predictive aids on situation understanding and controller performance is in keeping with a multitude of previous researched measures including Situation Awareness Global Assessment Technique (SAGAT) scores as documented at [88, 89, 90]. Those of Nunes [140] are particularly singled out as he conducted a study to assess the impact of a predictive aid on controller performance in a Direct Routing (DR) environment under varing airspace load. The predictive aid in this study extrapolated the future trajectory of an aircraft and displayed it graphically to the controller somewhat similar to the work in this thesis.

Great enhancement is forecast for the controller with the implementation of traffic situation awareness application and limited delegation with better forecast tools being the main contributor as confirmed by the real values of the first four *determinants* (-3.00,-2.91, -2.04 and –2.04). However, closer scrutiny of results for extended and full delegation revealed aspects of these applications will have negative impact on the controllers. Moreover, factors such as *traffic load, airspace management information* and *traffic flow complexity,* with high positive real values of 2.79, 1.44, 1.64 and 2.4 are all indicative of how these difficulties scale.

These results further confirm findings of Grossberg [136] who identified three groups of factors – control adjustments such as merging, spacing and speed changes; climbing and decending flight paths; and mixed of aircraft types as contributions to the complexity of operations in different sectors by air traffic controllers. Results also revealed a negative impact on controllers for *autonomy* Tables (4.7 – 4.8, 1.15, 1.15, and 2.29) during delegation applications, however these results did not affect the overall results of these three delegation levels as they revealed (50.07, 51.30 and 52.03) the various levels of making controllers tasks "easier to accept and learn". This can be attributed to some or all tasks being now transferred to pilots.

The utilities of the software, *determinants* and *criterion* were used for evaluating and measuring the complexity of the airspace and of specfic air traffic situation with specific emphasis on the traffic and airspace characteristics that impact on the cognitive and physical demands placed on controllers. As the current figures above represented only the traffic flow conditions a more realistic representation of this effect on the controllers could be obtained from the programme by incorporating criteria of structural charateristics like airway intersections within each application given that at present such individuality of technique makes it difficult to evaluate the effectiveness of an individual controller's actions to move a set of aircraft through a sector. Other dynamic flow events such as weather could also be considered. In addition, results (1.15, 1.15 and 2.29) for applications of limited, extended and full delegation also indicated a growing negative impact with regards autonomy.

The traffic load results (1.39) of the application of limited delegation, a simulation equated to that of shared separation, revealed a negative effect on controllers which is similar to results of Corker et al [41]. Corker et al in investigating a range of scenarios with shared separation without automation concluded that shifting separation authority between pilots and controllers showed an increase in controller workload as the percentage of self-separating aircraft increased. This was attributed to controllers operating trying to operate in a strategic mode in an operating context that does not support this mode due to the high level of unpredictability in the system. The results obtained in the simulation were also similar to reults of DiMeo et al [42] who conccluded that there was some discomfort for controllers when separation authority was shared by the fllight deck.

4.2 Results Comparison - Pilots and Controllers

Notwithstanding the difference in performance factors of the two operators, pilots eighty-five and controllers forty a numerical comparison of results to determine the impact and interrelationships between the two operators was also conducted. The overall global results at Table 4.5 and Table 4.10 were used to analyse the importance of the applications.

The difference between the concepts from Traffic Situation Awareness Application, 49.94 to Full Delegation 52.07 is less marked, 2.13 for controllers. The global results reveal potential improvements in the controllers' way of working for all the possible applications and from this standpoint any application is positive and profitable to the controller. This result notwithstanding one must be mindful of controller workload and performance which include factors that cannot be easily observed, and are, therefore, not easy to measure. For example, controllers constantly review aircraft positions, directions, and speeds and mentally project aircraft positions but may only occasionally take observable actions. Notably, only a few *determinants* were related to controller performance, and hence the relationships were not consistent across the different types of performace measures for the same simulations.

In the case of pilots the difference between the same concept, 60.34 and 64.45 respectively is 4.11. The use of MpE revealed that whereas shifting from applications of traffic situation awareness to limited delegation have the potential for improving the job of pilots, results for limited delegation are high as core roles remain unmodified given the controller irresponsibility for initiative and overall authority of the situation management. On the other hand, results of applications of full and extended delegation through showing the potential to improve the pilot's job, however will do so at a cost of increasing their overall demand as supported by Wickens et al [3].

Sheridan [163] in his contribution to the effect of role transfer indicates that placing human operators into the passive role of monitoring is detrimental to their performance. An inference drawn on the prediction made by Sheridan suggests that the role transfer will involve the controller being placed to an increasing extent into the role of supervisor, a role which involves visual monitoring and one that is not a strong role for the human. The overall results, 4.11 from the increase in more active control responsibilities for the pilots may confirm the belief of Wickens,[3] that such increase may lead to problems by increasing the operator demands beyond their human performance limits. In this regard comprehensive human in the loop (HITL) research is certainly needed to fully evaluate the effect these applications will have on pilots.

The positive real values of the sub-group determinants for *aviation tasks* and *sensory-motor* channel (1.44, 1.43, 1.28) all indicating negative effects, further highlight the dynamic interaction between the airborne elements and ground base systems and they critical coupling of control.

Chapter 5

Discussion

5.1 Introduction

This chapter provides a general discussion of pertinent issues derived from the result of the applications of the developed MpE framework and MACE simulations conducted for both pilots and air traffic controllers as shown in the previous chapter.

The use of the software to predict performance of pilots and air traffic controllers during situation awareness application and limited, full and extended delegation, also provided an insight into the tasks that are engaged in by pilots and air traffic controllers which were then translated into the effect they have on the respective operator. Results indicate that the extended framework successfully predicts the degree of difficulty for the pilots and provide construct validity regarding the application examined. Both tools, MpE and MACE were able to predict differences in each operator's workload. The workload of the pilot calculated at 4.11 and the air traffic controller at 2.13. These figures are consistent for the most part with predictions of operators workload from the literature. Althrough positive for the encouragement, acceptance and use of these tools, a very interesting and somewhat result surfaced which related to the contextual effect of the different operating environments and their influence on the workload predictions.

The most important result from this research is the value of the *regression coefficient* ρ from the 2000 simulations conducted for pilots, where a value of $\rho = 0.956$ was obtained. This value represents a really good indicator of the validity of the simulations as the square is nearer to 1 and by extension one can deduce that the work of pilots during the four applications will be easier.

5.2 Software Limitations

5.2.1 MpE

The development of MpE to an extended framework of eighty-five *determinants* represent a comprehensive and psychometrically sound description of pilot's operational factors and as such render the software applicable for reliable pilot performance assessment during ASAS application, namely Limited, Extended and Full, for the determination of the effects of role transfer. However, it should be noted that the application of the framework depended entirely on information provided by subject matter experts and literature review and as such was not tested. The application of the framework was unlike the *determinants* used in the original software, MACE which have been tested by the developers in the ATC environment for controllers. In this regard, MpE when used in the pilot's environment, effectiveness of the expanded *determinants* needs now to be evaluated through human-in the loop validation. The following is a list of problems which were encountered during the use of the software and detailed recommendations for improvement.

- MpE incorporates the utilities of multi-criteria analysis for concept evaluation (MACE) and as a result several problems were encountered when using the same ratings scale and measurements for pilots. The value scales embedded within the original software and which aid in quantifying the changes of the concepts introduced, through designed for an ATC environment, were designed specifically for controllers and found not applicable for pilots. While these value scales were adequate for the assessment of application of traffic Situation Awareness they were not fully inclusive and adequate for the applications of Limited, Extended and Full Delegation.

- The cognitive components termed *criteria,* when used in MpE, did not accurately describe the activities of the concept being examined – the transformation cost of applications of Traffic Situation Awareness, Limited, Extended and Full delegation describe activities of a pilot's environment. Currently, differences exist between the tools with regards predictions and by extension influencing the human performance values output from the programme.

- The structural differences that exist between the two programmes also appear to be a weak influence on the amount of workload that is experienced by the respective operator, pilot and air traffic controller. The relative simplicity of the original MACE generating structure may be associated with the greater performance effects as predicted by MpE and require major re-programming. The more detailed the *determinant,* such as presented by MpE, combined with much larger interactive *criteria* may result in more accurate measure of both pilot's and air traffic controller's performances.

- There is also the need for a broader performance rating scale or measurements within the programme. The user of both tools MACE and MpE, is required to provide subjective judgement of the future concepts which are then rated and values (Table 2.4 and Fig 3.3) to initially activate the programmes. Given this subjectivity and time-consuming nature of obtaining ratings, it would be desirable if the programme provided a broader range of ratings as this will assist in limitation of concept selection.

