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GUIDELINES FOR THE INTRODUCTION AND OPERATIONAL USE OF THE GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)

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Chapter 1

INTRODUCTION

1.1 PURPOSE

1.1.1 The purpose of this document is to provide guidelines for introducing GNSS and specifically for realizing, in the short and medium terms, operational and economic benefits from the existing satellite navigation systems and the augmentations that will supplement them over the next few years. It is aimed at a wide audience within the civil aviation authorities responsible for the planning, implementation and operation of the global navigation satellite system (GNSS).

1.1.2 The systems in operation at present are the global positioning system (GPS), which has been operational since 1994, and the global orbiting navigation satellite system (GLONASS), which became operational in 1996. Satellite-based augmentation systems will be implemented in the United States, Europe, Japan and other States. These systems will enhance the accuracy, integrity, availability and continuity of service of the GPS and GLONASS systems to allow more effective use of these systems.

1.1.3 This document includes a basic explanation of satellite navigation technology, existing satellite systems, augmentations and avionics. Based on the experience of States which have already implemented satellite navigation operations, detailed guidelines are provided to enable States to plan for, and implement, satellite navigation in the near term. Finally, future prospects for the evolution of a GNSS are described.

1.2 GENERAL

1.2.1 Recommendations for the use of satellite technology for aviation navigation were developed by the ICAO Special Committee for the Monitoring and Co-ordination of Development and Transition Planning for the Future Air Navigation System (FANS (Phase II)). The FANS (Phase II) Committee developed a strategy for exploiting modern satellite, communications and computer technology to improve air traffic management and bring benefits to aircraft operators around the world. The fourth meeting of the FANS (Phase II) Committee (FANS (II)/4) recommended (Recommendation 8/3) that ICAO encourage the achievement of early benefits through the use of existing technological advances, with early exploitation of, for example, global navigation satellite system (GNSS) -type services through use of GPS, GLONASS, overlays, ground augmentations, etc. The ICAO Council (141/2) approved this recommendation on 4 February 1994.

1.2.2 The GNSS system will provide significant improvements in relation to conventional radio navigation installations. It is more accurate than the systems currently in service. It also provides a universal reference time. GNSS system navigation data can be integrated with the data of various on-board sensors, inertial sensors, altimeters and with aerodynamic parameters to provide a high quality service for the most advanced aircraft. When combined with air/ground data transmission systems, the GNSS system will provide an excellent basis for automatic dependent surveillance (ADS) in all airspaces. The progress initiated by the GNSS system and the future possibility of eliminating ground navigation installations will provide for significant improvements in the regularity, efficiency and economy of air transport. GNSS also has the potential to enhance safety.

1.2.3 In order to begin development of the GNSS, the United States GPS and the Russian GLONASS were offered to ICAO as a means to support the evolutionary development of GNSS. The GPS was declared operational in February 1994; GLONASS was declared operational in 1996. In October 1994, the United States formally stated its offer to make GPS available for the foreseeable future (a minimum of ten years), on a continuous world-wide basis and free of direct user fees. On 26 October 1994, the ICAO Council decided to accept the offer of the Standard Positioning Service of the GPS made by the United States Government. This acceptance has been communicated to all ICAO Contracting States (State Letter LE 4/49.1-94/89, dated 13 December 1994, refers). In the first half of 1996, the Russian Federation formally offered to make the standard-accuracy GLONASS channel available to the civil aviation community on a non-discriminatory basis for a period of at least 15 years with no direct user charges. This offer has also been accepted by the ICAO Council and the acceptance has been communicated to all ICAO Contracting States (State Letter LE 4/49.1-96/80, dated 20 September 1996, refers).

1.2.3.1 These systems will be supplemented by regional installations which will cover various regions throughout the world. The United States has begun the installation of the wide area augmentation system (WAAS) which will cover the American continent; Europe has started to develop the European geostationary navigation overlay service (EGNOS) system and various similar projects exist in Japan and other countries. The next generation of GNSS will retain this international character and will certainly provide a safe, regular, permanent and global service. New institutions will have to be set up in which all States will be able to play their part.

1.2.4 GNSS is fundamentally different from traditional ground-based navigation aids. GNSS is global in scope, with the space systems provided by only a few agencies. With GNSS, States will be less involved in the design and acquisition of ground-based infrastructure; their efforts will focus on developing operating procedures and ATM techniques based on State and regional requirements and the capabilities of GNSS, and approving its operational use.

1.2.5 A key feature of GNSS is that it has the potential to support operations from en-route through Category III precision approach and surface guidance. While the more demanding operations will require augmentation by ground, space or aircraft systems, GNSS has the potential to provide a seamless navigation guidance system, possibly eliminating the need for separate systems for different phases of flight.

1.2.6 It is for Contracting States to make appropriate GNSS implementation decisions. A number of States have already implemented GNSS operations. Through global co-operation, the benefits of their experience will allow other States to proceed more quickly in achieving the benefits of GNSS.

1.3 EXPLANATION OF TERMS

Explanations of terms pertinent to GNSS may be found in Appendix 5 of this document. A Glossary of Acronyms used in this document may be found in Appendix 6.

