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NEW APPROACH TO NAVIGATION: FROM CONVENTIONAL SYSTEMS TO SATELLITE SYSTEMS

Alper OREN[1]
TuAF Air Technical Training Command
Gaziemir,IZMIR-TURKEY

Zeynep Seda MOR[2]
Turkish Aerospace Industries
Ankara,TURKEY

ABSTRACT

The aviation industry provides service to almost every corner of the globe, and has been an integral part of the creation of a global economy. The aviation industry itself is a major economic force, both in terms of its own operations and its impacts on related industries such as aircraft manufacturing and tourism, to name but two. With the emerging of aviation activities, both pilots and air traffic controller have focused on safety flight. To ensure the safety flight first step is taking of safely and the last step is landing safely. Generally normal flight consist on 5 phases which are taxi and take off, departure and climb, enroute cruise, descent and approach, arrival and taxi. Generally the longest part of flight is enroute cruise and conventional radio navigation systems use To-To navigation methods. But unfortunately today although sky is unlimited, it is hard to find suitable navigation road for each aircraft. Therefore airspace planners and managers have started to establish new navigation systems with the help of satellites. In this study, conventional radio navigation systems and CNS/ATM concept will be reviewed and the current radio navigation system's shortcomings and their effects to ATM will be discussed, technical advantages and disadvantages of conventional radio navigation system and GNSS will be compared and importance of usage GNSS in ATM will be introduced and will be given current applications.

INTRODUCTION

If you ask people today what comprises commercial aviation, they will undoubtedly tell you that it is "commercial airlines." The public's awareness of commercial airlines is likely due to their own personal experiences, representations of the airlines in the media, and an ongoing, robust advertising campaign by the air carrier industry itself [John G. WENSVEEN, 2007].

Economic expansion drives changes in the frequency and pattern of aviation all around the world. Citizens become more mobile, and the number of people travelling by aircraft for business and leisure reasons continues to increase.

The air transport industry has grown more rapidly than most other industries through the 1980s and 1990s [ICAO Doc 9750 AN/963, 2002]. Today this industry plays a major role in driving sustainable economic and social development in hundreds of nations [ICAO Doc 9750 DRAFT 2014-2016, 2013].

According to preliminary traffic statistics compiled by the International Civil Aviation Organization (ICAO), world passenger kilometres performed on total scheduled services (i.e. international and domestic services combined) increased by about 6.5% (7.1% international and 5.4% domestic) over 2010. The airlines of ICAO's 191 Member States carried approximately 2.7 billion passengers in 2011,

[1] Military Air Traffic Controller Instructor TUAF, MSc Student Electronic and Electronics Engineering CBU, Email: alperoren@hotmail.com
[2] Avionics Systems Design Engineer-TAI, Phd Student Space Sciences ASTIN, Email: zsmor@tai.com.tr

showing an increase of about 5.6 per cent over 2010. The number of departures on scheduled services reached 30.1 million globally in 2011 compared to 29 million in 2010 [ICAO Doc 9975, 2012].

Aircraft managers and operators of the larger airlines are expected to further develop new transportation technologies and policies, keeping up with the increase in point-to-point operations by smaller or low-cost operators. Conversely, there has been a remarkable increase in the total number of military aircraft and military aviation operations in recent years.

Air traffic diversity is expected to become more complex with the emergence of Very Light Jets (VLJs), Unmanned Aerial Systems (UAS) and the diversity of military aerial missions, which will alter the mix and flight profiles of the airspace users. This will lead to additional complexity in the airspace user requirements.

Faced with these realities, the airspace will have to become more flexible and adaptable, allowing an effective balance between capacity, mission effectiveness, flight efficiency, environmental requirements, and the diversity of user requirements. This must be accomplished while maintaining or improving the safety of operations [EUROCONTROL, 2008].

Improving air traffic control and air traffic management is currently one of the top priorities of the global research and development agenda. Massive, multi-billion euro programs like SESAR (Single European Sky ATM Research) in Europe and NextGen (Next Generation Air Transportation System) in the United States are on their way to create an air transportation system that meets the demands of the future.

Air traffic control is a multi-disciplinary field that attracts the attention of many researchers, ranging from pure mathematicians to human factors specialists, and even in the legal and financial domains the optimization and control of air transport is extensively studied [Max Mulder, 2010].

Traditionally, national air traffic services providers have provided most of the three types of services:

- Air Traffic Management (ATM). This segment includes providers of Air Traffic Services (ATSP), airspace management and Air Traffic Flow Management (ATFM).

- Communication, Navigation and Surveillance (CNS). Provides service to radar stations, navigational aids (NAVAIDs), and communication networks.

- Aeronautical Information Services (AIS). This situation could change in the future with the increasing corporatisation of air traffic service provision and the subcontracting of many of these services to other organizations [EUROCONTROL, 2003].