- There was a great degree of consistency in the results across all the delegation applications for pilots. The reason for this anomaly can only be speculated upon at the current time but it is likely that this anomaly occurred because of limitations in the contextual recognition of the software as MpE was unable to determine the contextual differences associated with the different determinants. This critical observation is indicative that more emphasis needs to be placed on accurately modelling the contextual properties of the pilot's environment and having the software tool recognize these contextual properties. Specifically, incorporating an accurate prioritisation and scheduling mechanism that is based on the contextual events in the virtual environment is required. Secondly, the fact that the simulation manipulations did not necessarily produced the expected effect or the effect that would have been expected of a human-in-the-loop experiment is a critical fact that needs to be addressed if the programme is to be introduced within the ATC environment.

5.2.2 MACE

If the framework of MACE is to be used in the development of MpE there need to be a comprehensive assessment of the models' abilities to accurately represent both controller and pilot and their actual human performance within the operating system of the programme as it appears to be much overlapping.

The programme fails to account for one of the main characteristics of human behaviour, namely, that human behaviour is characterised by variability and is not necessarily quantifiable. Events may be sequential but it is not sufficient to assume that this ordering organisation is casual. This is especially true when one considers the patterns of action that characterise human decision-making and complex human behaviour during the three levels of delegation and the application process examined in this thesis.

Data input is very subjective which allow for considerable possibilities of contamination and built in bias due the system parameters. In addition, both the *determinants* and *criteria* appear to be extremely sensitive to factors that contribute to bias and unreliability.

5.3 Pilot and Controller Improvements

An analysis of the comparative results obtained from the simulation conducted for controllers concluded that the process by which controllers are moving from active and strategic control in current operations to passive controlling requires that they be provided aiding information through systems. This is necessary so that they can be placed in an information state that is consistent with strategic control.

One important point made by the controllers at Prestwick and Glasgow airports during discussion is the fundamental fact that controllers have been trained to act and think tactically, not strategically. They also revealed that the mental picture of the airspace, particularly for Extended and Full Delegations does not accurately reflect all aircraft hence strategic resolutions may lead to conflict with other aircraft because of inadequate situation awareness. Emerging MpE capabilities have demonstrated, when used for (Limited and Full Delegation) the ability to enable more strategic planning by controllers as it defines the parameters within which the pilots operate and consequently facilitate such strategic planning. However, simply making M-pE available to controllers would not necessarily result in strategic planning because the controller's mindset and procedures are still based on a tactical culture and environment that date backs several decades as highlighted in section 2.1. The solution requires a fundamental change to the environment that controllers have been trained to support. It also implies that the circumstances presented to controllers in any given situation must have adequate solutions, via new tools and procedures, to give them confidence that by acting strategically, they are improving the overall traffic flow and not increasing their workload.

The overall results, 4.11 from the increase in more active control responsibilities for the pilots may confirm the belief of Wickens, [3] that such increase may lead to problems by increasing the operator demands beyond their human performance limits. In the case of Extended Delegation a specfic phraseology will be necessary for communication of instructions of delegation. In this regard comprehensive human in the loop (HITL) research is certainly needed to fully evaluate the effect these applications will have on pilots.

As stated in chapter 1 the aviation society is considering new concepts for a modern ATM. Experiments conducted on one of these new concepts using MpE and MACE have proven that they are an appropriate tool for determining the "transformation cost" of ASAS applications Limited, Extended and Full Delegation; and Traffic Situation Awareness. This team concept (MpE and MACE) appears appropriate for predicting human performance with sufficient accuracy under specific conditions particularly in the case of controllers where the tool can be used to provide feed back for strategic planning, the single most important criteria for achieving trajectory orientation.

Chapter 6

Conclusions and Recommendations for Future Work

6.1 Summary

The work in this thesis presents the development of a quantitative framework of a task index and self-assessment performance tool for the determination of cognitive and performance challenges of pilots during delegation applications of Limited, Extended and Full Delegation of Airborne Separation. The quantitative framework is an expansion of the performance utilities, termed *determinants*, of Multi-criteria Analysis for Concept Evaluation, MACE [9], one of many packages of tools, software and documents developed specifically for air traffic controllers by EUROCONTROL scientist and experts to analyse and access the transformation cost, seen from a human factors perspective, of future ATM systems and concepts.

Using the method of cognitive task analysis the determinants were extensively modified and expanded from their original forty factors to eighty five factors, incorporating the tasks required for cockpit environment during ASAS applications of Limited, Extended and Full delegation. The focus of the expansion has been on issues concerning problems such as mental representation of the changing situations and the context-dependent flexible coordination of concurrent cognitive tasks, which are inherent to dynamic situations during the respective applications.

The performance framework was then incorporated into an existing decision support tool, Multi-criteria Analysis for Concept Evaluation (MACE) [9] whose operating and performance utilities were extensively expanded and modified from forty factors to eighty five factors to presents the novel approach of this thesis. This novel approach is the development of another decision support tool, Multi-criteria Analysis for Pilot Evaluation, (MpE) for quantifying the increase in difficulty, determining how such difficulty scales and assessing which problems are most difficult for pilots during the respective application.

These new *determinants* together with the *criteria factors* of the original programme were used to illustrate the functionality and capabilities of MpE as a predictive human performance tool through the conduct and assessment of two thousand hypothetical simulations applications for pilots were conducted. To achieve one of the objective of MpE, three hundred and fifty hypothetical ASAS applications conducted by air traffic controllers were simulations using the programme in its original form of (MACE). Whereas Situation Awareness may not be deemed as an ASAS application it was however included as an ASAS application during both simulations to provide insight into the cognitive processes involved in dimension of regulation and to confirm whether CDTI would enable a better representation of the traffic situation.

Chapter 1 provides an introduction to the present and ATM and international efforts towards the implementation of a new system. Concepts and procedures of the new ATM were also provided.

In Chapter 2 an operations assessment of air traffic controllers in today's en-route environment was conducted to determined core operational issues which will inhibit the pilots' implementation of the applications.

Chapter 3 details the concept development and implementation to assess the effects of shift in authority for both pilots and air traffic controllers. As the original programme MACE was designed specifically to assess and measure the impact it was deemed necessary to ascertain whether the programme, as a predictive human performance tools, was capable of evaluating the impact and consequential changes in air traffic controller when analysed under similar operations as pilots. To this end three hundred and fifty application were conducted.

This chapter also provides an assessment of comprehensive goal direct tasks for commercial pilots and cockpit environment during the four levels of delegation was conducted and a performance profile created of the interactive aircrew – aircraft – environment system. These current operating parameters were extrapolated to future trajectory of the applications and resulted in the identification of the eighty five (85) performance factors, termed determinants were used in the extended development of the tool, MpE.

Chapter 4 details the applications of both tools and analysis of these results for each operator.

Chapter 5 provides a discussion highlighting the limitations of both software.

6.1.1. Conclusion

The International Civil Aviation Organisation's (ICAO's) 11th Air Navigation Conference held in autumn of 2003 was convened to establish a road map that moves the international civil aviation community towards a seamless, global air traffic management (ATM) system that meets safety and performance targets [190]. To increase airspace capacity, the conference recommended, among other things, greater harmonisation of air navigation systems between regions and collaborative decision making between air traffic controllers and flight crews. Much discussion at the conference also resolved around the planned shift from ground-based navigational to satellite-based navigation, a goal endorsed at the 10th Air Navigation Conference, held in 1991.

The following is a statement of Vince Gallotti, technical officer of ICAO in response to his view of the evolving roles of controllers and pilots: "We definitely do see a transfer of responsibility to the cockpit in the future in certain tactical situations. The controller's responsibility is probably going to move more to that of a manger, a person who is involved in the provision separation"[190]. He also pointed out that the ATM operational concept envisages a lot more strategic activity because of the incredible ability to transfer large amounts of information between all of the different players in the system, which is an integrated system of ground elements and airborne elements, balancing the airspace organisation and management. The theory is that when the pilot gets in the air he will be able to carry out tactical separation.

The work in this thesis is timely as the tool developed is a worthwhile contribution to a future ATM system as it is information-based, performance-based and strategically oriented for examining responsibilities of delegation during ASAS operations. Using the results from the analysis it can be inferred that airborne separation applications do not appear to be a simple compromise solution.