Chapter 2

EXPECTED BENEFITS

2.1 INTRODUCTION

2.1.1 Satellite navigation is expected to bring safety benefits through reducing hazards related to uncertain position and through more precise guidance. In some cases this technology will also increase the flexibility and efficiency of flight operations by reducing flight time and fuel required. Eventually, satellite navigation could also reduce the cost of providing services and expand aviation's ability to serve the public. These benefits are described in more detail below.

2.1.2 The benefits of GNSS can be classified in several ways, using the classification devised by the future air navigation systems (FANS) group: low and medium traffic density areas (such as over most oceans and lightly populated areas); high density traffic areas, for example oceanic areas, where there is no possibility of setting up ground installations; and areas of high traffic density with substantial ground infrastructure. In high density areas, GNSS alone may not provide benefits. It may be necessary to implement advanced ATM features to obtain all benefits.

2.2 SAFETY BENEFITS

2.2.1 It is either impractical or impossible to provide reliable and accurate ground-based guidance in remote and oceanic areas. The use of GNSS will allow pilots to know their position with a greater degree of certainty, thus decreasing the likelihood of some types of accidents. Even in areas well served by ground-based aids, the capabilities of GNSS provide greater awareness of aircraft position, thus reducing the possibility of accidents. The use of GNSS in conjunction with inertial navigation system/inertial reference system (INS/IRS) can eliminate some types of blunder errors normally associated with improper initialization of the INS/IRS. Finally, in areas where ground aids may be unreliable because of geographic, financial or other reasons, suitably trained pilots will be afforded the safety benefits of better navigation provided by GNSS.

2.2.2 Some ground-based aids currently used for non-precision approach, compared with GNSS, provide relatively coarse guidance to pilots and, in general, they do not provide critical information such as distance to the runway threshold. This means that visual manoeuvring may be required to land after sighting the runway, and in some cases late decisions to attempt a landing result in excessive speed and descent rate. These factors increase the probability of accidents. By providing more accurate guidance and distance to the missed approach point, GNSS will increase safety margins during non-precision approaches.

2.2.3 It is generally acknowledged that precision approaches are safer than non-precision approaches. The ground navigation equipment to support GNSS-based precision approaches is expected to be less costly than traditional instrument landing system (ILS) equipment, making it possible to provide this level of service at more airports, thereby increasing over-all safety. This equipment may also support surface guidance systems, reducing the possibility of conflicts on the ground.

2.3 OPERATIONAL EFFICIENCY BENEFITS

2.3.1 The global availability of accurate position and associated guidance may increase the efficiency of operations by reducing flight time and fuel required, through more precise navigation and, where practical, user-preferred routings. Weight limited flights can take advantage of the reduced fuel requirements, including contingency reserves, by increasing payloads and hence revenue.

2.3.2 The availability of GNSS-based non-precision approach guidance to runways not served by ground navigation aids, or served by unreliable ground navigation aids, will reduce delays, diversions, overflights and cancellations due to bad weather. This in turn will reduce operating costs. The increased number of airports served by precision approach based on GNSS will have a similar effect.

2.3.3 The potential of providing instrument approach capability at more airports could divert traffic from airports where delays are common due to congestion. With reduced congestion, operators using these airports will save flight time and fuel required.

2.3.4 The availability of accurate GNSS-based guidance on departure may allow greater flexibility in routings providing the possibility of lower climb gradients and higher payloads where currently terrain is a restricting factor.

2.3.5 The eventual use of 4D navigation capability of GNSS allows more precise timing of arrivals over an approach fix. The ability to meet required time of arrival is expected to contribute to capacity increases at airports and reductions in delays.

2.3.6 The eventual use of GNSS for all phases of flight is expected to provide savings for operators through a reduction in the types of on-board avionics. This will reduce capital costs and the cost of maintenance. Advanced integration techniques with inertial reference systems (IRS) may permit the use of less expensive inertial sensors.

2.3.7 In suitably equipped aircraft, the availability of accurate GNSS position and time may be additionally exploited through the use of such functions as automatic dependent surveillance (ADS) and controller pilot data link communications (CPDLC). Benefits will accrue particularly in areas of the world not currently served by radar. With the proper infrastructure in place to support ADS, it will be possible to reduce separation minima in remote and oceanic areas. This will provide time and fuel savings as more flights are able to operate along optimum routes and also increase system capacity by allowing reduced longitudinal and lateral separation.

2.4 OTHER BENEFITS

2.4.1 GNSS will allow safe and regular commercial operations at airports where, for geographic or cost considerations, it is not feasible to install ground aids.

2.4.2 Satellite navigation will allow operators to serve locations that were inaccessible using traditional aids due to terrain or other limitations. For example, emergency services will be enhanced by the ability to proceed directly to remote communities or to hospital helipads.

2.4.3 The availability of satellite navigation will allow the phased decommissioning and eventual elimination of traditional ground-based navigation aids. This will decrease costs in the longer term, resulting in savings for airspace users. Even in the early stages of GNSS implementation, civil aviation authorities may be able to avoid the cost of replacing existing navigation aids or installing new navigation aids.

