Evolution of Air Navigation Services during this Decade

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Current crises in the air traffic industry demonstrate that changes are required to present systems. The levels of delay and poor safety standards being experienced around the world dictate the need for improved Air Navigation Services (ANS). A multitude of reasons explain these problems. For instance, fragmentation of national systems prevents optimum use of the world's airspace. In addition, inherent limitations of present ANS technologies and procedures mean that it is usually not possible to separate numerous aircraft on random routings. Thus, aircraft must often plan their flights along routes and be channelled so that the necessary separation can be maintained. This results in fuel and time penalties, in addition to airspace capacity being consequently constrained. Accordingly, this paper provides an analysis of changes that should occur to ANS during this decade by evaluating current and planned technologies and procedures.

KEY WORDS

1. Air. 2. Communications. 3. Navigation. 4. Surveillance. 5. Air Traffic Management.

1. INTRODUCTION. Air traffic congestion problems in many areas of the world are well known and have been highly publicised in recent years. This airspace dilemma, which results in delays and other undesirable knock-on effects, is escalating at a phenomenal rate and requires immediate attention. Correspondingly, there is concern about safety standards in some worldwide airspace regions. It should be noted that congestion and poor safety levels affect all involved with aviation and, indeed, society in general. It is evident, therefore, that present methods are inefficient and unable to guarantee punctual or safe services now or in the future. It is imperative that the significant projected growth in air transport movements during this decade is accommodated. Thus, there is an urgent need to solve the current airspace problems and plan to meet forecast demand in a responsible manner.

Solutions to these predicaments have been developed and are encompassed under the auspices of the terms, 'future air navigation systems' or 'CNS/ATM systems'. Future air navigation systems use Communications, Navigation & Surveillance (CNS) technologies to provide enhanced Air Traffic Management (ATM) through continuous information on aircraft positions and intentions so that reductions in separation are possible without compromising safety. The systems include technologies and procedures that merge to optimise the potential of airport and airspace resources so that the capacity, flexibility and safety of these resources are maximised, while delays and their operating costs are minimised.

However, there has been a significant lack of progress to date in implementing the new technologies and procedures. Indeed, the assured integration of many systems is currently uncertain and far from guaranteed. Therefore, this paper discusses the evolution of Air Navigation Services (ANS) during this decade. Noting that the present systems will still fulfil many ANS roles in 2010, this paper considers both current and future CNS/ATM, split into the Communications, Navigation & Surveillance (CNS) technologies and Air Traffic Management (ATM) procedures.

2. PRESENT CNS/ATM TECHNOLOGIES AND PROCEDURES.

Although current ANS is based on CNS technologies and ATM procedures that were developed many years ago, their applications have been continually modified to suit the different types of airspace that exist around the world in an attempt to satisfy the various capacity requirements and specific operating environments. However, the levels of delay now being experienced in many airspace sectors, and the lack of adequate safety standards in other regions, have necessitated further development of these systems. Thus, the present systems form the basis of many planned technologies and procedures. Indeed, improvements in the efficiency, flexibility and safety of the overall ANS will only occur if present systems evolve into more responsive elements. Accordingly, it should be noted that, as most new CNS/ATM systems will be phased in using an evolutionary approach, present technologies will continue to be employed in many situations at the end of this decade. In addition, a description of present CNS and ATM serves to identify the functional shortcomings of present systems and highlight the potential benefits of implementing new technologies. Therefore, apart from facilitating a contrasting analysis of ANS evolution, there is a need to describe present CNS/ATM methods.

2.1 *Current Communications Technology*. Given that the main objective of an aeronautical communication service is to ensure that telecommunications and radio aids necessary for the safety, regularity and efficiency of air navigation are continuously available and reliable, two categories of Air Traffic Control (ATC) communication are presently conducted.

2.1.1. *Air-ground*. Very High Frequency (VHF) transceivers are used to provide voice contact between ATC and pilots when within line-of-sight coverage, which is invariably near or over land in dense traffic areas. Due to the nature of VHF signal propagation along the curvature of the Earth, it can be received and transmitted over greater distances from higher altitudes. However, the availability of VHF spectrum channels in the long-term is a concern. Europe recently implemented a narrowing of bandwidth to 8·33 KHz, which will soon be necessary in other parts of the world. High Frequency (HF) is used over areas exceeding VHF's range, such as in oceanic or remote continental areas. The fact that HF requires its waves to be reflected from the ionospheric layers above the earth is often a drawback because destructive interference can occur, where the transmitted signals arrive at the receiver at different times because they were reflected at different ionospheric levels and consequently sent via different routes. Additionally, there is limited availability of frequencies that work reasonably on a given day. The need for pilots constantly to monitor their assigned HF frequency is removed if SELect CALling (SELCAL) is fitted on the aircraft. Since the early 1990s, a development of VHF technology, VHF DataLink (VDL), has enabled electronic messages such as ATC clearances to be sent from the ground to the cockpit, where they arrive in digital format. HF DataLink (HFDL) is also being used, albeit in fewer locations. Datalink applications are similar to Aircraft Communications, Addressing and Reporting Systems (ACARS), which are operated by four ground network providers, namely Air Canada in Canada, AVICOM in Japan, in addition to ARINC and SITA on a worldwide scale. Correspondingly, it should be noted that Inmarsat is an international organisation that provides satellite communications for the aviation, maritime and land shipping industries. ARINC and SITA use Inmarsat for the satellite portion of their services.

2.1.2. *Ground-ground.* Adjacent Air Traffic Service (ATS) units are linked by dedicated telephone lines and telex systems between controllers and control centres. Many airlines are linked with the ATS units via the Aeronautical Fixed Telecommunications Network (AFTN).