The objective of ATM is to ensure a safe, orderly and expeditious flow of air traffic. Therefore the controller’s job is much more complicated and includes a number of other related tasks. This is mainly achieved through monitoring, conflict detection and resolution, and the separating and sequencing of air traffic [ICAO Doc 4444, 2007].

As technology advances, new systems and concepts will continue to emerge, offering potential improvements in terms of safety, efficiency and/or economy of international flights [ICAO Doc 9750 AN/963, 2002].

Air navigation has witnessed some important improvements in recent decades, with a number of states and operators having pioneered the adoption of advanced avionics and satellite-based procedures [ICAO Doc 9750 DRAFT 2014-2016, 2013].

Air navigation facilities, services and procedures recommended for the area under consideration should form an integrated system designed to meet the requirements of all international civil aircraft operations.

The solution to all of these concerns is a fully-harmonized Global Air Navigation System built on modern performance based technologies and procedures. This goal has been on the minds of CNS and ATM planners for many years now, but because technology never stands still the realization of a dependable strategic path proved elusive to determine up to this point [ICAO Doc 9750 DRAFT 2014-2016, 2013].

NAVIGATION

Navigation is the art and science of getting from point "A" to point "B" in the least possible time without losing your way. It is, in even simpler terms, always knowing one's location and the way to the desired destination. This requires knowledge of the *position* of points and the *direction* and *distance* between them.

In the early days of aviation, navigation was mostly an art. The simplest instruments of flight had not been invented, so pilots flew "by the seat of their pants". Today, navigation is a science with sophisticated equipment being standard on most aircraft.

The type of navigation used by pilots depends on many factors. The navigation method used depends on where the pilot is going, how long the flight will take, when the flight is to take off, the type of aircraft being flown, the on-board navigation equipment, the ratings and currency of the pilot and especially the expected weather.

To navigate a pilot needs to know the following:

a) Starting point (point of departure),
b) Ending point (final destination),
c) Direction of travel,
d) Distance to travel,
e) Aircraft speed,
f) Aircraft fuel capacity,
g) Aircraft weight & balance information.

With this information flight planning can commence and the proper method of navigation can be put to use.

Basic Navigation

Air navigation is accomplished by various methods. The method or system that a pilot uses for navigating through today's airspace system will depend on the type of flight that will occur (VFR or IFR), which navigation systems are installed on the aircraft, and which navigation systems are available in a certain area.

Pilotage

For a non-instrument rated, private pilot planning to fly VFR (Visual Flight Rules) in a small, single engine airplane around the local area on a clear day, the navigation is simple. The navigation process for such a local trip would be pilotage. (Figure 1)

The pilotage method of navigation developed naturally through time as aircraft evolved with the ability to travel increasingly longer distances. Flying at low altitudes, pilots used rivers, railroad tracks and other visual references to guide them from place to place. This method called pilotage is still in use today. Pilotage is mainly used by pilots of small, low speed aircraft who compare symbols on aeronautical charts with surface features on the ground in order to navigate. This method has some obvious disadvantages. Poor visibility caused by inclement weather can prevent a pilot from seeing the needed landmarks and cause the pilot to become disoriented and navigate off course. A lack of landmarks when flying over the more remote areas can also cause a pilot to get lost.

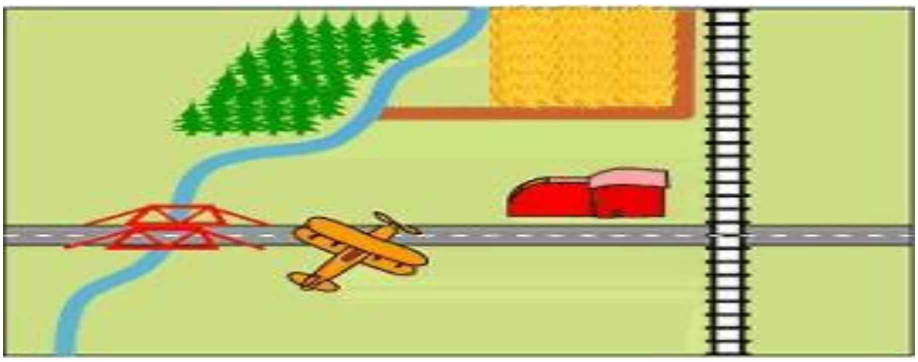

Figure 1: The Pilotage Method

Dead Reckoning

Dead Reckoning (or Dead for Deductive Reckoning) is another basic navigational method used by low speed, small airplane pilots. It is based on mathematical calculations to plot a course using the elements of a course line, airspeed, course, heading and elapsed time. During this process pilots make use of a flight computer.

Manual or electronic flight computers are used to calculate time-speed-distance measurements, fuel consumption, density altitude and many other en route data necessary for navigation.

The estimated time en route (ETE) can be calculated using the flight distance, the airspeed and direction to be flown. If the route is flown at the airspeed planned, when the planned flight time is up, the destination should be visible from the cockpit.