2.5 ACHIEVING THE BENEFITS

GNSS is but one element of the ICAO CNS/ATM concept. Great as the potential benefits offered by GNSS may be, they cannot be fully realized without the active co-operation of air traffic service (ATS) providers, aircraft and avionics manufacturers, operators, service providers and international organizations at a regional level. In the short term, supplemental means use of GNSS for en-route and non-precision approach, and primary means use for oceanic/remote en route, or Category I precision approach under special conditions (see 7.1.2 and Appendix 3, paragraph 4), is possible for States that wish to gain early benefits from the use of GNSS.

Chapter 3

GNSS OPERATIONAL REQUIREMENTS

3.1 INTRODUCTION

Eventually, the global navigation satellite system is expected to become the primary means of position determination in all airspace. However, at present, GNSS alone cannot meet all the needs of civil aviation. GNSS implementation will therefore be carried out in an evolutionary manner, allowing gradual system improvements to be introduced. Near-term applications of GNSS are intended to enable the early introduction of satellite-based navigation, based on the use of existing satellite systems (GPS and GLONASS) and the use of certain augmentations. Medium-term applications will address existing satellite navigation systems with any augmentation or combination of augmentations required for operation in a particular phase of flight. Longer-term applications will apply to future satellite navigation systems.

3.2 OPERATIONAL REQUIREMENTS — TOTAL SYSTEM

3.2.1 The primary aim of airspace system design is to provide for safe aircraft operations for the intended phases of flight. This includes navigation along the intended flight path, obstacle avoidance and support of separation standards that accommodate required system capacity and safety. Three of the main interdependent parameters which affect the achievement of such a pre-determined level of airspace system safety, ‘‘target level of safety’’ (TLS) for a given traffic density are: aircraft navigation performance; communications performance and surveillance performance. These performance capabilities are then used to determine airspace design (separation minima/route spacing/sectorization), instrument procedures and air traffic control intervention capability. An increase or decrease in any single parameter may allow a corresponding increase or decrease in some or all of the other parameters. As aircraft and system capabilities improve, it is expected that corresponding improvements in system safety should be realized. The ICAO *Air Traffic Services Planning Manual* (Doc 9426) and ICAO Circular 120, *Methodology for the Derivation of Separation Minima Applied to the Spacing between Parallel Tracks in ATS Route Structures*, are available, providing a means to allow a trade-off between the system aspects of separation, navigation and intervention to ensure that an agreed TLS is satisfied. Additional guidance in this regard is under development by the Review of the General Concept of Separation Panel (RGCSP). A draft manual entitled *Manual on Airspace Planning Methodology for the Determination of Separation Minima* was recommended for publication by the RGCSP/9 Meeting in May 1996. This manual addresses airspace planning methodology, taking into account implementation of the required navigation performance (RNP) concept and area navigation techniques, to assist States in the implementation of CNS/ATM systems.

3.2.2 For the purposes of this document, the following explanation of terms has been adopted:

a) *operational requirements* — the fundamental operational requirements for safety of flight are quantified for some types of airspace, operations and phases of flight by ICAO bodies and civil aviation authorities. These operational requirements are independent of the systems used for communications, navigation, surveillance and air traffic management; and

b) *performance requirements* — specify how a system will support meeting an operational requirement.

3.3 GNSS SUPPORT OF PRESENT CAPABILITIES

Although it is intended to obtain early benefits by exploiting the near term capabilities of existing GNSS systems, this must be done without adversely impacting the current TLS where available. When no TLS figure is available, GNSS must be introduced without reducing levels of safety when compared to the current operations. For this reason, operational performance requirements for the near term application of GNSS are based on existing requirements for current systems and States or regions will need to apply operational procedures and limitations in airspace where GNSS is used in order to maintain or enhance current levels of safety. Guidance on such procedures and limitations is given later in this document.

3.4 CURRENT REQUIREMENTS

A high level generic requirement for civil aviation is to provide a safe, efficient, cost-effective, all weather, high integrity navigation system for all phases of operation. The information on current generic and specific requirements, with supporting references where appropriate, is detailed below. See definitions in Appendix 5.

3.4.2 Accuracy

3.4.2.1 The navigation system shall meet accuracy requirements for the intended phase of flight, as defined by the required navigation performance (RNP) or the existing airspace requirements.

3.4.2.2 The ICAO *Manual on Required Navigation Performance (RNP)* (Doc 9613) gives the accuracy required for four prescribed en-route RNP types, defining the RNP type number as the 95 per cent position accuracy expressed in nautical miles. The four RNP types are RNP 1, RNP 4, RNP 12.6 and RNP 20. (Thus, for example, RNP 4 demands an accuracy of ± 7.4 km (4.0 NM) at 95 per cent level of containment).

Accuracy Requirement

Reference: *ICAO Manual on Required Navigation Performance (RNP)* (Doc 9613)

RNP Type	*Accuracy (95%)*
20	± 37 km (20.0 NM)
12.6	± 23.3 km (12.6 NM)
4	± 7.4 km (4.0 NM)
1	± 1.85 km (1.0 NM)

Note.— Other RNP types may be implemented for use in various airspace.