2.2. *Current Navigation Technology*. Navigation presently uses different aids in the following two categories of airspace types.

2.2.1. *Near or Over Land with Dense Traffic*. The Flight Management Computer (FMC) on board the aircraft, part of its Flight Management System (FMS), employs lateral navigation concepts such as aRea NAVigation (RNAV) using Non-Directional Beacons (NDB), VHF Omni-directional radio Range (VOR) and Distance Measuring Equipment (DME). These are ground-based navigational aids, many of which have been in use for decades. For instance, Basic-RNAV (B-RNAV) is in place over Europe, whereby flights must maintain a track keeping performance of within 5 nm of the centre-line trajectory for 95% of the time. Barometric altimetry is also employed, to provide vertical navigational guidance and separation. The terminal environment uses Instrument Landing Systems (ILS). A Microwave Landing System (MLS) has been operational for many years, but has had only limited introduction, even though it was previously envisaged that MLS would have replaced ILS at busy airports by 1998–2000. Reasons for the lack of comprehensive implementation to date include the continued international standardisation of ILS as the definitive landing system and the consequently poorly perceived cost-benefit scenarios particularly as landing systems based on satellite navigation are now being developed.

2.2.2. *In Oceanic and Remote Areas.* Long Range Navigation Systems (LRNS) are used, which include LORAN C and the self-contained Inertial Navigation System (INS). INS positioning errors increase with time and consequently limit the system's accuracy. Although Airborne Collision Avoidance Systems (ACAS) are primarily surveillance facilities, they are increasingly being developed for navigational purposes such as in-trail climbs and descents. The concept of Minimum Navigation Performance Specification Airspace (MNPSA), which requires that all flights in a designated region achieve high standards of navigational performance accuracy, is a method of navigational assurance frequently employed in oceanic and remote areas.

Some carriers have started to introduce the Global Positioning System (GPS), the US constellation of navigation satellites, as a source of navigation reference in all airspace types. GPS is part of the Global Navigation Satellite System (GNSS), as envisaged by the International Civil Aviation Organisation (ICAO). Because of concerns over integrity, GPS has not yet been accepted as a sole means of navigation, but it can be employed virtually anywhere on the globe. However, GPS has been approved as a primary means of navigation in a number of airspace regions around the world. It should be noted that Inmarsat has placed a set of navigational transponders on their Inmarsat-3 satellites, although use to date has only been for testing purposes.

2.3. *Current Surveillance Technology*. Surveillance is the basic tool for the controller to monitor the maintenance of safe separation, manage the airspace efficiently and to assist pilots in navigating their aircraft safely. The following surveillance techniques are presently employed in the respective categories of airspace.

2.3.1. *Near or Over Land with Dense Traffic*. The main means of surveillance by ATC in such areas is the use of radar, which is independent of the pilots' co-operation. This is usually Secondary Surveillance Radar (SSR), which requires aircraft to be fitted with a (Mode A or C) transponder that automatically transmits information when 'interrogated' by ATC. Primary radar is also still in use. Airborne Collision Avoidance Systems (ACAS), such as Traffic alert and Collision Avoidance Systems (TCAS), are technologies that enable aircraft to avoid each other in the air. They are not dependent on any ground-based system: the equipment interrogates SSR transponders of other aircraft in its vicinity, analyses the replies by computer to see which aircraft represent potential collision hazards and provides appropriate advisory information to the flight crew. TCAS has been mandatory in US airspace for many years and became requisite for aircraft with Maximum Take-Off Weights (MTOW) greater than 15 tonnes flying in Europe at the beginning of 2000. Other regions around the world are being actively encouraged to enforce its implementation on flight decks.

2.3.2. *In Oceanic and Remote Areas*. Surveillance methods in these regions, where radar coverage is not available, are usually dependent on co-operation from pilots. Aircraft positioning is determined on board and is transmitted to ATC using VHF and/or HF radio contact, invariably through procedural voice position reporting, particularly in oceanic areas. This necessitates large separations between aircraft due to the slow nature of the process. Supplemental monitoring is now conducted by ATC using technologies such as Enhanced Traffic Management Systems (ETMS) and Flight Data Processing Systems (FDPS), which constantly work out estimates of aircraft locations and alert controllers of any impending conflicts. However, it should be noted that aircraft report their positions automatically using datalink technologies in some areas. For example, aircraft equipped with 'FANS-1/A' avionics packages, designed to enable aircraft to exploit early benefits from future systems, presently provide automatic reporting in the North Atlantic and Pacific oceanic regions.

Additionally, aircraft users are encouraged to place some form of Ground-Proximity Warning System (GPWS) in their avionics for use in all airspace regions. GPWS monitors aircraft instruments and provides an audible warning of proximity to the ground. Enhanced GPWS (EGPWS) uses a world-wide digital terrain database to provide a visual display and advanced warning of threatening terrain to the pilots in a colour code to indicate the level of threat posed. EGPWS is being mandated in Europe and North America.

2.4. *Current Air Traffic Management Procedures*. Current Air Navigation Services (ANS) provide international Air Traffic Services (ATS) based on the availability of CNS technology. ICAO is the agency responsible for safe and orderly ATS operations at a worldwide level. ATS were formed to expedite the safe and orderly flow of air traffic. ATS usually consist of a flight information service, an alerting service and Air Traffic Control (ATC). The ATC service is further divided into aerodrome control at the airport, approach control in the vicinity of the airport and area control for en-route flights. Such services apply to both Instrument Flight Rules (IFR) and Visual Flight Rules (VFR) traffic. ATC control centres employ Air Space Management (ASM) and Air Traffic Flow Management (ATFM) to provide

Air Traffic Management (ATM). Ultimately, ATM is conducted through strategic and tactical planning from months in advance, in addition to real time monitoring and control of flights.