Airborne separation with full delegation, where aircraft are equipped with traffic display and conflict detection, and the aircraft crew is wholly responsible for ensuring safe separation, has several advantages over other control concepts. There is some extra workload for the pilot but this research results do not indicate that this will cause great difficulty to the pilot. The kinds of ATC controller cognitive engineering problems apparent in enhanced delegation are eliminated in normal operations. Some important issues of safety analyses of full delegation have been sketched out.

The role of the air traffic controller is theoretically shifting to that of the air traffic manager. Tasks related to tactical manoeuvring of aircraft under direct control in response to perceived impending loss of separation could be supplemented by strategic tasks that avoid the problems of today altogether. This uses automation to identify impending problems and longer lead times allow strategies to be applied profoundly impacting tasks and information required. Interaction between pilots and controllers will change as well. A shift towards strategic control enables some degree of flight deck input to resolution, because time pressures are reduced.

The addition of demand management tasks to avoid overloading ATC resources will be coincident with the shift towards strategic problem detection and resolution. The merge of ATC with traffic flow management is inevitable. Controllers can be expected to become more proactive in addressing problems in capacity management and pilots to become more aware in ATC situations through reference to a cockpit display of traffic information, which may be part of the traffic alert and collision avoidance system. What each party knows and the use of that information will change the nature of that interaction.

An equal profound change will come from the use of automated data links to replace routine voice communication between pilots and controllers. [192] describes the blending of voice and data to ACT communication and [193] identifies issues associated with evolution from verbal to datalink communication. Other changes identified include the inability to overhear communication between ATC and surrounding aircraft, reducing the pilot's knowledge of the traffic's intent.

6.1.2 Recommendation for Future Work

The domain of aviation human factors has stressed the importance of the human element in ensuring the safety and performance of pilots and controllers in complex dynamic systems. In response, the goal of this thesis was to develop a preliminary understanding of the human performance demands associated with conducting particularly complex tasks during ASAS applications.

The work in this thesis can be used to:

- Identify specifications of required aptitude for pilots.
- Define training content and approach

- Define tasks which can benefit from automation or aiding

- Identify appropriate evaluation techniques and support for the development of new policies for assessing pilots and controllers readiness-to perform ASAS applications.

The following recommendations are in addition to those highlighted at section 5.2.1 and divided into CTA and the tools (MpE and MACE are noted as follows.

Critical Tasks Analysis and Expansion

- Data could be used to identify design considerations for future hardware and human-technology interfaces.

- The critical task analysis developed for the expansion could benefit pilots and controllers in anticipating performance decrements and challenges associated with task difficulty and conditions, as well as being a first step towards deriving countermeasures designed to support crew members during ASAS applications.

MpE

- The tool developed presented quantitative results where the expected gain now need to be evaluated in a more realistic environment hence the need for human–in-the-loop validation.

- Future work should therefore be the use of these quantitative results with the objective of evaluating expected gains in a more realistic environment. This is because measures derived from operational data do not have the same limitations as measures derived from simulation and so may be more useful for predicting performance.

- Further research is required into the nature and rate of future conflicts in ASAS applications

More research is needs to be done on the development of computer-derived measures of performance.

Appendix 1

Information sources from the Internet

Information sources used from the internet are listed in Table A1.

INFORMATION SOURCE	INTERNET ADDRESS
ATM R&D seminars (FAA & EUROCONTROL)	http://www.atm-seminar-2000.eurocontrol.fr
Aviation safety links	http://www.aviation.org/links.htm
Ergonomic Resources	http://www.geocities.com/CapeCanaveral/1129
Ergonomic Information Analysis Centre	http://ww.bham.ac.uk/manmecheng/ieg/eiac.htlm
Ergonomics Society (UK)	http://www.ergonomics.org.uk
FAA Human Factors	http://www.hf.faa.gov
HCI sites	http://www.acm.org/sigchi/hic-sites
HCI resources on the net	http://www.ida.liu.se/labs/aslab/groups/um/hci
Human Factors & Ergonomics Society	http://hfes.org
Human Factors International Inc.	http://www.humanfactors.com
International Ergonomics	http://www-iea.me.tut.fi
International Standards Organisation	http://www.iso.ch
Inventory of tools and methods	http://www.megatag.mcg.gla.ac.uk./sumi.html
NASA Ames Research Centre	http://human-factors.arc.nasa.gov
NASA Human Factors	http://olias.arc.nasa.gov/home-page.html
University College Core HFRG	http://www.ucc.ie/hfrg
Usability engineering resources	http://inf2.pira.co.uk/jzus1.htm

Table 7.1 Information Source and Internet Address

Appendix 2

Air Traffic Controllers Discussion

A2.1 Discussion Guidelines and Areas of Observation

The following information formed the guidelines of a brief used during discussion with (15) controllers and three (3) traffic supervisors of Prestwick International Airport and Glasgow Airport, Scotland during the periods (March/April and Nov/Dec, 2002).

Areas addressed were: Communication, management of air traffic flow, separation, and sector workload, coordination, performed multitasks and attention. These have been narrowed down as follows detailing the corresponding areas investigated for each particular factor.

Areas of Observation

1. COMMUNICATION

The observations and discussions were conducted with emphasis on the following:

- Use of standardise/prescribed phraseology.
- Properly established, maintained, and terminated communication.
- Length of clearances.
- Issued clearances that were complete, correct and timely.
- Communicated clearly and concisely.
- Used appropriate speech rate.
- Listened carefully to pilots and other controllers.

2. MAINTAINING ATTENTION AND SEPARATION AWARENESS

- Maintained awareness of total traffic situation.
- Recognised and responded to pilot deviation from ATC clearances.
- Listened to read backs and ensure they were accurate.
- Assigned requested altitude in timely manner.
- Accepted/performed timely handoffs
- Reviewed and ensured appropriate route of flight.
- Scanned properly for air traffic events, situation and potential problems.

- Reviewed and ensured appropriate route of flight.

3. MAINTAINED EFFICIENT AIR TRAFFIC FLOW

- Accuracy in predicting sector traffic overload and how they took appropriate action.
- How they control traffic to ensure efficient and timely traffic flow.
- How efficiently they reacted to and resolved potential conflictions.

4. MAINTAINED SEPARATION

- Checked separation and evaluated traffic movement to ensure separation standards were maintained.
- Detected and resolved impending conflictions.
- Analysed pilot requests, plans and issued clearances
- Established and maintained proper aircraft identification.
- Considered aircraft performance parameters when issuing clearances.

5. COORDINATION

- Performed handoff and point out procedures correctly.
- Processed flight plan amendments as requested.
- Performed required co-ordinations effectively.
- Provided complete/accurate position relief briefings.
- Effectively coordinated clearances, changes in aircraft destinations, altitudes, etc.

6. PERFORMED MULTIPLE TASKS

- Kept track of large number of aircraft/events at a time.
- Shifted attention between several aircraft.
- Prioritised activities.
- Whether they communicated in a timely fashion while performing other actions and tasks.

7. MANAGED SECTOR WORKLOAD

- How effectively heavy, emergency and unusual traffic situations were handled.
- Responded to impose airspace restrictions.
- Responded to traffic management constraints and initiatives.
- Dealt with situations for which there were no clearly prescribed.

Appendix 3

Software Spreadsheets Expansion

A3.1 Coverage of Assisted Tasks - Determinants Valuations and Interrelationships

The following tables detail the elements; aviation, navigation, communication & system management, back-up procedures, tool complexity, usability & HMI, new features and autonomy, as they relate to the category of coverage of assisted tasks.

Tables 9.1-9.18 detail the Determinants valuation and justification with corresponding detail pertaining to the Determinants / Criteria interrelationship and valuations.

DETERMINANTS	APPLICATION VALUATION	JUSTIFICATION
Traffic Density	A=-1 B=-1 C=-2 D=-2	Forecasted traffic increased for the period of implementation: A & B=+25%; C & D=+50%
Traffic Complexity	A=0 B=0 C=-1 D=-1	Except for applications A & B aircraft equipment will be designed to accommodate a more complex flow of the traffic.
Technical System Appeal	A=1 B=1 C=1 D=1	Pilots have been trained to use and are familiar with the new tools.
Explicit Added-value of Concept	A=1 B=1 C=0 D=-1	The new features in traffic information are appealing however require great levels of responsibility in separation tasks.
Zone of Operation	A=-2 B=-2 C=-2 D=-2	Zone of high-density busy traffic environment with mixed aircraft equipment.
Responsibility & Delegation	A=0 B=-1 C=-2 D=-3	Values reflect the growth of responsibility from A (no change) to D (high increase).