3.4.2.3 The ICAO ‘‘Consolidated Guidance Material’’ (NAT Doc 001, T13.5) says that ‘‘aircraft which are approved for operations within the NAT MNPS airspace shall have navigation performance capability such that:

a) the standard deviation of lateral track errors shall be less than 6.3 NM (11.7 km);

b) the proportion of the total flight time spent by aircraft 30 NM (55.6 km) or more off the cleared track shall be less than 5.3×10^{-4}; and

c) the proportion of the total flight time spent by aircraft between 50 and 70 NM (92.6 and 129.6 km) off the cleared track shall be less than 13×10^{-5}.''

3.4.3 Integrity

The navigation system shall ensure integrity by providing timely positive indication of relevant failure and/or out of tolerance conditions within the performance limits specified for the intended phase of flight.

3.4.4 Availability

3.4.4.1 Availability is the percentage of time that the services of the system are usable. There should be sufficient redundancy within the system to meet the availability requirements. Availability should be high enough to allow safe and expeditious aircraft operations.

3.4.4.2 This requirement includes the concepts of ''coverage'', ''capacity'' and ''navigation fix rate''. ''Coverage'' is the space volume in which the signals are adequate to permit the user to determine position to a specified level of accuracy. ''Capacity'' is the number of navigating units that can simultaneously operate within the system coverage without saturating the system. ''Navigation fix rate'' is the number of outputs of the navigation quantity per unit of time.

3.4.4.3 ''GNSS planned non-availability'' is the proportion of time that the signal-in-space of the GNSS is not useable taking into consideration scheduled outages only (i.e. those with at least 24-hours notice). ''GNSS random non-availability'' is the proportion of time (excluding planned non-availabilities) and space over the area of interest when the services of the GNSS are not useable to support the required navigation performance.

3.4.5 Continuity

3.4.5.1 The navigation system shall provide a continuous service for airspace in use. The system design must preclude failures that result in erroneous data for operationally significant time periods. Any unscheduled break in service or the provision of false information shall be sufficiently short or rare as not to degrade the safety of aircraft beyond acceptable levels.

3.4.5.2 GNSS continuity is the probability that the GNSS will be available for the duration of a phase of flight, presuming that the GNSS was available at the beginning of that phase of flight.

3.4.6 Interference

The navigation system requires a properly allocated and protected spectrum in order to control potential sources of interference. In addition, the navigation system shall not cause harmful interference to any associated or adjacent radio electronic equipment installation in aircraft or on the ground. Refer to Chapter 5 and Appendix 2 of this document for more information on interference.

3.4.7 Navigation aid monitoring

3.4.7.1 Requirements for States to provide information on the operational status of navigation aids are documented in ICAO Annex 11, Chapter 7, which states that ATS units shall be kept informed of the current operational status of non-visual navigation aids. The *Air Traffic Services Planning Manual* (Doc 9426) also contains information on the monitoring of visual and non-visual aids. These documents were written prior to the development of space-based navigation systems. Each State must determine how to provide for these requirements when implementing GNSS.

3.4.7.2 The development of a monitoring policy for GNSS should consider that different performance can be expected from different receivers and autopilots. For example, the availability of RAIM is affected by algorithms used in the receiver, the ability of the receiver to acquire and track satellites and the integration of GNSS sensors with other sensors. There is also a wide variance in autopilots' ability to reduce flight technical error. For these reasons and due to the global nature of GNSS, the approach to monitoring will evolve as GNSS is implemented.

3.4.8 Notices to Airmen (NOTAM)

3.4.8.1 NOTAM will be required to report on the status of GNSS components. The adoption of GNSS will require that procedures be developed and implemented by each State to disseminate information to pilots on unavailability of any operations due to breaks in the availability of satellite signals.

3.4.8.2 GNSS is basically different from traditional navigation systems with fixed coverage areas. The implication of loss of service from a particular navigation satellite is not apparent without analysis requiring specialized computer software, because GNSS coverage is dynamic and the area of reduced capability due to a satellite outage moves rapidly.

3.4.8.3 In the United States, the Department of Defense notifies the FAA in a timely manner through a formal procedure of any changes, planned or unplanned, in the number of GPS satellites transmitting usable signals. The planned satellite outages are announced in the form of Notice Advisories to Navstar Users (NANU) at least 48 hours in advance of the event, as specified in the United States Federal Radionavigation Plan (FRP). The FAA generates a NOTAM based on space vehicle outages.

3.4.8.4 The FAA has developed the GPS Aeronautical Information System which became operational November 2, 1995. This system provides GPS aeronautical information for non-precision approaches.

3.5 MEETING THE OPERATIONAL REQUIREMENT

3.5.1 The basic operational requirement is to provide for safety, regularity and efficiency, with safety of paramount importance. For some operations, safety is assured through meeting specific ICAO or State standards, some of which are under revision to exploit the benefits provided by GNSS and other communications, navigation, and surveillance/air traffic management (CNS/ATM) components. It is important to recognize that for many operations, specific standards do not exist. In these situations, the safety of an operation is based on operational judgement.

3.5.2 To determine whether an existing operation can benefit from GNSS, an analysis must be performed to assess if an improvement in regularity or efficiency is possible while maintaining or increasing the level of safety. The starting point for the analysis is the operation itself, which must be defined and understood. Existing requirements for the operation must then be identified to the extent possible.