It should be noted that the world is divided into many Flight Information Regions (FIR) for the purpose of providing ATS. Some only occupy small volumes of airspace because FIR boundaries are usually defined by national borders or by agreed lines of demarcation over water. Air navigation facilities and procedures of each region are referred to in ICAO Air Navigation Plans (ANP). The FIRs can span the boundaries of more than one nation, but each country's Civil Aviation Authority (CAA) puts together its own ATS system.

Controlled airspace areas are manifested as TerMinal control Areas (TMA), interconnecting airways and area-type control areas. The latter two are further divided into ATC sectors. Other than the aforementioned types of controlled airspace and ConTRol zones (CTR), which facilitate the separation of aircraft operating within the vicinity of busy airports, the airspace within FIRs is usually uncontrolled. Airspace is categorised into different classes, the exact composition being determined by each nation.

The ATM procedures within an FIR are based on the types and densities of air traffic, the CNS technology and infrastructure that is available, in addition to the topography and economic conditions of the country involved. Thus, similar to the applications of the various types of CNS technology in the different categories of airspace, ATM is presently based on procedures and separation standards, which vary with operating environment.

2.4.1. *Near or Over Land with Dense Traffic*. ATM in these situations uses ATC strips, based on the aircraft's flight plan, which are colour-coded to denote the direction of the aircraft. Strips incorporate information about the flight such as its timings, desired route level and radar code. The controller places the strip on a flight progress board in geographical and time order. After taking the requirements of all other traffic in the sector airspace at that time and in the immediate future, the controller plans a safe Flight Level (FL) and route for the aircraft using an ATS route structure of Upper Airways (UA). The exact altitude of the FL is dependent on the aircraft track, whether between 0° and 179° or between 180° and 359°. Vertical separation between FLs is in the process of being reduced from 2,000 ft to 1,000 ft in some worldwide areas above FL290. The programme is termed Reduced Vertical Separation Minima (RVSM); vertical separation is already at 1,000 ft below FL290. Horizontal separation minima, which are split into longitudinal (along the track) and lateral (across the track) components, vary and are dependent on the availability of ground-based navigational aids and radar surveillance. Horizontal separation can be based on time or distance. ATC presently enables automated functions such as short/medium-term conflict alert, trajectory prediction and flight progress monitoring. Central Flow Management Units (CFMU), such as that operated by Eurocontrol in Brussels and the Central Flow Control Facility by the US FAA in Washington DC, facilitate co-ordination of flights. Efforts such as Eurocontrol's Free Route Airspace Project (FRAP), which offers users direct routes through the upper airspace of eight European nations, are currently adding capacity to ATM systems.

2.4.2. *In Oceanic and Remote Areas*. A lack of surveillance information due to absence of radar technology means that flights are often controlled using procedural ATC methods in such areas. These methods use very large separation criteria, which result in low system capacity and poor availability of efficient flight profiles. Flight tracks are based on route structures that are not necessarily the desired routings of aircraft. The aircraft are assigned slot entry times to a track and told to fly at a specific speed, to facilitate the application of the Mach Number Technique (MNT). Reduced Vertical Separation Minima (RVSM) were successfully introduced in the North Atlantic in 1997–1998 and are presently being implemented in the Pacific. The latter region facilitates Dynamic Airborne Re-routing Procedures (DARP), whilst the former is planning to implement direct routing and Reduced Horizontal Separation Minima (RHSM).

2.4.3. *In the Terminal Area*. Standard Instrument Departure (SID) and STandard ARrival (STAR) routes are established at busy aerodromes to ensure that traffic departs and arrives at an airport in a safe, orderly and expeditious flow. SID and STAR routes link with significant points of ATS en-route tracks and are designed to take account of noise abatement procedures. Separation is maintained between aircraft in such a manner that wake vortices from larger, preceding aircraft do not affect the safe flight of other aircraft. Guidance is sometimes given by ATC using radar vectors, but routes are created for navigation using the ground-based VOR/DME radio navigation facilities. At some cities with more than one airport, aerodromes share SIDs, STARs and holding patterns. Many ATM programmes, such as staggered, dual runway approaches, attempt to maximise the approach capacity of slot-restricted airports.

Due to the fragmented nature of ATC between countries, different systems and standards have resulted in poor harmonisation between adjacent units. Correspondingly, the lack of common air to ground data interchange systems means that current ATM is still based on a multitude of traditional methods. This is manifested by inflexible fixed route structures, which result in demand exceeding capacity levels, air traffic delays and increased operating costs for users. Coupled with poor ATC infrastructure in many countries, there are many FIRs that are considered unsafe. The future CNS/ATM concepts aim to alleviate such problems by introducing an interoperable, seamless system, with full global coverage for safe ATM.

3. FUTURE CNS/ATM TECHNOLOGIES AND PROCEDURES.

The key to optimisation of air traffic flow in the various types of airspace is the introduction of automated Communications, Navigation and Surveillance (CNS) systems that can provide enhanced Air Traffic Management (ATM) with continuous information on aircraft position and intentions. Hence ICAO's insistence that Future Air Navigation Systems (FANS) be known as CNS/ATM, which aims to be a method of using technology to:

(a) Enhance *communication* links between aircraft and air traffic controllers with computers selecting the optimum method of transmission;
(b) Improve pilots' ability to *navigate* their aircraft safely; and
(c) Increase air traffic controllers' capacity to monitor and *survey* flights.