Table 9.1 Determinants Valuation and Justification

DETERMINANTS	VALUATION	CRITERIA
Traffic Density	-2	Stress & mental workload
Traffic Complexity	-1	Stress & mental workload (eliminated the dependence on the other crew members)
Technical System Appeal	-1	Job motivation
Explicit Added-value of the Concept	1	Job motivation
Zone of Operations	1	New: stress & mental workload
Responsibility & Delegation	2	New: mental workload & job motivation

Table 9.2 Determinants & Criteria Inter-relationship and Valuation

COVERAGE OF ASSISTED TASKS - AVIATION			
TASK(S)	DETERMINANTS	APPLICATION VALUATION	JUSTIFICATION
Aviation	Control & Flight Monitor	A=0 B=0 C=0 D=0	From this point of view the CDTI does not provide enhancement.
	Maintain Clearances, Restriction and Separation with Traffic & Terrain	A=1 B=2 C=2 D=2	CDTI along with GPS will provide major improvement in the execution of manoeuvres and accomplishment of orders. In application A the enhancement is reduced since no role change is expected

Table.9.3 Determinants Valuation and Justification - Aviation Tasks

COVERAGE OF ASSISTED TASKS – AVIATION			
TASK(S)	DETERMINANTS	VALUATION	CRITERIA
Aviation	**Control & Flight Monitor**	-2	**New subgroup: confidence in the system, Control Process: Direct Monitoring & plan, Control Process: checking**
	Maintain Clearances, Restriction and Separation with Traffic & Terrain	2	**New subgroup: confidence in the system, Control Process: Direct monitoring & plan, Control Process: checking**

Table.9.4 Criteria Interrelationship and Valuation - Aviation Tasks

COVERAGE OF ASSISTED TASKS - NAVIGATION			
TASK(S)	**DETERMINANTS**	**APPLICATION VALUATION**	**JUSTIFICATION**
Navigation	Situation Understanding	A=2 B=2 C=2 D=2	A cornerstone of ASAS application is a major improvement in SA of the crew.
	Problem detection	A=1 B=1 C=1 D=2	A, B & C: increase assistance is expected from CDTI (especially for weather problems) even without a dedicated traffic conflict detection tool; for application D, conflict detection tools are available.
	Problems Resolution	A=0 B=1 C=2 D=2	Application A no change; In application B, resolution is planned by ATC with additional assistance for the implementation; With C & D conflict solver tool available
	Route program & optimisation (time, fuel, cost)	A=1 B=1 C=1 D=2	Real time free routing and conflict detection tools will be granted to autonomous aircraft; for the other delegation levels this will be at the discretion of controller.

Table.9.5 Determinants Valuation and Justification - Navigation Tasks

COVERAGE OF ASSISTED TASKS – NAVIGATION			
TASK(S)	DETERMINANTS	VALUATION	CRITERIA
Navigation	Situation Understanding	2	Confidence in the system, checking, monitoring
	Problem detection	2	Confidence in the system, checking, monitoring
	Problems Resolution	2	Confidence in the system, checking, monitoring
	Route program & optimisation (time, fuel, cost)	2	Confidence in the system, checking, monitoring

Table.9.6 Criteria Inter-relationship & Valuation - Navigation Tasks

COVERAGE OF ASSISTED TASKS – COM & SYSTEM MGMT			
TASK(S)	DETERMINANTS	APPLICATION VALUATION	JUSTIFICATION
Communication	Ground/ATC/ Company	A=1 B=1 C=1 D=1	Information pertaining to a/c non-equipped with ASAS will be broadcast through TIS-B
	Other aircraft	A=0 B=0 C=0 D=0	No new tools of this kind are forecasted
	Uplink & downlink data and information	A=2 B=2 C=2 D=2	ADS-B and Data-link will provide a major improvement in data exchange between a/c and with the ground
System Management	Manage & correct system faults	A=0 B=0 C=0 D=0	No change is expected in this area
	Monitor aircraft subsystem	A=0 B=0 C=0 D=0	No change is expected in this area
	Communication & co-ordination management with crew	A=1 B=1 C=1 D=1	The availability of a CDTI for pilot and first officer will enhance their co-operation

Table.9.7 Determinants Valuation and Justification - Communication & System Management

COVERAGE OF ASSISTED TASKS – COM & SYSTEM MGMT			
TASK(S)	**DETERMINANTS**	**VALUATION**	**CRITERIA**
Communication	Ground/ATC/ Company	2	Confidence in the system air/ground interaction
	Other aircraft	2	Confidence in the system air/air interaction
	Uplink & downlink data and information	2	Confidence in the system air/ground interaction air/air interaction
System Management	Manage & correct system faults	2	Direct monitoring, checking and planning
	Monitor aircraft subsystem	2	Direct monitoring, checking and planning
	Communication & co-ordination management with crew	2	Pilot/crew interaction

Table 9.8 Criteria Inter-relationship & Valuation - Com & System Management

COVERAGE OF ASSISTED TASKS – BACK-UP PROCEDURES			
TASK(S)	**DETERMINANTS**	**APPLICATION VALUATION**	**JUSTIFICATION**
Existence of back up procedures	Autonomous (Manual / on board)	A=0 B=0 C=0 D=0	In the event ASAS systems have a failure then a/c is blind and invisible and there is no manual procedure available
	Ground Support	A=1 B=0 C=-1 D=-1	New means of communication can improve application (A) However controllers face great difficulty in the event of ASAS failure when used in other applications e.g.; (B) Implementation (C) Resolution (D) Free routing
	Automatic	A=0 B=0 C=0 D=0	TCAS is still present but no other automatic tool is available in case of ASAS failure
	Redundancy of human competencies and action means	A=0 B=1 C=1 D=1	Except in application A, the double CDTI will allow a better cross monitoring of the situation and sharing of the delegation tasks
	Disturbance	A=0 B=0 C=0 D=0	No change is expected

Table 9.9 Determinants Valuation and Justification – Back-up Procedures

COVERAGE OF ASSISTED TASKS – BACK-UP PROCEDURES			
TASK(S)	**DETERMINANTS**	**VALUATION**	**CRITERIA**
Existence of back up procedures	Autonomous (Manual / on board)	1	Error recovery strategies
	Ground Support	1	Error recovery strategies
	Automatic	1	Error recovery strategies
	Redundancy of human competencies and action means	1	Error recovery strategies
	Disturbance	1	Stress/pilot crew disturbance

Table.9.10 Criteria Inter-relationship & Valuation – Back-up Procedures

COVERAGE OF ASSISTED TASKS – TOOL COMPLEXITY			
TASK(S)	**DETERMINANTS**	**APPLICATION VALUATION**	**JUSTIFICATION**
Tool Complexity	Technology maturity (reliability & consistency)	A=0 B=0 C=0 D=0	ASAS tools are presently being developed and tested. Reliability and performance is forecasted before the implementation date
	Amount of information	A=-1 B=-1 C=-2 D=-2	An increase in the amount of information will be presented to the pilots. This is necessary to facilitate adequately separation tasks and free routing.
	Asyncronism for communication & time of response	A=2 B=2 C=2 D=2	In addition to the actual means, ADS-B will permit an automatic broadcast of data between the ownership and the ground or other a/c; Data-link greatly reduces asynchronies of communications

Table 9.11 Determinants Valuation and Justification - Tool Complexity

COVERAGE OF ASSISTED TASKS – TOOL COMPLEXITY			
TASK(S)	**DETERMINANTS**	**VALUATION**	**CRITERIA**
Tool Complexity	Technology maturity (reliability & consistency)	0	Confidence in the system
	Amount of information	2	Mental work load, error risk
	Asyncronism for communication & time of response	2	Mental work load, error risk

Table.9.12 Criteria Inter-relationship & Valuation - Tool Complexity

COVERAGE OF ASSISTED TASKS – USABILITY & HMI			
TASK(S)	**DETERMINANTS**	**APPLICATION VALUATION**	**JUSTIFICATION**
Tools Usability and Human Machine Interface	Complexity of technology	A=0 B=0 C=-1 D=-1	Even if HF are considered, in the most advanced levels of delegation the future technology is supposed to be more complicated than today (conflict solver, route planning, etc.)
	Feedback provision	A=0 B=0 C=1 D=1	An increase in feedback provision in the more autonomous applications of the delegation concept is forecasted
	Kind of assistance provided	A=1 B=1 C=1 D=1	A semi-automated mode is the more probable given the ongoing debate for fully automated separation and human centred system.
	Data insertion ease	A=-1 B=-1 C=-1 D=-1	Although there are new graphical and intuitive interfaces, the use of Data-link will probably create some difficulties
	Data achieving easiness	A=-1 B=-1 C=-1 D=-1	The pilot is now present with a plenty data sources which can create some problems in assimilating.
	New features	A=0 B=-1 C=-1 D=-1	Depending on the application, some new features are expected to change the interaction man-machine relationship (object manipulation and graphical editing)