Navigating using known measured and recorded times, distances, directions and speeds makes it possible for positions or "fixes" to be calculated or solved graphically. A "fix" is a position in the sky reached by an aircraft following a specific route. Pilots flying the exact same route regularly can compute the flight time needed to fly from one fix to the next. If the pilot reaches that fix at the calculated time, then the pilot knows the aircraft is on course. The positions or "fixes" are based on the latest known or calculated positions. Direction is measured by a compass or gyro-compass. Time is measured on-board by the best means possible. And speed is either calculated or measured using on-board equipment. Figure 2 shows simple dead reckoning method between Phoenix and El Paso airports.

Navigating now by dead reckoning would be used only as a last resort, or to check whether another means of navigation is functioning properly. There are navigation problems associated with dead reckoning. For example, errors build upon errors. So if wind velocity and direction are unknown or incorrectly known, then the aircraft will slowly be blown off course. This means that the next fix is only as good as the last fix.

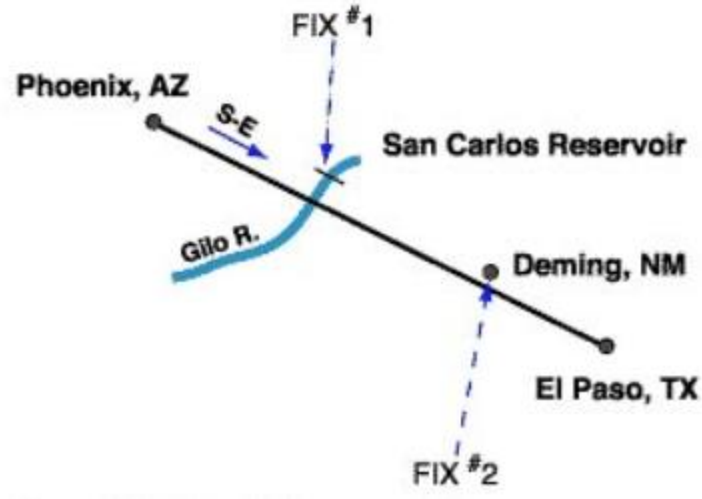

Figure 2 : Two Possible Fixes Along a Route from Phoenix to El Paso

Radio Navigation

Radio navigation is used by almost all pilots. Pilots can find out from an aeronautical chart what radio station they should tune to in a particular area. They can then tune their radio navigation equipment to a signal from this station. A needle on the navigation equipment tells the pilot where they are flying to or from station, on course or not.

Pilots have various navigation aids that help them takeoff, fly, and land safely. One of the most important aids is a series of air route traffic control, operated throughout the world. Most of the traffic control uses a radar screen to make sure all the planes in its vicinity are flying in their assigned airways. Airliners carry a special type of radar receiver and transmitter called a transponder. It receives a radar signal from control center and immediately bounces it back. When the signal got to the ground, it makes the plane show up on the radar screen.

Pilots have special methods for navigating across oceans. Three commonly used methods are:

a) **Inertial Guidance:** This system has computer and other special devices that tell pilots where are the plane located.

b) **LORAN Long Range Navigation:** The aircraft has equipment for receiving special radio signals sent out continuous from transmitter stations. The signals will indicate the aircraft location.

c) **GPS Global Positioning System**: GPS is the only system today able to show your exact position on the earth any time, anywhere, and any weather. The system receiver on the aircraft will receive the signals from satellites around the globe.

CONVENTIONAL NAVIGATION SYSTEMS

ADF : Radio waves have directional characteristics. This is the basis of the Automatic Direction Finder (ADF); one of earliest forms of radio navigation that is still in use today. ADF is a short–medium range (200 nm) navigation system providing directional information.

VOR : During the late 1940s, it was evident to the aviation world that an accurate and reliable shortrange navigation system was needed. Since radio communication systems based on very high frequency (VHF) were being successfully deployed, a decision was made to develop a radio navigation system based on VHF. This system became the VHF Omnidirectional Range (VOR) system. This system is in widespread use throughout the world today. VOR is the basis of the current network of airways that are used in navigation charts.

DME : DME is a system for measuring distance to a navigation aid. The advent of radar in the 1940s led to the development of a number of navigation aids including Distance Measuring Equipment (DME). This is a short/medium-range navigation system, often used in conjunction with the VOR system to provide accurate navigation fixes. The system is based on secondary radar principles.

ILS : ADF, VOR and DME navigation aids are installed at airfields to assist with approaches to those airfields. These navigation aids cannot however be used for precision approaches and landings. The standard approach and landing system installed at airfields around the world is the Instrument Landing System (ILS). The ILS can be used for approach through to autoland. The ILS uses a combination of VHF and UHF radio waves and has been in operation since 1946.