3.5.3 Next, the capabilities of a GNSS system, including the space segment, avionics and possible augmentation systems, must be assessed. In determining whether GNSS can be used for a given operation, it will be necessary to determine if the GNSS solution provides an equivalent level of safety, while improving regularity or efficiency.

3.5.4 In the near term, it will sometimes be evident that the GNSS system alone does not meet all requirements. It must be recognized, however, that as new standards for avionics are developed, GNSS system capabilities may be enhanced, meaning that new applications may be possible with the next generation of avionics.

3.5.5 Shortfalls in meeting requirements may be addressed by developing suitable procedures and limitations, which will be conditions of approval of the operation. This may be an iterative process, requiring that procedures and limitations be developed to ensure safety levels are maintained. The types of procedures that can be used to ensure that the basic GNSS can be used safely are:

a) pilot procedures, as specified in the Aircraft Operating Manual, that ensure that the pilot will operate the avionics properly and react properly to such things as Receiver Autonomous Integrity Monitoring (RAIM) (see 4.3.2) warnings and other abnormal situations, as well as indicate the limitations imposed on the operation;

b) air traffic procedures, including restrictions, combined with communications and surveillance capabilities, to support GNSS operations, and in some cases to monitor the integrity of GNSS operations;

c) State procedures to ensure the integrity of surveys and the data base used in receivers;

d) instrument procedure design standards matched to GNSS performance and conceived with the intent of avoiding problems;

e) certification of the procedure, which may involve flight inspection and signal monitoring, perhaps on a continuous basis;

f) specifying the need for back-up using traditional aids or radar for certain operations; and

g) pre-departure checks to verify that a sufficient number of satellites will be operating during the proposed flight.

3.5.6 In the final analysis, the operation with GNSS, combined with suitable procedures and limitations, must be assessed either against existing standards or against the current operation. In many cases, operational judgement, rather than mathematical analysis, will be used in this assessment. In any case, it must be established that the operation can be performed using GNSS while not reducing the level of safety. In some cases, it may be advisable to begin with a trial or demonstration period to develop a level of confidence in the GNSS system, procedures and limitations.

Chapter 4

GNSS SYSTEM DESCRIPTION

4.1 GNSS OVERVIEW

4.1.1 GPS and GLONASS have the capability to provide accurate position and time information world-wide, but have limited ability to warn users of malfunctions. The accuracy provided by both systems meets aviation requirements for en route through non-precision approach, but does not meet requirements for precision approach. Augmentation systems can be used to meet the four basic operational performance requirements. Integrity, availability and continuity can be provided using on-board, ground- or space-based techniques or systems. Accuracy can be enhanced using differential techniques. The total system, including GPS/GLONASS and all augmentation is referred to as GNSS. Efforts to bring the full benefits of satellite navigation to users focus on developing these augmentations and certifying them for operational use.

4.1.2 As successive RNP standards are met through enhancements, conditional approvals will be granted, thus providing benefits to users in an incremental fashion. At first, a backup system of traditional navigation aids will be used to meet some RNP Standards. As GPS and GLONASS evolve through augmentations into a mature GNSS, GNSS will be approved for primary or sole means use.

4.1.3 Satellite systems providing navigational functions to the international civil aviation user must comply with the ICAO approved common geodetic reference datum, i.e. World Geodetic System 1984 (see 6.4). It should be noted that GPS utilizes WGS-84 as the reference datum; however, GLONASS utilizes PE-90.

4.1.4 Described below are the system descriptions, technical specifications and operational performance parameters of GPS and GLONASS as well as augmentations and avionics associated with the two systems.

4.2 EXISTING SATELLITE-BASED NAVIGATION SYSTEMS

4.2.1 Global positioning system (GPS)

4.2.1.1 *Brief description*

4.2.1.1.1 The global positioning system (GPS) is a satellite-based radio navigation system which utilizes precise range measurements from the GPS satellites to determine precise position and time anywhere in the world. The system is managed for the government of the United States by the United States Air Force, the system operator, providing significant benefits to the civil aviation community through a variety of applications. The standard positioning service (SPS), which utilizes a coarse acquisition (C/A) code on the L1 frequency, is designed to provide accurate positioning capability for civil users throughout the world. A precise positioning service (PPS), which utilizes the Precise Code (P-code) is designated to provide a more accurate positioning capability. Currently, the

P-code is encrypted to Y-code restricting access to the more accurate positioning capability to users authorized by the USA Department of Defense. The PPS uses a second frequency (L2) which has not been authorized for public use. The GPS has three major segments: space, control and user. Basic GPS technical and performance characteristics are shown in Table 4-1 below.

4.2.1.1.2 The GPS space segment is composed of 24 Block II/IIA satellites in six orbital planes. The Block II and IIA satellite and a modified version, the Block IIR satellite, will be the mainstay of the constellation over the next decade. From a civil aviation user's perspective, the Block II, II/A and IIR satellites provide an identical service. The satellites operate in near-circular 20 200 km (10 900 NM) orbits at an inclination angle of 55 degrees to the equator and each satellite completes an orbit in approximately 12 hours. The spacing of satellites in orbit is arranged so that a minimum of four satellites with a position dilution of precision (PDOP) of 6 and a 5-degree mask angle are in view to users with a global average availability of 99.75 per cent with twenty-four operational satellites.