Table 9.13 Determinants Valuation and Justification - Usability & HMI

COVERAGE OF ASSISTED TASKS – USABILITY & HMI			
TASK(S)	**DETERMINANTS**	**VALUATION**	**CRITERIA**
Tools Usability and Human Machine Interface	Complexity of technology	1	Confidence in the system
	Feedback provision	2	Mental workload, error risk Air/ground interaction Air/air interaction Pilot/system interaction
	Kind of assistance provided	2	Mental workload
	Data insertion easiness	2	Mental workload
	Data achieving easiness	2	Mental workload
	New features	2	Knowledge evolution, perception

Table 9.14 Criteria Inter-relationship & Valuation - Usability & HMI

COVERAGE OF ASSISTED TASKS – NEW FEATURES			
TASK(S)	**DETERMINANTS**	**APPLICATION VALUATION**	**JUSTIFICATION**
New Features In Technical System Functioning & Aeronautic Information	Aviation	A=0 B=0 C=0 D=0	No change
	Navigation	A=-1 B=-1 C=-1 D=-2	New features in many of these areas will be implemented on every level. I Application D will notice an increase (conflict detection, route planning, etc.)
	Communication	A=-2 B=-2 C=-2 D=-2	Data-link and ADS-B are new features common to all the cases
	Manage systems	A=0 B=0 C=0 D=0	No change
	New features in airspace management information	A=0 B=-1 C=-1 D=-2	Application A - no change in the role of the pilot; applications B & C - new procedures and rules to learn for their new tasks and in application D - all separation tasks represent a real revolution for pilots
	Continuity of existing information	A=0 B=0 C=0 D=0	No concerns are forecasted

Table.9.15 Determinants Valuation and Justification - New Features

COVERAGE OF ASSISTED TASKS – NEW FEATURES			
TASK(S)	**DETERMINANTS**	**VALUATION**	**CRITERIA**
New Features In Technical System Functioning & Aeronautic Information	Aviation	0	Knowledge evolution, perception
	Navigation	0	Knowledge evolution, perception
	Communication	0	Knowledge evolution, perception
	Manage systems	0	Knowledge evolution, perception
	New features in airspace management information	0	Knowledge evolution, perception
	Continuity of existing information	0	Knowledge evolution, perception

Table.9.16 Criteria Inter-relationship & Valuation - New Features

COVERAGE OF ASSISTED TASKS – AUTONONMY			
TASK(S)	DETERMINANTS	APPLICATION VALUATION	JUSTIFICATION
Autonomy	Dependence on ground	A=0 B=0 C=1 D=2	Application A - no new task and no change in dependence level, B - same dependence from controller decision ; C - less dependence for conflict resolution; D - total decisional control
	Dependence on computer	A=0 B=-1 C=-2 D=-2	Application A - no new task and no change; B - the system relies on CDTI, and ADS-B for important information about traffic; applications C & D - without the computer aid these concepts are not applicable.
	Dependence on procedures & rules	A=0 B=0 C=0 D=1	Less restrictive rules will be introduced in ATM which will afford more freedom. This will support application D
	Dependence on other crew member	A=0 B=0 C=0 D=-1	For autonomous aircraft, considering the number of new tasks, a slight increase in co-operation with the other members of the crew would be necessary
	Dependence on other aircraft crew	A=0 B=1 C=-1 D=-1	Application A - no new tasks and no change in dependence level; B - the most important information are automatically transmitted via ADS-B; applications C & D - to solve conflicts a co-operative strategy will be required

Table.9.17 Determinants Valuation and Justification – Autonomy

COVERAGE OF ASSISTED TASKS – AUTONONMY			
TASK(S)	DETERMINANTS	VALUATION	CRITERIA
Autonomy	Dependence on ground	2	Error recovery strategies
	Dependence on computer	2	Error recovery strategies
	Dependence on procedures & rules	2	Error recovery strategies
	Dependence on other crew member	2	Error recovery strategies
	Dependence on other aircraft crew	2	Error recovery strategies

Table.9.18 Criteria Inter-relationship & Valuation – Autonomy

Appendix 4

Role Modification Expansion

A4.1 Role Modification - Determinants and Criteria Interrelationships Valuations

The following tables detail the elements; aviation, navigation, communication & system management, back-up procedures, tool complexity, usability & HMI, new features and autonomy, as they relate to the category role modification.

Tables 10.1 – 10.20 detail the Determinants valuation and justification, with corresponding detail pertaining to the Determinants / Criteria interrelationship and valuations.

ROLE MODIFICATION – AVIATION			
TASK(S)	DETERMINANTS	APPLICATION VALUATION	JUSTIFICATION
Aviation	Control & monitor flight of the aircraft	A=0 B=0 C=0 D=0	No change
	Maintain clearances, restriction, separation with traffic & terrain	A=0 B=-1 C=-2 D=-2	Application A - no change in pilot's role; B - a small change as a consequence of the implementation and monitoring tasks; applications C & D - great change in order to fulfil conflict resolution and detection, particularly in application D.

Table 10.1 Determinants Valuation and Justification – Aviation Tasks

ROLE MODIFICATION – AVIATION			
TASK(S)	DETERMINANTS	VALUATION	CRITERIA
Aviation	Control & monitor flight of the aircraft	2	Job motivation, mental workload
	Maintain clearances, restriction, separation with traffic & terrain	2	Job motivation, mental workload

Table 10.2 Criteria Inter-relationship & Valuation – Aviation Tasks

ROLE MODIFICATION – NAVIGATION			
TASK(S)	DETERMINANTS	APPLICATION VALUATION	JUSTIFICATION
Navigation	Situation understanding	A=0 B=-1 C=-1 D=-2	Application A - monitoring is not mandatory; more monitoring is required for B & C and becomes more important for application D as the pilot is also charged with detection task
	Navigation problems detection	A=0 B=0 C=0 D=-1	No special execution tasks are required for A, B & C; in D concept navigation is one of the most important goal to accomplish and will require additional effort on the part of the pilot even if supported by automatic tool
	Navigation problems resolution	A=0 B=0 C=-2 D=-2	Application A - no change; B - the solution is indicated by ATC hence no changes; C & D - solution is delegated to aircraft crew
	Route program & optimisation (time, fuel, costs)	A=0 B=0 C=0 D=-1	Route programming is executed before take-off; in application D this task is not supposed to require many actions especially in long flight especially if automation support is provided

Table 10.3 Determinants Valuation and Justification - Navigation Tasks

ROLE MODIFICATION – NAVIGATION			
TASK(S)	DETERMINANTS	APPLICATION VALUATION	JUSTIFICATION
Navigation	Situation understanding	2	Job motivation, mental workload
	Navigation problems detection	2	Job motivation, mental workload
	Navigation problems resolution	2	Job motivation, mental workload
	Route program & optimisation (time, fuel, costs)	2	Job motivation, mental workload

Table 10.4 Criteria Inter-relationship & Valuation - Navigation Tasks

ROLE MODIFICATION – COMM & SYSTEM MANAGEMENT			
TASK(S)	**DETERMINANTS**	**DELEGATION VALUATION**	**JUSTIFICATION**
Communication	Communication with the ground: Air Traffic Control, company, etc.	A=1 B=1 C=1 D=1	Decrease in communication is expected as a result of ADS-B and Data-link
	Communication with other aircraft flight crew	A=1 B=1 C=1 D=1	Decrease in communication is expected as a result of ADS-B and Data-link
	Uplink & downlink data and information	A=-1 B=-1 C=-1 D=-1	Read and compose message – advanced form s of communication
Systems Management	Manage & correct system faults	A=0 B=0 C=0 D=0	No change
	Monitor aircraft subsystem	A=0 B=0 C=0 D=0	No change
	Communication & co-ordination management with the crew	A=0 B=0 C=0 D=0	No suitable change when compared with today situation

Table 10.5 Determinants Valuation and Justification – Comm. & Systems Management

ROLE MODIFICATION – COMM & SYSTEM MANAGEMENT			
TASK(S)	DETERMINANTS	VALUATION	CRITERIA
Communication	Communication with the ground: Air Traffic Control, company, etc.	2	Job motivation, mental workload Air/ground interaction
	Communication with other aircraft flight crew	2	Job motivation, mental workload Air/ground interaction
	Uplink & downlink data and information	2	Job motivation, mental workload Air/ground interaction
Systems Management	Manage & correct system faults	2	Job motivation, mental workload Air/ground interaction
	Monitor aircraft subsystem	2	Job motivation, mental workload Air/ground interaction
	Communication & co-ordination management with the crew	2	Job motivation, mental workload Air/ground interaction