ICAO defined their envisaged CNS/ATM in terms of technologies and procedures of future ATC systems. Indeed, if their plans were adhered to, then ATC systems would evolve as listed below during this decade.

(a) 2000–2005: Full CNS/ATM services will be available in parallel with existing systems so that appropriately equipped aircraft can have maximum operating benefits from CNS/ATM;

(b) 2005–2010: The international terrestrial system not required for the CNS/ATM systems will be progressively dismantled;

(c) 2010: The CNS/ATM systems are the sole means for international use.

Given the lack of progress on implementation to date, it will not be possible to operate full CNS/ATM services in parallel until 2005. Correspondingly, given the US FAA and other countries' decisions not to begin decommissioning of ground-based navigational aids in 2000 as planned, it is probable that the international aviation community will also leave their terrestrial system in place for the foreseeable future. Indeed, it should be noted that ground-based aids such as Distance Measuring Equipment (DME) and VHF Omni-directional radio Range (VOR) are still being purchased in large quantities.

Thus, it is most likely that CNS/ATM systems will still be heavily reliant on today's technologies and procedures at the end of this decade and not as advanced as ICAO's vision. However, due to the recent proliferation of flight delays, particularly in Europe and the US, in addition to illustrations of the industry's vulnerability in terms of safety, the systems will contain new elements based on future CNS/ATM technologies and procedures, which will usually be integrated in an evolutionary, project by project manner. Noting that, according to the International Federation of Air Traffic Controllers' Associations (IFATCA), 'there are so many variables in the development of the ATM system that it is extremely difficult to forecast the final version of the system', there is no one, unique CNS/ATM solution that can be documented here. Instead, there are a variety of CNS/ATM-related implementations, which should bring improvements if their introduction is expedited. Therefore, this section analyses envisaged plans by referring to various components of future CNS/ATM systems and, in particular, those that will realistically be implemented by 2010.

3.1. *Future Communications Technology*. Use of data transmission will introduce many changes in air-ground communication. Future communications systems will allow more direct and efficient linkages between ground and airborne automated systems, thereby offering the possibility of the most routine pilot-controller communication taking place via datalink. Such Controller Pilot DataLink Communications (CPDLC) use displays instead of voice and may be seen as the key to development of new ATM concepts. However, it is not currently expected that CPDLC will be used for urgent messages. It should be noted that CPDLC is already in use in the Pacific oceanic region.

The transmission of voice will continue to take place over existing Very High Frequency (VHF) channels, certainly in 2010, with reduced channel spacing to 8·33 KHz in many areas. The continued use of VHF voice communications will be essential for safety-related communications and in high traffic density terminal areas, which both require high integrity and rapid response. Therefore, there is a need to safeguard aviation's current spectrum allocation and not lose frequencies to commercial, mobile telecommunications. Standards are also being developed for a time division multiple access digital radio as the medium-term solution to spectrum congestion and enhanced air-ground services. In addition to a new generation of Inmarsat satellites (Inmarsat-4), Low Earth Orbit (LEO) and Medium Earth Orbit

(MEO) satellite constellations, such as Globalstar and New ICO, will provide additional communications facilities.

The VHF channels will additionally be used to transmit digital data using enhanced modes of today's VHF DataLink (VDL), such as VDL Modes 2, 3 and 4. VDL is presently employed to send electronic messages from the ground to the cockpit, where they appear in paper format. VDL Mode 2 will replace Aircraft Communications, Addressing and Reporting System (ACARS) by 2004. VDL Mode 3, which is particularly suited to digital voice communications, is being developed in the US and is expected to be operational before 2008. VDL Mode 4, which is being developed in Europe, uses a Self-organising Time Division Multiple Access (STDMA) technique that, in addition to providing its intended data communication functions, makes navigation and surveillance datalink capabilities available. The implementation date for VDL Mode 4 is uncertain. It should be noted that, although ICAO is developing standards for both Mode 3 and Mode 4, there is an industry-wide debate regarding which mode to adopt. In addition, HF DataLink (HFDL) will continue to be employed at the end of this decade.

Satellite data and voice communications, capable of global coverage, will be introduced using Aeronautical Mobile Satellite Services (AMSS). The introduction of satellite-based data and voice communication technology is not subject to the many limitations of today's other communications infrastructure, thereby ensuring greater, global availability and integrity of such services. For example, AMSS may well become the primary method of obtaining weather reports, in lieu of the current Automatic Terminal Information Service (ATIS). It will also be used on a more widespread basis for issuing clearances to aircraft, consequently removing the need for the present, lengthy methods. The benefits of satellite communications currently available should be maximised. Indeed, it is ironic that passengers are sitting in the cabin, talking in a crystal clear manner to their associates on the ground, while the cockpit crew is struggling to understand ATC instructions via poor quality HF communications. It is even more ironic that over 80% of the global wide-body fleet is now equipped with satellite communications technologies.

Secondary Surveillance Radar (SSR) Mode S, which will be used for surveillance in high-density airspace, will also have the capability of transmitting digital communications data. SSR Mode S will provide an air-ground datalink that is specifically suitable for limited data messaging in high-density airspace. However, although it is not expected to be fully operational before 2005, Mode S should be integrated by 2010.