MLS : There are a number of shortcomings with ILS; in 1978 the Microwave Landing System (MLS) was adopted as the longterm replacement. The system is based on the principle of time referenced scanning beams and provides precision navigation guidance for approach and landing. MLS provides three dimensional approach guidance, i.e. azimuth, elevation and range. The system provides multiple approach angles for both azimuth and elevation guidance. Despite the advantages of MLS, it has not yet been introduced on a worldwide basis for commercial aircraft. Military operators of MLS often use mobile equipment that can be deployed within hours.

Hyperbolic Radio Navigation : Is a type of Long-range radio navigation systems. These systems are based on hyperbolic navigation; they were introduced in the 1940s to provide en route operations over oceans and unpopulated areas. Several hyperbolic systems have been developed since, including Decca, Omega and Loran. The operational use of Omega and Decca navigation systems ceased in 1997 and 2000 respectively. Loran systems are still available for use today as stand-alone systems; they are also being proposed as a complementary navigation aid for global navigation satellite systems.

Doppler Navigation : A unique form of dead reckoning navigation system based on radar and a scientific principle called Doppler Shift. This system requires no external inputs or references from ground stations. Doppler Navigation Systems were developed in the mid-1940s and introduced in the mid-1950s as a primary navigation system. Being self-contained, the system can be used for long distance navigation and by helicopters during hover manoeuvres.

RNAV : The advent of computers, in particular the increasing capabilities of integrated circuits using digital techniques, has led to a number of advances in aircraft navigation. One example of this is the Area Navigation System (RNAV). Area navigation is a means of combining, or filtering, inputs from one or more navigation sensors and defining positions that are not necessarily co-located with ground based navigation aids.

INS : A major advance in aircraft navigation came with the introduction of the Inertial Navigation System (INS). The inertial navigation system is an autonomous dead reckoning system, i.e. it requires no external inputs or references from ground stations. The system was developed in the 1950s for use by the US military and subsequently the space programmes. Inertial navigation systems (INS) were introduced into commercial aircraft service during the early 1970s. The system is able to compute navigation data such as present position, distance to waypoint, heading, ground speed, wind speed, wind direction etc. The system does not need radio navigation inputs and it does not transmit radio frequencies. Being self-contained, the system can be used for long distance navigation over oceans and undeveloped areas of the globe.

GPS : Navigation by reference to the stars and planets has been employed since ancient times; aircraft navigators have utilised periscopes to take celestial fixes for long distance navigation. An artificial constellation of navigation aids was initiated in 1973 and referred to as Navstar (navigation system with timing and ranging). This Global Positioning System (GPS) was developed for use by the US military; it is now widely available for use in many applications including aircraft navigation. GPS and other global navigation satellite systems that are in use, or planned for future deployment.

FMS : The term ‘navigation’ can be applied in both the lateral and vertical senses for aircraft applications. Vertical navigation is concerned with optimising the performance of the aircraft to reduce operating costs. During the 1980s, lateral navigation and performance management functions were combined into a single system known as the Flight Management System (FMS). Various tasks previously routinely performed by the crew can now be automated with the intention of reducing crew workload.

Weather Radar : How the planned journey from A to B could be affected by adverse weather conditions. Radar was introduced onto passenger aircraft during the 1950s to allow pilots to identify weather conditions and subsequently reroute around these conditions for the safety and comfort of passengers. A secondary use of weather radar is the terrain-mapping mode that allows the pilot to identify features of the ground, e.g. rivers, coastlines and mountains.

ATC System : Increasing traffic density, in particular around airports, means that we need a method of Air Traffic Control (ATC) to manage the flow of traffic and maintain safe separation of aircraft. The ATC system is based on Secondary Surveillance Radar (SSR). Ground controllers use the system to address individual aircraft. An emerging ATC technology is ADS-B.

TCAS : With ever increasing air traffic congestion, and the subsequent demands on air traffic control (ATC) resources, the risk of a mid-air collision increases. The need for improved traffic flow led to the introduction of the Traffic Alert and Collision Avoidance System (TCAS). TCAS is an automatic surveillance system that helps aircrews and ATC to maintain safe separation of aircraft. TCAS is an airborne system based on secondary radar that interrogates and replies directly with aircraft via a high integrity data link. The system is functionally independent of ground stations, and alerts the crew if another aircraft comes within a predetermined time to a potential collision.

NEW APPROACH TO NAVIGATION : SATELLITE SYSTEMS

In 1983, ICAO founded the Future Air Navigation Systems (FANS) Committee to constitute the foundations for "the development of air navigation for international civil aviation over a period of twenty-five years". But, just a few years later the FANS Committee (later known as FANS Phase 1) concluded that the utilization of satellite technology to provide communications, navigation, and surveillance (CNS) services to civil and military aviation on a global basis is the only viable solution that will provide one to overcome the shortcomings of the present air navigation system and fulfill the needs and requirements of the foreseeable future. The proposed FANS system espoused the satellite-based CNS concept and greatly improved arrangements on the ground for the purpose of ATM.