4.2.1.1.3 The GPS control segment has five monitor stations and three ground antennas with uplink capabilities. The monitor stations use a GPS receiver to passively track all satellites in view and accumulate ranging data from the satellite signals. The information from the monitor stations is processed at the master control station to determine satellite clock and orbit states and to update the navigation message of each satellite. This updated information is transmitted to the satellites via the ground antennas, which are also used for transmitting and receiving health and control information.

4.2.1.1.4 The GPS user segment consists of an antenna and receiver-processor to receive and compute navigation solutions to provide positioning and precise timing to the user. The satellites broadcast a pseudo-random code timing signal and data message that the airborne equipment processes to obtain satellite position and status data as well as a measurement of how long a radio signal takes to reach the receiver from each satellite. Every satellite's exact measured orbital parameters (ephemeris data) are broadcast as part of the data message sent in the GPS signal. The receiver uses the ephemeris data to calculate satellite location. By knowing the precise location of each satellite and precisely matching timing with the atomic clocks on the satellites, the receiver can solve four simultaneous equations for the three components of position and time.

4.2.1.1.5 Measurements from a minimum of four satellites are required to establish three-dimensional position and time, a minimum of three satellite measurements are required to determine a two-dimensional position and time if altitude is known. Accuracy is dependent on the precision of the measurements from the satellites and the geometry of the satellites used.

4.2.1.1.6 The GPS and GLONASS satellites can, under exceptional circumstances, transmit incorrect signals or signals which are outside the tolerances laid down by the standards without providing an immediate warning to users. Such incidents must be detected in a timely fashion; it is for this reason that RAIM and the integrity monitoring feature of augmentation systems are required. These augmentation systems may also compensate for a lack of satellites which may arise, for example, in the event of the permanent failure of one or more satellites.

4.2.1.1.7 Finally, the accuracy of the GPS system is limited to several tens of metres, for technical and physical reasons. These limitations require the use of augmentation systems, which will enhance the accuracy of the GNSS system in certain locations.

Table 4-1. GPS technical and performance characteristics

1. Satellites (space segment)	
Constellation	24 satellites (4 satellites x 6 orbits)
Altitude	20 200 km
Period	11 hours 56 minutes
Inclination	55 degrees
Satellite design life	7.5 years
2. Ground stations (control segment)	
Master control station	1
Ground antenna	3
Monitor station	5
3. RF signal	
Carrier frequency	1 575.42 MHz (L1)
Signal power level	–160 dBW (at Earth's surface)
Polarization	Right-hand circular
4. Accuracy (SPS)	
Position	
Horizontal	100 m (95 per cent probability) 300 m (99.99 per cent probability)
Vertical	156 m (95 per cent probability)
Pseudorange	
Velocity	not to exceed 2 m/s
Acceleration	8 mm/s^2 (95 per cent probability) not to exceed 19 mm/s^2 340 ns (95 per cent probability)
5. Coverage	Global
6. User capacity	Unlimited
7. Coordinate system	World geodetic system 1984 (WGS-84) Earth-centred Earth-fixed

4.2.2 Global orbiting navigation satellite system (GLONASS)

4.2.2.1 *Brief description*

4.2.2.1.1 The Russian Federation is in the process of implementing the GLONASS to provide signals from space for accurate determination of position, velocity and time for properly equipped users. GLONASS will provide high accuracy and availability to users. Navigation coverage will be continuous, world-wide and all-weather. Three-dimensional position and velocity determinations are based upon the measurement of transit time and Doppler shift of RF signals transmitted by GLONASS satellites. Basic GLONASS technical and performance characteristics are shown in Table 4-2 below.

4.2.2.1.2 The GLONASS space segment consists of twenty-four operational satellites and several spares. GLONASS satellites orbit at an altitude of 19 100 kilometres with an orbital period of 11 hours and 15 minutes. Eight evenly spaced satellites are to be arranged in each of the three orbital planes, inclined 64.8 degrees and spaced 120 degrees apart.

4.2.2.1.3 A navigation message transmitted from each satellite consists of satellite coordinates, velocity vector components, corrections to GLONASS system time and satellite health information. To obtain a system fix, a user's receiver tracks at least four satellite signals, either simultaneously or sequentially, and solves four simultaneous equations for the three components of position and time (a position solution may be derived from three satellites if an external source of time or altitude is provided).

4.2.2.1.4 GLONASS satellites broadcast in two L-band portions of the RF spectrum and have two binary codes, the C/A code and the P code, and the data message. GLONASS is based upon a frequency division multiple access (FDMA) concept. GLONASS satellites transmit carrier signals in different L-band channels, i.e. at different frequencies. A GLONASS receiver separates the total incoming signal from all visible satellites by assigning different frequencies to its tracking channels. The use of FDMA permits each GLONASS satellite to transmit identical P and C/A codes.

4.2.2.1.5 Each GLONASS satellite transmits navigation data at a rate of 50 bits per second. The navigation data message provides information regarding the status of the individual transmitting satellite along with information on the remainder of the satellite constellation. From a user's perspective, the primary elements of information in a GLONASS satellite transmission are the clock correction parameters and the satellite position (ephemeris). GLONASS clock corrections provide data detailing the difference between the individual satellite's time and GLONASS system time, which is related to UTC.