The Aeronautical Telecommunications Network (ATN) will provide for the interchange of digital data between end users over dissimilar air-ground and ground-ground communication links by adopting common interface services and protocols based on the International Organisation for Standardisation (ISO) Open Systems Interconnection (OSI) reference model. It may be compared with the Internet. Automated ATM interaction between ground-based and aircraft-located computer systems will be supported using On-Line Data-Interchange (OLDI). Recent trials suggest that the ATN will be available from 2003 in Europe and 2005 in the US. However, noting that aircraft have been benefiting from the FANS-1/A package and CPDLC technologies in some airspace regions such as the Pacific Ocean, there is an issue regarding the choice of datalink platform as the ATN or FANS-1/A.

Although the availability of several communication systems does provide a degree of flexibility to planning and implementation in the different types of airspace, the proliferation of sub-networks will undoubtedly add to the operational complexity of global communications. Thus, there is a need to translate all relevant operational requirements in a particular airspace into a series of communication performance parameters: the concept of Required Communication Performance (RCP) refers to a set of requirements such as capacity, availability, error-rate and transit delay. By 2010, the RCP will be specified by ICAO for operational scenarios in various airspace environments, indicating that any single communication system, or combination of systems, meeting the set parameters can be considered operationally acceptable.

3.2. *Future Navigation Technology*. Improvements in navigation will include the progressive introduction of aRea NAVigation (RNAV) capabilities and elements of the Global Navigation Satellite System (GNSS). These systems will provide worldwide en-route navigational coverage and, ultimately, precision approaches using a service with high integrity and accuracy. The implementation of these systems will eventually enable aircraft to navigate in all types of airspace around the world. For instance, more so-called 'FANS routes' will proliferate.

By 2010, based on the current situation, it is inevitable that ground-based equipment will still be used as navigational aids, although many nations will have dismantled at least a portion of their ground-based infrastructures. Aids such as Distance Measuring Equipment (DME) and VHF Omni-directional radio Range (VOR) will continue to be used for RNAV in a manner similar to today's system or as a back-up to GNSS. In the future CNS/ATM system, however, RNAV will operate with a greater dependency on satellite-based systems to determine aircraft positions. This will facilitate a greater proportion of flights flying on direct routes, especially if RNAV is employed with Dynamic Aircraft Route Planning (DARP). The Flight Management Computer (FMC) will periodically download its 4D trajectory and expected routing to allow for automated negotiation of flight plans. It should be added that the B-RNAV presently in place over Europe will evolve in 2005 to become Precision-RNAV (P-RNAV), where the tolerance is reduced to 1 nm. Indeed, the airspace will be designated as 'RNP-1'.

GNSS will be a worldwide position and time determination system that includes one or more satellite constellations, aircraft receivers, ground monitor stations and system integrity monitoring devices. Only three satellite constellations are currently available with navigational capabilities: the US Global Positioning System (GPS); GLONASS, which is provided by the Russian Federation and is similar to GPS; and Inmarsat-3 satellites which, as well as their comprehensive communications capability, are equipped with navigational transponders. In addition, it should be noted that Europe aims to declare its proposed constellation of 'Galileo' satellites operational by 2008. GNSS will be the key feature of the future navigation system and will evolve to be a sole means of navigation with the intent that it eventually replaces current systems. This will occur, in certain cases, by 2010. Integration of GPS and the Inertial Navigation System (INS) may be seen as a step towards full GNSS.

To overcome inherent system limitations and to meet the performance accuracy, integrity, availability and continuity requirements for all phases of flight, GNSS will require varying degrees of augmentation to support the actual phase of operation. Such systems, which monitor signal reliability and enhance accuracy to make GNSS suitable for civilian use, are still being developed and may be broadly categorised as space-based (SBAS), aircraft-based (ABAS) and ground-based (GBAS). Based on

GPS, Inmarsat and planned Japanese satellite systems, three SBAS should be operational by 2005: the Wide Area Augmentation System (WAAS) in the US, the European Geostationary Navigation Overlay Service (EGNOS) and the Multi-functional transport Satellite Augmentation System (MSAS) in Japan. ABAS either use Receiver Autonomous Integrity Monitoring (RAIM), where satellite signals over and above the four required to provide a three-dimensional fix are used to check the integrity of those used in this positioning solution, or the same integrity function is achieved using other aircraft sensors such as INS or VOR/DME. GBAS are being designed primarily to provide high integrity and accuracy for airfield approach systems as described below.

The standard non-visual aids to precision approach and landing that will be used in 2010 include a continuation of Instrument Landing System (ILS) operations as long as they are operationally acceptable. Microwave Landing Systems (MLS) will be implemented in cases where they are operationally required and economically beneficial. Based on current progression of its development, Differential GPS (DGPS) should be available in the near future. DGPS uses GPS signals, augmented on a local basis using a Local Area Augmentation System (LAAS), to guide the aircraft on its approach to landing; these systems are becoming known as Satellite Landing Systems (SLS). Other technologies are being developed, such as a completely airborne system, Autonomous Precision Approach and Landing System (APALS), Head-Up Displays (HUD) and Multi-Mode Receivers (MMR) to enable the flexibility for aircraft to use ILS, MLS or SLS.

Similar to the aforementioned RCP concept, Required Navigation Performance (RNP) recognises that aircraft navigation systems are capable of achieving predictable levels of performance accuracy within a defined airspace. RNP types for operations are identified by a single accuracy value, defined as the minimum navigation performance accuracy required within a specified containment level. Noting that success to date with RNP has been better than RCP, the navigational requirements for many airspace environments will be stated in RNP terms by 2010.