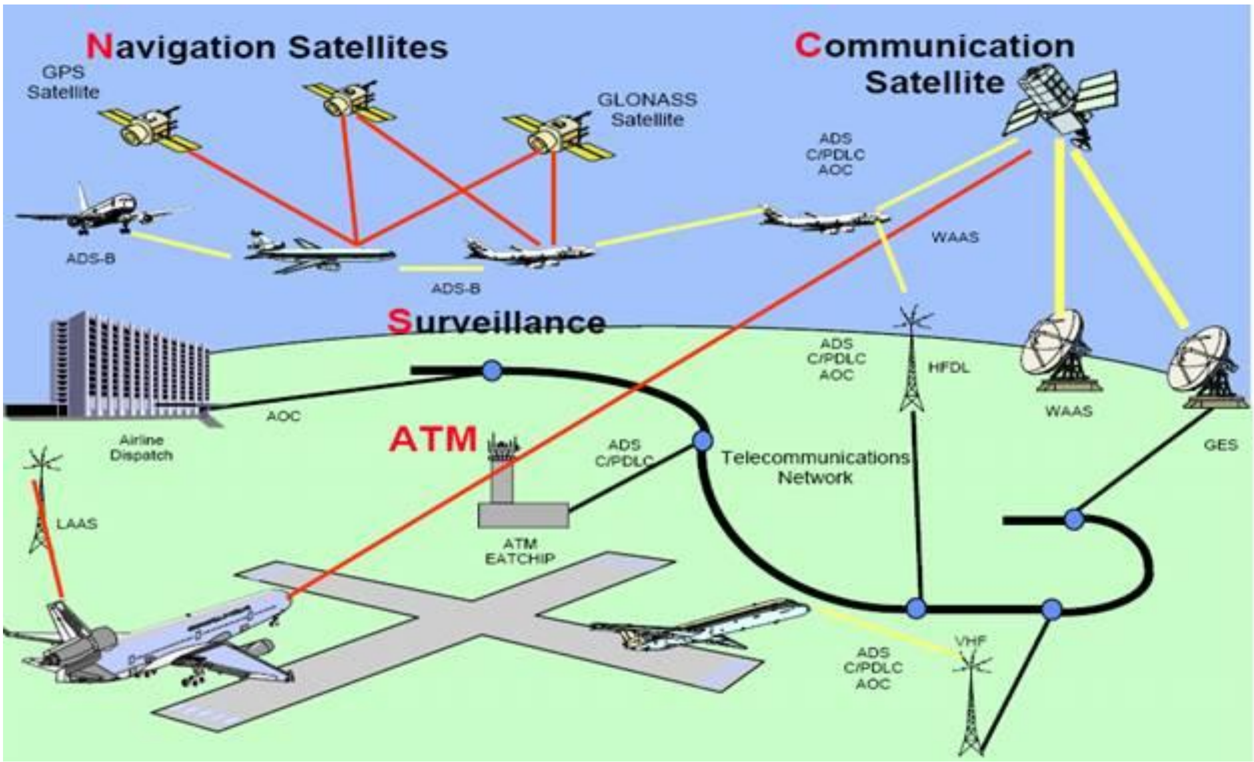

Figure 3 : CNS/ATM Infrastructure

Communications, navigation, and surveillance systems, employing digital technologies, including satellite systems together with various levels of automation, applied in support of a seamless global air traffic management system [ICAO Doc 9750 AN/963, 2002].

Communications, navigation and surveillance (CNS) is to air traffic management (ATM) what a bicycle is to a cyclist. In short: ATM cannot exist without the enabling technologies of communication, navigation and surveillance – commonly referred to as CNS [EUROCONTROL Skyway Magazine, 2010].

The FANS Committee, early in its work, recognized that for an ideal worldwide air navigation system, the ultimate objective should be to provide a cost effective and efficient system adaptable to all types of operations in as near four-dimensional freedom (space and time) as their capability would permit. With this ideal in mind, it was recognized that the existing overall air navigation system and its subsystems suffered from a number of shortcomings in terms of their technical, operational, procedural, economic and implementation nature[ICAO Doc 9750 AN/963, 2002].

In 1996, the International Civil Aviation Organization (ICAO) endorsed the development and use of GNSS as a primary source of future navigation for civil aviation. ICAO noted the increased flight safety, route flexibility and operational efficiencies that could be realized from the move to space-based navigation. Since then, air navigation service providers (ANSPs), airline operators and avionics/receiver manufacturers have engaged in an ambitious effort to develop GNSS, related augmentation systems, airborne receivers and ground infrastructure and to implement procedures, equip aircraft and train pilots in the use of satellite navigation.