Table 10.6 Criteria Inter-relationship & Valuation – Comm. & Systems Management

ROLE MODIFICATION (DECISION TASKS) – AVIATION			
TASK(S)	DETERMINANTS	APPLICATION VALUATION	JUSTIFICATION
Aviation	Control & monitor flight of the aircraft	A=-1 B=-1 C=-1 D=-1	This process requires greater attention and monitoring of flight. Parameters are provided to assist in providing reliable transmission of intent data and accurate trajectory prediction
	Maintain clearances, restriction, separation with traffic & terrain	A=0 B=0 C=0 D=0	Application A - no change; B - pilot has only to implement instructions of ATC in order to solve a conflict; C & D - the execution of programmed plan does not require any change from today's situation

Table 10.7 Determinants Valuation and Justification: – Aviation (Decision)

ROLE MODIFICATION (DECISION TASKS) – AVIATION			
TASK(S)	DETERMINANTS	VALUATION	CRITERIA
Aviation	Control & monitor flight of the aircraft	2	Job motivation, Mental workload
	Maintain clearances, restriction, separation with traffic & terrain	2	Job motivation, Mental workload

Table 10.8 Criteria Inter-relationship & Valuation – Aviation (Decision)

ROLE MODIFICATION (DECISION TASKS) – NAVIGATION			
TASK(S)	DETERMINANTS	APPLICATION VALUATION	JUSTIFICATION
Navigation	**Situation understanding**	A=0 B=0 C=0 D=-1	SA is paramount for application D for a better general management of the mission
	Navigation problems detection	A=0 B=0 C=0 D=-1	Application D will see an increase in the number of decision task
	Navigation problems resolution	A=0 B=0 C=-1 D=-1	The supposed increase in the number of decision tasks are small as a result of automation support (expected available and reliable!)
	Route program & optimisation (time, fuel, costs)	A=-1 B=-1 C=-1 D=-2	A, B & C - the choice of the route is made before take-off and eventual changes during flight. This information is submitted to ATC and subject to revision before implementation; D - on-board planning and total independence which requires greater effort

Table 10.9 Criteria Inter-relationship & Valuation – Aviation (Decision)

ROLE MODIFICATION (DECISION TASKS) – NAVIGATION			
TASK(S)	DETERMINANTS	VALUATION	CRITERIA
Navigation	Situation understanding	2	Job motivation, Mental workload
	Navigation problems detection	2	Job motivation, Mental workload
	Navigation problems resolution	2	Job motivation, Mental workload
	Route program & optimisation (time, fuel, costs)	2	Job motivation, Mental workload

Table 10.10 Criteria Inter-relationship & Valuation – Navigation (Decision)

ROLE MODIFICATION (DECISION TASKS) – COMM. & SYSTEMS MANAGEMENT			
TASK(S)	**DETERMINANTS**	**APPLICATION VALUATION**	**JUSTIFICATION**
Communication	Communication with the ground: ATC, company, etc.	A=0 B=0 C=-1 D=-1	Applications A & B - no change expected; C & D - a slight increase in communication use is forecasted as this will be required to assist in solving complicate navigation problems
	Communication with other aircraft flight crew	A=0 B=0 C=-1 D=-1	Applications A & B - : no change expected; C & D – might need to implement this process
	Uplink & downlink of data and information	A=-1 B=-1 C=-1 D=-1	Greater effort will be necessary since Data-link is expected to be widely used
System Management	**Manage & correct system faults**	A=0 B=0 C=0 D=0	No change
	Monitor aircraft subsystem	A=0 B=0 C=0 D=0	No change
	Communication & co-ordination management with the crew	A=0 B=0 C=0 D=-1	A slight increase in co-ordination decision tasks is expected to face the many new tasks

Table 10.11 Determinants Valuation and Justification: – Comm. & Systems Management

ROLE MODIFICATION (DECISION TASKS) – COMM. & SYSTEMS MANAGEMENT			
Task(s)	**Determinants**	**Valuation**	**Criteria**
Communication	Communication with the ground: ATC, company, etc.	2	Job motivation, mental workload
	Communication with other aircraft flight crew	2	Job motivation, mental workload
	Uplink & downlink of data and information	2	Job motivation, mental workload
System Management	Manage & correct system faults	2	Job motivation, mental workload
	Monitor aircraft subsystem	2	Job motivation, mental workload
	Communication & co-ordination management with the crew	2	Job motivation, mental workload pilot/crew interaction

Table 10.12 Criteria Inter-relationship & Valuation – Comm. & Systems Management

ROLE MODIFICATION (DECISION TASKS) – PROCEDURE MODIFICATION			
TASK(S)	**DETERMINANTS**	**APPLICATION VALUATION**	**JUSTIFICATION**
Aviation procedure modification	Number of actions	A=0 B=0 C=0 D=0	No change – the same efforts in use today to implement the manoeuvres will be used
	Time constraints	A=0 B=0 C=0 D=0	No change
Navigate procedure modification	**Number of actions**	A=0 B=0 C=-1 D=-2	Applications A & B - no change; C - slight increase due to the conflict solution process; D - the same as C but with real time routing now an additional consideration
	Time constraints	A=0 B=0 C=-1 D=-1	Only in C & D concepts a slight increase in the time constraint is expected caused by possible negotiation and decisional process

Table 10.13 Determinants Valuation and Justification: – Aviation & Navigation Procedure Modification (Decision Tasks)

ROLE MODIFICATION (DECISION TASKS) – PROCEDURE MODIFICATION			
TASK(S)	DETERMINANTS	VALUATION	CRITERIA
Aviation procedure modification	Number of actions	2	Mental workload, error risk
	Time constraints	2	Stress, mental workload, planning
Navigate procedure modification	Number of actions	2	Mental workload, error risk
	Time constraints	2	Mental workload, error risk

Table 10.14 Criteria Inter-relationship & Valuation – Aviation & Navigation Procedure Modification (Decision Tasks)

ROLE MODIFICATION (DECISION TASKS) – PROCEDURE MODIFICATION			
TASK(S)	DETERMINANTS	APPLICATION VALUATION	JUSTIFICATION
Communicate procedure modification	Number of actions	A=-1 B=-1 C=-1 D=-1	More means of communication and the exact composition of messages using Data-link
	Time constraints	A=0 B=0 C=0 D=0	No change
Manage system procedure modification	Number of actions	A=0 B=0 C=0 D=0	No change
	Time constraints	A=0 B=0 C=0 D=0	No change

Table 10.15 Determinants Valuation and Justification: – Communication & Management System Procedure Modification (Decision Tasks)

ROLE MODIFICATION (DECISION TASKS) – PROCEDURE MODIFICATION			
TASK(S)	DETERMINANTS	VALUATION	CRITERIA
Communicate procedure	Number of actions	2	Mental workload, error risk
	Time constraints	2	Mental workload, error risk
Manage system procedure modification	Number of actions	2	Mental workload, error risk
	Time constraints	2	Mental workload, error risk

Table 10.16 Criteria Inter-relationship & Valuation – Communication & Management System Procedure Modification (Decision Tasks)

ROLE MODIFICATION (DECISION TASKS) – SENSORY CHANNEL			
TASK(S)	**DETERMINANTS**	**APPLICATION VALUATION**	**JUSTIFICATION**
Sensory-motor channel	Visual channel	A=-2 B=-2 C=-2 D=-2	New information will be acquired through this sense
	Auditory channel	A=1 B=1 C=1 D=1	A slight decrease in radio communication time is forecasted as a result of new devices that use other channels
	Tactile channel	A=0 B=0 C=0 D=0	No change
	Voice use	A=1 B=1 C=1 D=1	A slight decrease in radio communication time is forecasted as a result of new devices that use other channels
	Writing use	A=-1 B=-1 C=-1 D=-1	Data-link will cause an increase in the use of this ability

Table 10.17 Determinants Valuation and Justification: – Sensory Channel

ROLE MODIFICATION (DECISION TASKS) – SENSORY CHANNEL			
TASK(S)	DETERMINANTS	VALUATION	CRITERIA
Sensory-motor channel	Visual channel	2	Physiological workload Air/ground interaction Air/air interaction Pilot/crew interaction Pilot/system interaction
	Auditory channel	2	Physiological workload Air/ground interaction Air/air interaction Pilot/crew interaction Pilot/system interaction
	Tactile channel	2	Physiological workload Pilot/system interaction
	Voice	2	Physiological workload Air/ground interaction Air/air interaction Pilot/crew interaction Pilot/system interaction
	Writing	2	Physiological workload Air/ground interaction Air/air interaction Pilot/crew interaction Pilot/system interaction

Table 10.18 Criteria Inter-relationship & Valuation – Sensory Channel

A4.2 Executed Tasks

ROLE MODIFICATION (DECISION TASKS) – INFORMATION AVAILABILITY			
TASK(S)	**DETERMINANTS**	**APPLICATION VALUATION**	**JUSTIFICATION**
Information Availability	From ground	A=1 B=1 C=1 D=1	Easier availability as a result of TIS-B
	From other aircraft	A=0 B=1 C=-1 D=-1	Application A - no change B – no communication will be required for implementation of tasks C & D - conflict solution may require communication between aircraft
	From computer	A=1 B=1 C=2 D=2	Embedded systems will supply information pertaining to weather and traffic situation as a result of ADS-B and automatic conflict detection and solver (when available)
	From crew member	A=0 B=0 C=0 D=0	No change
	From rules, regulations & procedures	A=0 B=0 C=0 D=-1	A, B & C - no change D - fewer restrictions.