3.3. *Future Surveillance Technology*. Over the next 5 to 10 years, it is expected that both Primary and Secondary Surveillance Radar (PSR and SSR) will continue to be used, with the gradual introduction of Mode S (Selective) datalink in both terminal areas and high-density continental airspace from 2003 in Europe; 2008 in the US. SSR Mode S will be used in high-density airspace regions to provide high accuracy, reliable surveillance capable of providing conflict alerts. Accordingly, more advanced versions of the current Airborne Collision Avoidance Systems (ACAS), such as TCAS 2 – Change 7, will be standard by 2005. In addition, TCAS 4 will be developed, which uses satellite-based position data to provide better conflict detection and resolution advisories.

The major breakthrough, however, will be the more widespread implementation of Automatic Dependent Surveillance (ADS), which allows aircraft automatically to transmit their position and other data, such as heading, speed and intentions. This will be performed via satellite or some other air-ground communication link to an Air Traffic Control (ATC) unit, where the position of the aircraft will be displayed as on conventional radar screens. ADS is particularly appropriate to oceanic and remote regions. It may be seen as a beneficial merging of communication and navigation technology, which enables oceanic airspace to make use of the Aeronautical Mobile Satellite Services (AMSS). Software is being developed to allow ground computers to use ADS digital data to detect and resolve conflicts through conformance monitoring. Eventually, this could lead to clearances being negotiated between airborne and ground-based computers, with little or no human intervention.

ADS-B (Broadcast) is an application of ADS technology that enables an aircraft to broadcast its position, altitude and vector information for display by other aircraft and also by ground users, such as ATS providers. ADS-B will be available from 2003 in the US, and current interest remains high in widely implementing this technology before the end of the decade. ADS-B information can also be used as a basis for a Cockpit Display of Traffic Information (CDTI). In addition to CDTI, other Situational Awareness Systems (SAS) will provide flight crews with wake vortex hazard prediction and avoidance; synthetic vision with HUDs; and enhanced meteorological awareness. On the ground, ADS-B will be implemented with ground movement radar and airport surface detection equipment such as Surface Movement Guidance and Control Systems (SMGCS). Indeed, it should also be noted that parallel precision runway monitors will increase approach traffic capacity at airports with closely spaced parallel runways.

As with the communications and navigational elements of CNS/ATM, although the availability of a plethora of surveillance systems provides planning flexibility, it complicates the harmonisation of surveillance functions. To facilitate the planning, it is necessary to translate the relevant operational requirements into a series of surveillance performance parameters, termed Required Surveillance Performance (RSP). Once ICAO has specified the RSP for an operational scenario for a given airspace, any single system or combination of surveillance systems meeting the set parameters can be considered operationally acceptable. This will occur before 2010.

3.4. *Future Air Traffic Management Procedures*. The objectives to be reached through the envisaged, evolutionary ATM system include:

(a) To meet evolving air traffic demand;
(b) To support a safe and orderly growth of international civil aviation;
(c) To enhance safety, regularity and efficiency;
(d) To optimise benefits through global integration;
(e) To enhance economy of commercial air transport.

Specifically, it is how each country and worldwide region will achieve these aims that differentiates the concepts being developed and determines the ATM procedures that will be in place by 2010. Within this timeframe, the controller will still play a pivotal role using skills such as spatial perception, information processing, reason and decision making, which are presently employed. Indeed, many of today's ATM procedures will still be used in the latter half of this decade.

Significant improvement will only be achieved through the development of powerful decision support software tools. The creation of automated ATM will provide an enhanced set of such tools that will assist the controller with conflict prediction, detection and resolution. The introduction of the future CNS technologies described in the previous sections will enable the evolution of more sophisticated ATM. This particularly applies to technologies that facilitate the automatic sending of aircraft position data. The combined benefits from the aforementioned advances in CNS technologies will serve as tools to support ATM. Indeed, according to ICAO, the integrated benefits and technical attributes of CNS technology will amalgamate to improve ATM, as portrayed in Figure 1.

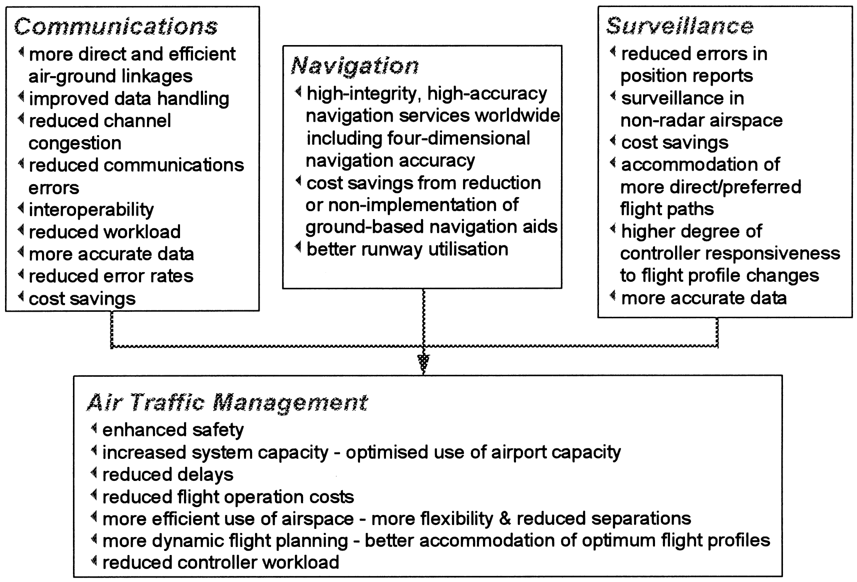

Figure 1. Benefits of CNS/ATM systems.