4.2.2.1.6 The GLONASS ground segment performs satellite monitoring and control functions and determines the navigation data to be modulated on the coded satellite navigation signals. The ground segment includes a master control station, monitoring and upload stations. Measurement data from each monitoring station is processed at the master control station and used to compute the navigation data that is uploaded to the satellites via the upload station. Operation of the system requires precise synchronization of satellite clocks with GLONASS system time. To accomplish the necessary synchronization, clock correction parameters are provided by the master control station.

4.2.2.1.7 The GLONASS user segment is covered in the avionics section (see 4.4.3).

4.2.2.1.8 To provide ephemeris information, GLONASS satellites broadcast their three-dimensional Earth-centred Earth-fixed (ECEF) position, velocity and acceleration for every half-hour epoch. For a measurement time somewhere between the half-hour epochs, a user interpolates the satellite's coordinates using position, velocity and acceleration from the half-hour marks before and after the measurement time. The resulting ECEF coordinates are referenced to the Parameters of the Earth 1990 (PE-90), a non-ICAO Standard.

Table 4-2. GLONASS technical and performance characteristics

1. Satellites (space segment)	
Constellation	24 satellites (operational) (8 satellites x 3 orbits)
Altitude	19 100 km
Period	11 hours and 15 minutes
Inclination	64.8 degrees
Satellite design life	not less than 3 years (in future a life span of at least 5 years)
2. Ground stations (Control segment)	
Master control station	1
Upload station	4
Laser tracking station	1
Beacon monitor station	2
3. RF signal	24 L1 carrier frequencies possible until 1998. Carrier spacing is 0.5625 Mhz starting from channel 1 at 1 602.5625 MHz.
Frequency bandwidth	(1 602.5625 – 1 615.5 + 0.5 MHz (L1) – see Note)
Signal power level	161 dBW (at Earth's surface)
Radio link energetic potential	(39-44) dB.Hz
Polarization	Right-hand circular
4. Accuracy (CSA)	
Position	
Horizontal	50-70 m (99.7 per cent probability)
Vertical	70 m (99.7 per cent probability)
Velocity	15 cm/s (99.7 per cent probability)
Time	1 µs
5. Coverage	Global
6. User capacity	Unlimited
7. Coordinate system	Parameters of the Earth 1990 (PE-90) Earth-centred Earth-fixed

Note.— No carriers currently operate in the 1 610.6 — 1 613.8 MHz band. After 1998, GLONASS carriers will not operate above 1 610 MHz, only the lower twelve channels will be used. GLONASS will probably migrate to channels –7 to +4 by 2005. Channels five and six will be used for technical purposes over Russian territory. This will be the final configuration.

4.3 GNSS AUGMENTATION

To meet the operational performance requirements (accuracy, integrity, availability and continuity) for all phases of flight, both GPS and GLONASS require varying degrees of augmentation. To overcome inherent system limitations, augmentations have been proposed in three broad categories: on-board, ground-based and satellite-based.

4.3.2 On-board augmentation

4.3.2.1 One type of on-board augmentation is called receiver autonomous integrity monitoring (RAIM), which can be used if there are more than four satellites with suitable geometry in view. With five satellites in view, five independent positions can be computed. If these do not match it can be deduced that one or more of the satellites are giving incorrect information. If there are six or more satellites in view more independent positions can be calculated and a receiver may be able to identify one faulty satellite and exclude it from the position determination calculations. The latter is called fault exclusion while the former is called fault detection. Based on this information, the pilot can determine the level of performance available and modify operations as required.

4.3.2.2 RAIM for GPS or GLONASS is not globally available 100 per cent of the time. Availability of RAIM is determined by such parameters as receiver mask angle, phase of flight, on-board system augmentations, satellite outages and geographic position.

4.3.2.3 Other on-board augmentations can also be implemented and are usually termed aircraft autonomous integrity monitoring (AAIM). An inertial navigation system is a very powerful augmentation for GPS/GLONASS. It can be used during short periods when the satellite navigation antennas are shadowed by the aircraft during manoeuvres or during periods when insufficient satellites are in view.

4.3.2.4 Other augmentation techniques, particularly useful for improving availability of the navigation function, could include altimetry-aiding, more accurate time sources or some combination of sensor inputs combined through filtering techniques.

4.3.3 Ground-based augmentation

4.3.3.1 For ground-based (also referred to as local area) augmentation systems, a monitor is located at or near the airport where precision operations are desired. Signals are sent to aircraft in the vicinity (out to approximately 37 km (20 NM). These signals provide corrections to increase the position accuracy locally along with satellite integrity information. To do this it is necessary to have a data link between the ground and the aircraft. Many such systems have been proposed and tested using different techniques and frequency bands.