Table 10.19 Determinants Valuation and Justification: – Information Availability

ROLE MODIFICATION (DECISION TASKS) – INFORMATION AVAILABILITY			
TASK(S)	**DETERMINANTS**	**VALUATION**	**CRITERIA**
Information Availability	From ground	2	Error risk Error recovering strategies Perception, memory, plan Air/ground interaction
	From other aircraft	2	Error risk Error recovering strategies Perception, memory, plan Air/air interaction
	From computer	2	Error risk Error recovering strategies Perception, memory, plan Pilot/system interaction
	From crew member	2	Error risk Error recovering strategies Perception, memory, plan Pilot/crew interaction
	From rules, regulations & procedures	2	Error risk Error recovering strategies Perception, memory, plan

Table 10.20 Criteria Inter-relationship & Valuation – Sensory Channel

Appendix 5

Interdependencies Relationships

A5.1 Criteria and Dependency Interdependencies Relationship

Tables 11.1 and 11.2 detail the interdependencies between the criteria which are typed and weighted:

- "↗" means a linear positive dependency,
- "∩" means a parabolic dependency, i.e. increasing then decreasing,
- the number of "+" indicates the strength of the influence.

Tables 11.3 and 11.4 detail relationship between *Determinants* and *Criteria*.

On: Influence of:	Job motivation°	Stress	System Confidence	Physiological Workload	Mental Workload	Error risk	Error Recovery.	Interact° air / ground
Job motivation		↗ +				∩ +		
Stress	∩ ++				↗ +++	↗ +++	↗ +	↗ +
Confidence in system	↗ +	↗ ++						↗ +
Physiological Workload		↗ +				↗ +		
Mental Workload		↗ +	↗ +			↗ +++	↗ +	↗ ++
Error risk (intention / slip)		↗ +		↗ +	↗ +			
Error recovering means (technical support or human)		↗ +	↗ ++		↗ +			
Interaction air / ground			↗ +		↗ +	↗ +		
Interaction air / air			↗ +		↗ +	↗ +		
Interaction pilot / crew			↗ +		↗ +	↗ +		
Interaction pilot / system			↗ +		↗ +	↗ +	↗ +	
Knowledge evolution					↗ ++	↗ +	↗ +	
C. Process: perception			↗ +	↗ +				
C. Process: memory					↗ +++	↗ +	↗ ++	
C. Process: DM & plan.		↗ ++	↗ +		↗ +++	↗ +		
C. Process: checking		↗ ++	↗ ++		↗ +++	↗ ++	↗ ++	

Table 11.1 Criteria Interdependencies Relationship

On: Influence of:	Interaction Air / air	Interaction Pilot / crew	Interaction Pilot / system	Knowledge Evolution	C. Proc. Percept.	C. Proc. Memory	C. Proc. DM & P	C. Proc. Checking
Job motivation								
Stress	↗ +	↗ +						↗ ++
Confidence in system	↗ +	↗ +						
Physiological Workload								
Mental Workload	↗ ++	↗ ++				↗ +++		↗ ++
Error risk (intention / slip)								
Error recovering means (technical support or human)								
Interaction air / ground								
Interaction air / air								
Interaction pilot / crew								
Interaction pilot / system					↗ +	↗ +		
Knowledge evolution					↗ +	↗ ++		↗ ++
C. Process: perception				↗ ++				
C. Process: memory							↗ +	↗ ++
C. Process: DM & plan.		↗ +						↗ ++
C. Process: checking		↗ +				↗ ++		

Table 11.2 Criteria Interdependencies Relationship

RELIABILITY	RELATED DETERMINANTS (CONCEPT & ACTIVITY	RELATION
Error Risk	Tools functioning complexity: amount of information	↗
	Tools functioning complexity: asyncronism for	↗
	Tools usability & HMI : feedback provision	↗
	Tools usability & HMI : kind of assistance provided	↗
	Tools usability & HMI : data insertion easiness	↗
	Tools usability & HMI : data achieving easiness	↗
	Aviation task procedure modification: (all domains)	↗
	Navigate task procedure modification: (all domains)	↗
	Communicate task procedure modification: (all domains)	↗
	Manage system task procedure modification: (all domains)	↗
	Task procedure modification: availability of information	↗
Error Recovering Strategies	Task Procedure modification: availability of information	↗
	Existence of back-up procedures (all domains)	↗
	Redundancy of human competencies and action means	↗
	Autonomy (all domains)	↗

Table 11.3 Determinant and Reliability Factors Relationship

Psycho-Physiological	Related Determinants (Concept & Activity)	Relation
Job Motivation	Technical system "appeal"	↗
	Concept "communicability"	↗
	Responsibility & delegation	↗
	Role modification: number of execution	∩
	Role modification: number of decision	∩
Stress	Traffic: number of aircraft (density)	↗
	Traffic flow (complexity)	↗
	Zone of operations	↗
	Disturbance	↗
	Aviation task procedure modification: time	↗
	Navigate task procedure modification: time	↗
	Communicate task procedure modification:	↗
	Manage system task procedure	↗
System Confidence	Coverage of assisted tasks	↗
	Technology maturity	↗
	Complexity of technology	↗
Physiological Workload	Task procedure modification	↗

Table 11.4 Determinant and Psycho-physiological Factors Relationship

Cognitive Factors	Related Determinants (Concept & Activity)	Relation
Knowledge Evolution	**Tools usability & HMI: new features**	↗
	New features in technical system functioning information &	↗
	New features in airspace management information	↗
	Continuity of existing information	↗
Cognitive Processes: Information Gathering Solicitation & Support	**Tools usability & HMI: new features**	↗
	New features in technical system functioning information &	↗
	New features in airspace management information	↗
	Task procedure modification: availability of information (all	↗
Cognitive Processes: Working Memory Solicitation & Support Cognitive Processes: Planning & Decision Making	**Task procedure modification: availability of information (all**	↗
	Coverage of assisted tasks: aviation tasks	↗
	Coverage of assisted tasks: navigate tasks	↗
	Coverage of assisted tasks: manage system tasks (<u>except</u> communication & coordination management with the crew)	↗
	Autonomy (all domains)	↗
	Aviation task procedure modification: time constraints	↗
	Navigate task procedure modification: time constraints	↗
	Communicate task procedure modification: time constraints	↗
	Manage system task procedure modification: time constraints	↗
	Task procedure modification: availability of information (all	↗
Cognitive Processes: Checking	**Coverage of assisted tasks: aviation tasks**	↗
	Coverage of assisted tasks: navigate tasks	↗
	Coverage of assisted tasks: manage system tasks (<u>except</u> communication & coordination management with the crew)	↗