The ultimate expectation is that accuracy could be improved through the rapid calculations associated with automation. Conflict prediction and detection, based on advanced computational methods, should allow more direct routings. These systems will be introduced in an evolutionary manner, and it is the rate of implementation that will determine the standard of ATM procedures by 2010. Nonetheless, some success is evident, such as the 'Direct-To' tool, which automatically searches for aircraft eligible for shorter trajectories to downstream fixes. Since software completion in 1999, it has been operating in shadow mode. The new Canadian Automated Air Traffic System (CAATS), which offers a paper-free environment with functions such as 4-D conflict probe and clearance validation, is also an example of advances in automated systems. Similarly, The Australian Advanced Air Traffic System (TAAATS), which became fully operational in 2000, incorporates new technology that links ground ATM automation systems with airborne avionics, thereby increasing flight path flexibility and providing more time for decision making.

Based on the current activity around the world regarding future ATM, the expected status of ATM by the end of the decade varies for different regions, but will ultimately be the result of many capacity enhancing programmes. For instance, regions that are capacity constrained will continue to see the implementation of Reduced Vertical Separation Minima (RVSM) above FL290 and implementation of the Flexible Use of Airspace (FUA) concepts. Also, the fragmentation of airspace structures will be simplified, in order to provide seamless systems with greater capacity. For example, Europe's 'Single Sky' must be achieved in this decade. Additionally, mandatory requirements to have Airborne Collision Avoidance Systems (ACAS) will complement future ATM.

ATM solutions will be brought about by ATM operational concepts, which are intended to assist and guide airspace planners with ATM design, in order to provide efficient and safe operations for all phases of flight. For instance, ICAO's operational concept in the 'Global ATM plan' is still being developed. The concept will be complete when consensus has been obtained on issues such as autonomy of flight, separation assurance, situational awareness and collision avoidance. The concept will be functionally integrated with Air Traffic Services (ATS), AirSpace Management (ASM) and Air Traffic Flow Management (ATFM) on the part of the providers, in addition to ATM aspects of flight operations from the airspace users. The concept will provide the means to quantify and assure performance in terms of safety, efficiency and regularity. There is an urgent need for ICAO to finish developing this concept.

The USA is implementing a programme for its operational concept of Free Flight, which aims to add levels of autonomous flight. The latest version of the programme, the Operational Evaluation Plan (OEP), was released recently. The US Federal Aviation Administration (FAA) plans to complete Free Flight, Phase 1 by 2002. This is mostly ground-based and involves making existing, but not widely used, ATM capabilities quickly available to airspace users so that short-term benefits can be achieved in a desperate attempt to alleviate the country's air traffic congestion. Phase 2 aims to deploy decision-support systems for ATM between 2003 and 2007. Phase 3 will take place thereafter, when the FAA aims to complete the required infrastructure and integration of new automation to enable limited Free Flight operations. The FAA has found that the best method of achieving advanced ATM procedures is to work in conjunction with industry. Indeed, industry is conducting many trials itself, particularly in the area of new technologies.

Eurocontrol's gate-to-gate operational concept, 'ATM Strategy for 2000+', expects to meet capacity needs until 2015. In contrast with the US notion that future ATM will enable aircraft to navigate more cost-efficient routes, the European idea of future ATM is more concerned with being able to satisfy demand through improved airspace organisation and flow management. Noting the escalation of delays in recent times, Eurocontrol aims to provide greater levels of capacity by 2005. Indeed, there is need for serious short-term action in Europe. Thus, Eurocontrol is targeting the Area Control Centres (ACC) that were highlighted in recent performance review reports as having created many ATC delays over the last few years. Specific improvements in the ATM procedures of these centres should bring benefits. Accordingly, Eurocontrol's implementation programmes, which are discussed in previous sections of this paper, should increase capacity if they are conducted in a timely manner. They include, among others, RVSM, 8·33 KHz, SSR Mode S, P-RNAV and FRAP. In addition, Collaborative Decision Making (CDM) will aid procedural ATM in terms of better slot co-ordination, airspace management and information management.

Another integral aspect of improving ATM in this region is the increased co-operation of member nations in sharing the ATM of their upper airspace, with a view to creating a uniform region. Therefore, ventures such as the Central European ATS (CEATS) centre in Vienna should also act as suitable solutions to the predicament. The European Commission (EC) is involved, having created a High Level Group on ATM reform. In order that the ATM 2000+ Strategy may be implemented, the EC believes that the European Union, not Eurocontrol, should be given greater powers based on new decision-making mechanisms and regulatory frameworks.

Ultimately, attaining the goal of an integrated, global ATM system requires harmonisation and standardisation of regional and national system elements, which, in turn, must be based on plans that are specific to the different airspace types. It is the evolutionary implementation of the CNS elements and their orchestrated interaction that will form the backbone of the integrated ATM system in 2010.

4. SUMMARY – EVOLUTION OF CNS/ATM SYSTEMS. With reference to the contents of the two previous main sections, Figure 2 summarises the planned evolution of CNS systems in the future.