At present GNSS include two fully operational global systems, the United States' Global Positioning System (GPS) and the Russian Federation's GLObal NAvigation Satellite System (GLONASS), as well as the developing global and regional systems, namely Europe's European Satellite Navigation System (GALILEO) and China's COMPASS/Bei- Dou, India's Regional Navigation Satellite System (IRNSS) and Japan's Quasi-Zenith Satellite System (QZSS). Once all these global and regional systems become fully operational, the user will have access to positioning, navigation and timing signals from more than 100 satellites.

In addition to these, there are satellite-based augmentation systems, such as the United States' Wide-area Augmentation System (WAAS), the European Geostationary Navigation Overlay Service (EGNOS), the Russian System of Differential Correction and Monitoring (SDCM), the Indian GPS Aided Geo Augmented Navigation (GAGAN) and Japanese Multi-functional Transport Satellite (MTSAT) Satellite-based Augmentation Systems (MSAS). Combining them with proven terrestrial technologies such as inertial navigation, will open the door to new applications for socio-economic benefits. The latter are applications that require not just accuracy, but in particular reliability or integrity. Safety-critical transportation applications, such as the landing of civilian aircraft, have stringent accuracy and integrity requirements [United Nations Office For Outer Space Affairs, 2012].

States should evaluate navigation systems against four essential criteria [ICAO Doc 9849 AN/457, 2005]:

a) Accuracy;

b) Integrity (Including time-to-alert);

c) Continuity of service; and

d) Availability of service.

Accuracy : GNSS position accuracy is the difference between the estimated and actual aircraft position. Ground-based systems such as VHF omnidirectional radio range (VOR) and instrument landing system (ILS) have relatively repeatable error characteristics. Therefore their performance can be measured for a short period of time (e.g. during flight inspection) and it is assumed that the system accuracy does not change after the measurement. GNSS errors however can change over a period of hours due to satellite geometry changes, the effects of the ionosphere and augmentation system design. While errors can change quickly for a core satellite constellation, satellite-based augmentation system (SBAS) and ground-based augmentation system (GBAS) errors would vary slowly over time.

Integrity and Time-to-Alert : Integrity is a measure of the trust which can be placed in the correctness of the information supplied by the total system. Integrity includes the ability of the system to alert the user when the system should not be used for the intended operation (or phase of flight). The necessary level of integrity for each operation is established with respect to specific horizontal/lateral (and for some approaches, vertical) alert limits. When the integrity estimates exceed these limits, the pilot is to be alerted within the prescribed time period.

The type of operation and the phase of flight dictate the maximum allowable horizontal/lateral and vertical errors and the maximum time to alert the pilot. These are shown in Table 1.

Operation	Oceanic En-Route	Continental En-Route	Terminal	Non-Precision Approach	Approach Procedure with Vertical Guidance (APV)		Category I
					APV-I	***APV-II***	
Horizontal / Lateral Alert Time	7.4 km (4 NM)	7.4 km to 3.7 km (4 to 2 NM)	1.85 km (1 NM)	556 m (0.3 NM)	40 m (130 ft)	40 m (130 ft)	40 m (130 ft)
Vertical Alert Limit	N/A	N/A	N/A	N/A	50 m (164 ft)	20 m (66 ft)	10 to 15 m (33 to 50 ft)
Maximum Time-to-Alert	5 min	5 min	15 s	10 s	6 s	6 s	6 s

Table 1 : GNSS Integrity Alert Limits by Airspace

Following an alert, the crew should either resume navigating using traditional navigation aids (NAVAIDs) or comply with procedures linked to a GNSS-based level of service with less stringent requirements.

Continuity : Continuity is the capability of the system to perform its function without unscheduled interruptions during the intended operation. This is expressed as a probability. Continuity requirements vary from a lower value for low traffic density en-route airspace to a higher value for areas with high traffic density and airspace complexity, where a failure could affect a large number of aircraft.

Where there is a high degree of reliance on the system for navigation, mitigation against failure may be achieved through the use of alternative navigation means or through the use of air traffic control (ATC) surveillance and intervention to ensure that separation is maintained.

For approach and landing operations, each aircraft can be considered individually. The results of a disruption of service would normally relate only to the risks associated with a missed approach. For non-precision, APV and Category I approaches, missed approach is considered a normal operation, since it occurs whenever the aircraft descends to the minimum altitude for the approach and the pilot is unable to continue with visual reference. This is therefore an operational efficiency issue, not a safety issue.

States should design an SBAS or GBAS to meet SARPs continuity standards. However, it is not necessary to issue a Notice to Airmen (NOTAM) on a service outage if continuity falls below the design level temporarily due to the failure of a redundant element.

Availability : The availability of a service is the portion of time during which the system is simultaneously delivering the required accuracy, integrity and continuity. The availability of GNSS is complicated by the movement of satellites relative to a coverage area and by the potentially long time it takes to restore a satellite in the event of a failure. The level of availability for a certain airspace at a certain time should be determined through design, analysis and modelling, rather than through measurement. When establishing the availability requirements for GNSS, the desired level of service to be supported should be considered. Availability should be directly proportional to the reliance on a GNSS element used in support of a particular phase of flight.