Table 11.5 Determinant and Cognitive Criteria Factors Relationship

Communication Factors	Related Determinants (Concept & Activity)	Relation
Air / Ground Interaction	Coverage of assisted tasks: Communication with the ground	↗
	Uplink & downlink data and information	↗
	Tools usability & HMI: Feedback provision	↗
	Tools usability & HMI: Kind of assistance provided	↗
	Tools usability & HMI: Data insertion easiness	↗
	Tools usability & HMI: Data achieving easiness	↗
	Role modification: number of execution tasks (communication	↗
	Role modification: number of execution tasks (uplink &	↗
	Role modification: number of decision tasks (communication	↗
	Role modification: number of decision tasks (uplink & downlink	↗
	Task procedure modification: sensory-motor channel use (all	↗
	Task procedure modification: availability of information (from	↗
Air / Air Interaction	Coverage of assisted tasks: Communication with other aircraft	↗
	Uplink & downlink data and information	↗
	Tools usability & HMI: Feedback provision	↗
	Tools usability & HMI: Kind of assistance provided	↗
	Tools usability & HMI: Data insertion easiness	↗
	Tools usability & HMI: Data achieving easiness	↗
	Role modification: number of execution tasks (communication with other aircraft)	↗
	Role modification: number of execution tasks (uplink & downlink data)	↗
	Role modification: number of decision tasks (communication	↗
	Role modification: number of decision tasks (uplink & downlink data)	↗
	Task procedure modification: sensory-motor channel use (all domains except tactile channel)	↗
	Task procedure modification: availability of information (from	↗
Pilot / Crew Interaction	Coverage of assisted tasks: Communication & communication management with the crew	↗
	Role modification: number of execution tasks (Communication & communication management with the crew)	↗
	Role modification: number of decision tasks (Communication & communication management with the crew)	↗
	Task procedure modification: sensory-motor channel use (all domains except tactile channel and writing use)	↗
	Task procedure modification: availability of information (from	↗
Pilot / System Interaction	Tools usability & HMI: Feedback provision	↗
	Tools usability & HMI: kind of assistance provided	↗
	Tools usability & HMI: data insertion easiness	↗
	Tools usability & HMI: data achieving easiness	↗
	Task procedure modification: sensory-motor channel use (all	↗
	Task procedure modification: availability of information (from	↗

Table 11.6 Determinant and Communication Factors Relationship

Appendix 6

Coefficient Regression Values

Tables 12.1 to 12.5 detail the values of the coefficient α_1 of the regression as computed from the simulations.

N°		Determinants	α_i
		Constant	62,53
1		Traffic: number of aircraft (density)	-0,72
2		Traffic flow (complexity)	-0,78
3		Technical system «appeal»	0,01
4		Concept «communicability» (explicit added-value of the concept)	0,03
5		Zone of operations	-0,64
6		Responsibility & delegation	-0,14
7	Aviation Tasks	Control & monitor flight of the aircraft	-1,02
8		Maintain clearances, restriction, separation with traffic & terrain	-1,01
9		Situation understanding	-1,02

Table 12.1 Coefficient Regression values - Aviation / Navigation Tasks

N°		Determinants	α_i
10	Navigation Tasks	Navigation problems detection	-1,01
11		Navigation problems resolution	-1,06
12		Route program & optimisation (time, fuel, costs)	-0,25
N°		Determinants	α_i
13	Communication Tasks	Communication with the ground Air Traffic Control, company, etc.	-0,18
14		Communication with other aircraft flight crew	-0,23
15		Uplink & downlink data and information	-0,27
16	System Management Tasks	Manage & correct system faults	-0,95
17		Monitor aircraft subsystem	-1,02
18		Communication & co-ordination management with the crew	-0,28
19	Existence of Back-up Procedures	autonomous (Manual / on board)	-0,15
20		provided by the ground (Air Traffic Control , dispatchers, company, etc.)	-0,09
21		Automatic	-0,11
22		Redundancy of human competencies and action means	-0,11
23		Disturbance	-0,82
24	Pilot Tools Functioning Complexity	Technology maturity (reliability & consistency)	-0,07
25		amount of information	-0,19
26		Asyncronism for communication & time of response	-0,22
27	Pilot Tools Usability And HMI Interface	Complexity of technology	-0,14
28		Feedback provision	-0,55
29		Kind of assistance provided	-0,55
30		Data insertion easiness	-0,58
31		Data achieving easiness	-0,52
32		New features	-0,42

Table 12.2 Coefficient Regression Values

N°		Determinants	α_i
33	New Features In Technical System Function Information	Aviation	-0,46
34		Navigation	-0,49
35		Communication	-0,37
36		Manage systems	-0,47
37		New features in airspace management information	-0,49
38		Continuity of existing information	-0,40
39	Autonomy	dependence from ground	-0,28
40		dependence from computer	-0,31
41		dependence from procedures & rules	-0,31
42		dependence from other crew member	-0,29
43		dependence from other aircraft crew	-0,31
44	Aviation Tasks	Control & monitor flight of the aircraft	-0,10
45		Maintain clearances, restriction, separation with traffic & terrain	-0,10
46		Situation understanding	-0,13
47	Navigate Tasks	Navigation problems detection	-0,13
48		Navigation problems resolution	-0,12
49		Route program & optimisation (time, fuel, costs)	-0,07
50	Communicate Tasks	Communication with the ground	-0,22
51		Communication with other aircraft flight crew	-0,23
52		Uplink & downlink data and information	-0,29
53	Manage System Tasks	Manage & correct system faults	-0,06
54		Monitor aircraft subsystem	-0,11
55		Communication & co-ordination management with the crew	-0,34

Table 12.3 Coefficient Regression Values

N°		Determinants	α_i
56	Aviation Tasks	Control & monitor flight of the aircraft	-0,13
57		Maintain clearances , restriction, separation with traffic & terrain	-0,08
58		Situation understanding	-0,11
59	Navigate Tasks	Navigation problems detection	-0,14
60		Navigation problems resolution	-0,17
61		Route program & optimisation (time, fuel, costs)	-0,07
62	Communicate Tasks	Communication with the ground: Air Traffic Control, company, etc.	-0,25
63		Communication with other aircraft flight crew	-0,28
64		Uplink & downlink data and information	-0,31
65	Manage System Tasks	Manage & correct system faults	-0,07
66		Monitor aircraft subsystem	-0,13
67		Communication & co-ordination management with the crew	-0,13
68	Aviation Task Procedure Modification	number of actions	-0,21
69		time constraints	-0,94

Table 12.4 Coefficient Regression Values

N°		Determinants	α_i
70	**Navigate Task Procedure Modification**	**number of actions**	**-0,19**
71		**time constraints**	**-0,96**
72	**Communicate Task Procedure Modification**	number of actions	-0,18
73		time constraints	-0,96
74	**Manage System Task Procedure**	**number of actions**	**-0,16**
75		**time constraints**	**-0,92**
76	**Task Procedure Modification: Sensory-Motor Channel Use**	Visual channel	-0,71
77		Auditory channel	-0,74
78		Tactile channel	-0,35
79		Voice use	-0,78
80		Writing use	-0,54
81	**Task Procedure Modification: Availability Of Information**	**from ground**	**-1,22**
82		**from other aircraft**	**-1,19**
83		**from computer**	**-1,27**
84		**from crew member**	**-1,33**
85		**from rules & procedures**	**-1,16**

Table 12.5 Coefficient Regression Values

Appendix 7

A7.1 Coverage of Assisted Tasks - Determinants Valuations and Interrelationships – Air Traffic Controllers

The following tables detail the elements; traffic load, traffic flow, technical system appeal, explicit added-value of concept and technology maturity as they relate to the traffic controllers

Tables 13.1 and 13.2 detail the Determinants valuation and justification, whereas, corresponding Table 13.3 details the Determinants / Criteria interrelationship and valuations.

DETERMINANTS	DELEGATION LEVELS VALUATION	JUSTIFICATION
Traffic Load	A=-1 B=-1 C=-2 D=-2	Forecasted traffic increased for the period of implementation: A & B=+25%; C & D=+50%
Traffic flow	A=0 B=0 C=-1 D=-1	Except for applications A & B aircraft equipment will be designed to accommodate a more complex flow of the traffic.

Table 13.1 Determinants Valuation and Justification – Air Traffic Controller

DETERMINANTS	DELEGATION LEVELS VALUATION	JUSTIFICATION
Technical System Appeal	A=2 B=2 C=2 D=2	Change in the ground system to facilitate control of autonomous operation..
Explicit Added-value of Concept	A=1 B=1 C=1 D=-1	Concept well received by controllers. s.
Technology Maturity	A=-1 B=-1 C=-2 D=-2	Advance technological improvements by 2009 for A & B and similar improvements by 2015 for C & D.

Table 13.2 Determinants Valuation and Justification – Air Traffic Controllers

DETERMINANTS	VALUATION	CRITERIA
Traffic load	-2	Stress & mental workload
Traffic Complexity	-1	Stress & mental workload (eliminated the dependence on the other crew members)
Technical System Appeal	-1	Job motivation
Explicit Added-value of the Concept	1	Job motivation
Technology Maturity	1	New: stress & mental workload

Table 13.3 Determinants & Criteria Inter-relationship and Valuation – Air Traffic Controllers

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