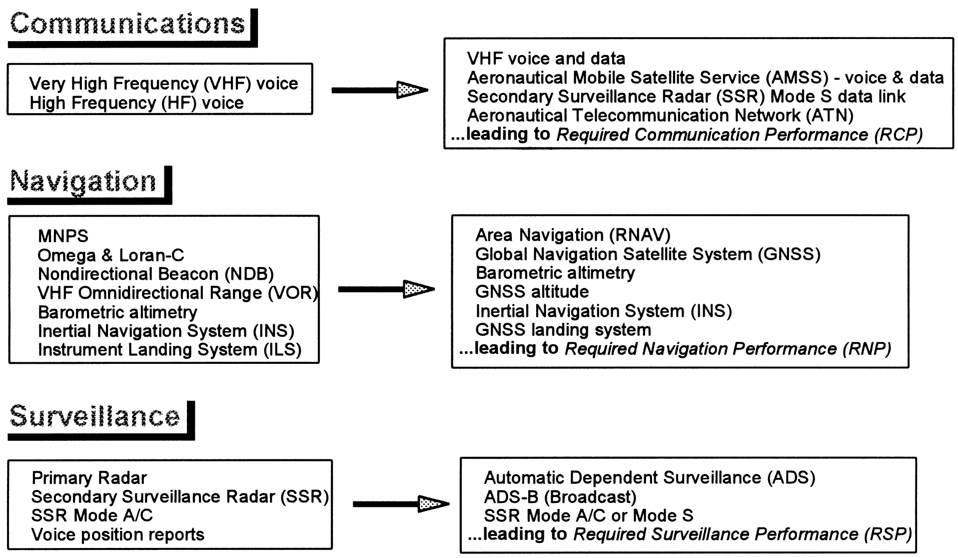

Figure 2. The planned evolution of CNS systems in this decade.

To maximise use of CNS technologies for airspace planning purposes, given a region's ATM requirements, each of the three categories will be based on their required performance criteria, thus: Required Communications Performance (RCP); Required Navigation Performance (RNP); and Required Surveillance Performance (RSP).

The introduction of these performance criteria (RCP, RNP and RSP) will help simplify the basis of ATM in the various types of airspace in addition to enabling the appropriate technologies and procedures to be developed. Many limitation factors of the present CNS system will inhibit the development of ATM throughout the world unless the more advanced technologies described in this paper are implemented. Accordingly, Figure 3 summarises suitable CNS systems upon which ATM will most likely be based in 2010 for different airspace types.

Hence, there is a need for the new technologies and ATM approaches that will lead to reductions in separation between aircraft and allow for increases in airspace capacity, cost-effectiveness, efficiency, flexibility and safety. Indeed, CNS/ATM systems provide an opportunity to overcome the present system's shortcomings and accommodate forecast traffic levels. However, there are many issues that affect their rate of introduction, which incorporate political, management, regulatory, technical, certification, liability, financial and institutional aspects. Therefore, in order to implement CNS/ATM successfully, these different issues must be addressed. For

Airspace	Function	Current Systems	Systems in 2010
Continental and oceanic en-route airspace with low-density traffic	Communications	VHF data & voice HF data & voice	ATN VHF data & voice AMSS data & voice HF data, particularly in Polar regions
	Navigation	LORAN-C NDB VOR/DME Barometric altimetry INS/IRS	RNAV GNSS (with SBAS) Barometric altimetry GNSS altitude INS/IRS
	Surveillance	Primary radar/SSR Voice position reports	ADS & ADS-B
Continental airspace with high-density traffic	Communications	VHF voice	VHF data & voice AMSS data & voice SSR Mode S datalink
	Navigation	LORAN-C NDB VOR/DME Barometric altimetry INS/IRS	RNAV GNSS (with SBAS) Barometric altimetry GNSS altitude INS/IRS
	Surveillance	Primary radar SSR Mode A/C	SSR (Mode A/C & S) ADS & ADS-B
Oceanic airspace with high-density traffic	Communications	HF data & voice	AMSS data & voice
	Navigation	MNPS LORAN-C Barometric altimetry INS/IRS	RNAV GNSS (with SBAS) Barometric altimetry GNSS altitude INS/IRS
	Surveillance	Voice position reports	ADS & ADS-B
Terminal areas with high-density traffic	Communications	VHF voice	ATN VHF voice/data AMSS data/voice SSR Mode S datalink
	Navigation	NDB VOR/DME ILS Barometric altimetry INS/IRS	RNAV GNSS (using LAAS) ILS/MLS DME Barometric altimetry INS/IRS
	Surveillance	Primary radar SSR Mode A/C	SSR (Mode A/C & S) ADS & ADS-B

Figure 3. Current and expected CNS technologies for different airspace types.

instance, institutional problems relating to ATS providers may often be solved through (part) privatisation or corporatisation, whereby commercialisation is seen as a means of improving their investment capability and institutional efficiency. It is thought that ATS organisations become more competitive with such status and that they do not possess the apparent hindrances associated with being government departments. Similarly, ATS providers are encouraged by ICAO to partake in 'international co-operation in the provision and operation of air navigation services where this is beneficial for the providers and users concerned'. Thus, changing the structure of ATS providers can reduce adverse institutional issues.

Ultimately, mixed opinion exists about where Air Navigation Services (ANS) will be at the end of this decade in terms of CNS/ATM technologies and procedures. This particularly applies to when the satellite-based systems will replace ground-based aids, noting that there will be greater advances in some nations and regions than others. Indeed, concepts such as Free Flight per se will be more applicable to specific types of airspace. Nonetheless, it may be observed that the present dilemmas would not exist if the future air navigation systems had already been sufficiently applied around the world. However, many technologies and procedures are nearly ready for mainstream implementation, advances have been made with datalink applications and satellite-based communications facilities, GPS enhanced navigation procedures in all flight phases are becoming more mature, while the concept of RNP is aiding airspace planning and facilitating adherence to standards in many regions. Correspondingly, the success of surveillance systems, such as ADS and ADS-B, is encouraging, and enhanced ATM procedures, such as automated sequencing tools and dynamic aircraft re-routing, are currently operational. Therefore, it would appear that the evolution of ANS is at a crossroads and that this decade will witness profound changes, which will hopefully alleviate many of the existing air traffic problems.

REFERENCE

Whelan, C. (2001). Evaluating and improving worldwide implementation of future air navigation systems, *PhD Thesis*, College of Aeronautics, Cranfield University.