Traffic density, alternate NAVAIDs, primary/secondary surveillance coverage, potential duration and geographical size of outages, flight and ATC procedures are considerations that the States should take into account when setting availability specifications for an airspace, especially if the decommissioning of traditional NAVAIDs is being considered. An assessment of the operational impact of a degradation of service should also be completed.

GNSS provides significant improvements in relation to conventional radio navigation installations because of the global availability and accuracy of the GNSS signal. The potential for using GNSS for the application of separation was identified by SASP, and it has been working on developing GNSS-based separation minima since 2002. The first minima, for GNSS longitudinal separation, were published in November 2007, and the second will relate to GNSS lateral separation minima.

The GNSS receiver functions differently from conventional avionics receivers in that it presents data in reference to the waypoint the aircraft is approaching. Once an aircraft passes this waypoint, the GPS receiver again sequences the next waypoint as the “active” waypoint, and all information displayed is in reference to this new waypoint. This is referred to as “TO-TO” navigation [ICAO Cir 321 AN/183, 2010].

GNSS offers position measurements that are equal to or more accurate than distance measuring equipment (DME), very high frequency omnidirectional radio range (VOR) and non-directional radio beacons (NDB). The collision risk calculations done to establish the GNSS longitudinal separation referred to in this circular assumed the GNSS along-track accuracy to be ±0.124 NM, GNSS cross-track accuracy to be ±1 NM, DME fix tolerance to be ±0.25 NM plus 1.25 per cent of the distance to the antenna, VOR accuracy to be ±1 NM and ±5.2 degrees and NDB accuracy to be ±1 NM and ±6.9 degrees. All of them were assumed to be 95th percentile containment values.

In addition to superior accuracy, the GNSS receiver ensures integrity by providing alerts when a position with respect to the phase of flight cannot be guaranteed within a specific degree of certainty. These alert limits are shown at Table-2 [ICAO Cir 321 AN/183, 2010]:

Typical Operation	Horizontal Alert Limit
En-Route	3.7 km (2 NM)
Terminal	1.85 km (1 NM)
Approach	556 m (0.3 NM)

Table 2 : Alert Limit Times

The continuing growth of aviation increases demands on airspace capacity therefore emphasizing the need for optimum utilization of available airspace. Improved operational efficiency derived from the application of area navigation (RNAV) techniques has resulted in the development of navigation applications in various regions worldwide and for all phases of flight. These applications could potentially be expanded to provide guidance for ground movement operations.

RNAV systems evolved in a manner similar to conventional ground-based routes and procedures. A specific RNAV system was identified and its performance was evaluated through a combination of analysis and flight testing. For domestic operations, the initial systems used very high frequency omnidirectional radio range (VOR) and distance measuring equipment (DME) for estimating their position; for oceanic operations, inertial navigation systems (INS) were employed. These “new” systems were developed, evaluated and certified. Airspace and obstacle clearance criteria were developed based on the performance of available equipment; and specifications for requirements were based on available capabilities. In some cases, it was necessary to identify the individual models of equipment that could be operated within the airspace concerned. Such prescriptive requirements resulted in delays to the introduction of new RNAV system capabilities and higher costs for maintaining appropriate certification. To avoid such prescriptive specifications of requirements, this manual introduces an alternative method for defining equipage requirements by specifying the performance requirements. This is termed performance-based navigation (PBN) [ICAO Doc 9613 AN/937, 2008].

As a result of the large number of aircraft equipped with instrument flight rules (IFR)-certified GNSS equipment for navigation and its potential use for separation in the procedural environment, the Separation and Airspace Safety Panel (SASP) developed the separation minima detailed for interim use in the period of transition to a widespread implementation of performance-based navigation (PBN) [ICAO Doc 9613 AN/937, 2008].

GNSS makes RNAV affordable and accessible for all airspace users. Flexibility of sector and facility structure is facilitated through a homogeneous navigation infrastructure. As airspace transitions from current static to future dynamic structures, it is important to set a level of priority for GNSS implementation, taking into account the effects of GNSS introduction on oceanic, continental and terminal area operations [ICAO Doc 9849 AN/457, 2005].

The level of CNS/ATM services within the airspace in question and the traffic density suggest the degree of GNSS implementation that should be considered.

Generic airspace designations are:

a) oceanic/continental en-route airspace with low density traffic;

b) oceanic airspace with high density traffic;

c) continental airspace with high density traffic;

d) terminal area with low density traffic; and

e) terminal area with high density traffic.

Oceanic En-route Airspace

The efficient use of this airspace is currently limited due to the absence of traditional NAVAIDs, lack of surveillance and poor communications coverage. GNSS introduces accurate navigation where track spacing is generally set at one degree of latitude. The advent of GNSS in this type of airspace will certainly help deliver more efficient service to the user community by providing additional efficient trajectories.

In higher density traffic areas like the North Atlantic Organised Track System, where users want to take advantage of the jet stream or avoid it, optimum trajectories are limited due to the necessity of large lateral separation minima. Since the improved accuracy provided by GNSS is a prime contributor to the required target level of safety for reduced separation standards, lateral separation reductions and dynamic management of route structures will be made possible by using advances in surveillance based on automatic dependent surveillance (ADS).

Continental En-route and Terminal Airspace

Where continental en-route airspace is served by radar, independent surveillance and the availability of traditional NAVAIDs already allow for expeditious traffic flow. Benefits from GNSS should be accurately evaluated in order to ensure that the transition from the traditional environment is in fact an improvement both in efficiency and in economical terms.

Many States have already embraced GNSS implementation in terminal areas in the form of RNAV arrival and departure procedures that reduce delays and lessen pilot and controller workload. Other key benefits will be realized from closely spaced terminal routings that will enable aircraft to profit from more efficient vertically unrestricted flight profiles. The introduction of GNSS will also increase the availability of alternate aerodromes.

Terminal, Approach/Departure Airspace

GNSS implementation should be evaluated thoroughly so as not to compromise already optimized air traffic management processes.

The main benefits from GNSS implementation in this airspace will be derived from precision, APV and non-precision approaches at aerodromes and runway ends that are not served adequately by traditional NAVAIDs. As an RNAV system, GNSS allows the design of procedures to be tailored to user and environmental requirements, such as noise abatement. In addition, tighter departure corridors may be realized through the application of GNSS-based procedures for the transition to en-route airspace.

In planning GNSS approach and departure procedures, the impact on existing traffic flows should be considered. In particular close attention should be paid to holding patterns, missed approach procedures, and the determination of initial, intermediate and final approach fixes [ICAO Doc 9849 AN/457, 2005].

CONCLUSION

Being global in scope, GNSS is fundamentally different from traditional navigational aids(NAVAIDs). It has the potential to support all phases of flight by providing seamless global navigation guidance. This could eliminate the need for a variety of ground and airborne systems that were designed to meet specific requirements for certain phases of flight [ICAO Doc 9849 AN/457, 2005]

As work on the ATM operational concept is ongoing, consensus on several emerging concepts have to be reached (e.g. autonomy of flight, separation assurance, situational awareness, required total system performance (RTSP), required communication performance (RCP), required surveillance performance (RSP)). The operational requirements and functional specifications of some technologies (automatic dependent surveillance-broadcast (ADS-B)*) also have to be developed. Where these issues and/or technologies are addressed in the Global Plan, they are accompanied by a footnote indicating that work and consensus is still to be achieved through the ICAO process [ICAO Doc 9750 AN/963, 2002].

Requirements for navigation applications on specific routes or within a specific airspace must be defined in a clear and concise manner. This is to ensure that the flight crew and the air traffic controllers (ATCs) are aware of the on-board RNAV system capabilities in order to determine if the performance of the RNAV system is appropriate for the specific airspace requirements.

RNAV procedures that rely on GPS positioning are being used to provide improved approach and departure procedures at some of the biggest airports, including Hartsfield–Jackson Atlanta International Airport, Dallas/Fort Worth International Airport, New York John F. Kennedy International Airport and Phoenix Sky Harbour International Airport. Airlines say that these procedures are saving millions of dollars a year on reduced fuel consumption while helping reduce delays and trimming aircraft exhaust emissions [Air Traffic Technology International 2013 Magazine, 2013].

Advantages of GNSS services include the use of GPS/ABAS for en-route and non-precision approach operations where the coverage of ground-based navigation aids does not exist or is limited. In such an environment, GNSS would become the only navigation service as soon as it is introduced. SBAS-based precision approach capability to runways that currently only have a non-precision approach capability will provide further advantages in terms of increased safety and operational efficiency [ICAO Doc 9750 AN/963, 2002].

Benefits of the new systems can be analyzed in two difference categories. Firstly, from the point of navigation system we can list the benefits as listed below:

- High-integrity, high-reliability, all-weather navigation services worldwide,
- Improved four-dimensional navigation accuracy,
- Cost savings from reduction or non-implementation of groundbased navigation aids,
- Better airport and runway utilization,
- Provision of non-precision approach/precision approach (NPA/PA) capabilities at presently non-equipped airports,
- Reduced pilot workload,

On the other hand, the benefits can be listed from the point of view on air traffic management (ATM);

- Enhanced safety,
- Increased system capacity; optimized use of airport capacity,
- Reduced delays,
- Reduced flight operating costs,
- Reduced fuel consumption and emissions,
- More efficient use of airspace; more flexibility; reduced separations,
- More dynamic flight planning; better accommodation of optimum flight profiles,
- Reduced controller workload/increased productivity.

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