4.3.3.2 Ground-based augmentation has the potential to support operations down through Category III precision approach.

4.3.4 Satellite-based augmentation

4.3.4.1 It would not be practical to provide coverage with ground-based systems for all flights. One way to provide augmentation coverage over large areas is to use satellites to transmit augmentation information. This is known as satellite-based augmentation (also referred to as wide area or regional augmentation). The first satellites with the transponders to support this capability are Inmarsat-3 geostationary satellites, the first of which was launched in early 1996. The operational service in the United States (WAAS) is expected to be available from 1998. In Europe, availability of the European Geostationary Navigation Overlay Service (EGNOS) is planned for 1999. In the Asia-Pacific area, a service provided by the Japanese Multi-Functional Transport Satellite (MTSAT) is expected to be available in 1999. Further details on satellite-based augmentation are contained in section 7.2.

4.3.4.2 It is envisaged that a satellite-based augmentation service could provide integrity information, extra ranging signals and a differential component that will together support all operations down through Category I precision approach.

4.3.4.3 The provision of satellite-based augmentation by geostationary satellites has certain limitations. These satellites orbit above the equator, so that the elevation angle above the horizon is low at high latitudes. This can mean that their signals are masked by aircraft structure or terrain, making it impossible to rely on service provided by these satellites. This suggests that other GNSS augmentation satellite orbits and/or ground-based augmentation must be considered to support operations in these areas.

4.3.4.4 The realization of satellite-based augmentation benefits requires world-wide implementation to a common standard. This suggests regional co-operation to establish networks of reference stations and to develop agreements for the sharing of master stations and geostationary communications links.

4.4 AVIONICS

4.4.1 Single sensor and multisensor equipment

4.4.1.1 Simple GPS or GLONASS receivers that do not use RAIM (or similar forms of integrity monitoring based on non-GNSS augmentation) generally cannot be certified as meeting requirements for any phase of flight. The more sophisticated GNSS-based systems use various integrity monitoring systems and augmentations and are suitable for en-route and non-precision approach operations.

4.4.1.2 Avionics are being introduced in stages as GNSS evolves to a sole means system of navigation. The first instrument flight rules (IFR) use of GPS was based on multisensor receivers. In these installations, a GPS sensor was installed to enhance guidance accuracy, but it could not be used as the only sensor for IFR operations. In these units, the GPS position is continuously compared with positions derived from other sensors, such as Omega or INS. If the GPS position differs by a set amount (about 3 NM), the GPS sensor is rejected.

4.4.1.3 Multi-sensor systems, using GNSS as one of the sensors, are expected to be in use on civil transports for the foreseeable future. Multi-sensor navigation systems generally exhibit better levels of performance than the individual sensor or stand-alone systems. Aircraft using multi-sensor navigation systems, such as integrated GNSS/IRS or GNSS/IRS/FMS, may be certified as meeting levels of RNP which could not be obtained by use of GPS or GLONASS alone.

4.4.2 Supplemental equipment

4.4.2.1 The second IFR use of GPS was as a supplemental system. The ‘‘supplemental’’ designation means GPS is approved for use in conjunction with a navigation system approved for sole means operation, such as VOR. This approval allows GPS to be used most of the time as the primary source of guidance, with the understanding that pilots will back up GPS with sole means systems. Currently, the standard for GPS supplemental avionics is United States Technical Standard Order (TSO) C129. The key feature of TSO-C129 involves providing integrity for GPS, either through RAIM or an equivalent technique.

4.4.2.2 There are three basic classes of equipment specified in TSO-C129:

a) Class A equipment incorporates both the GPS sensor and navigation capability in one unit, which is typically panel-mounted. The receiver incorporates RAIM to ensure integrity. Class A1 equipment is approved for en-route, terminal and non-precision approach operations. Class A2 equipment is approved for en-route and terminal operations. Class A equipment is typically installed in small aircraft or to retrofit older large aircraft where it is not possible to integrate GPS capability with the on-board navigation system;

b) Class B equipment consists of a GPS sensor that provides data to an integrated navigation system. Classes B1 and B2 provide RAIM capability. B1 allows en-route, terminal and non-precision approach, while B2 allows en-route and terminal operations. Classes B3 and B4 sensors are integrated to provide integrity at the aircraft level equivalent to the integrity provided by RAIM; B3 allows en-route, terminal and non-precision approach, while B4 allows en-route and terminal operations; and

c) Class C equipment consists of a GPS sensor that provides data to an integrated navigation system which provides enhanced guidance to an autopilot or flight director to reduce flight technical error. It is approved for installation in air carrier aircraft (FAR Part 121). Otherwise, sub-classes C1 through C4 correspond to sub-classes B1 through B4.

4.4.2.3 TSO C129 also requires predictive RAIM capability for non-precision approach. This allows the pilot to determine, before take-off, if RAIM will be available at the planned destination within 15 minutes before or after the estimated time of arrival, for flight planning purposes. Prior to initiating an approach, the receiver must automatically inform the pilot if RAIM will not be available upon reaching the final approach fix. The availability of RAIM depends on actual and planned satellite outages. Information on planned outages is not currently contained in the GPS navigation message. Therefore, States must consider providing the information pilots need to account for RAIM availability when planning their flights. (See also 6.12).

4.4.2.4 The first equipment approved under TSO-C129 was a Class C4 unit, in July 1993. The first Class A2 unit was approved in September 1993. The first equipment approved for non-precision approach was a Class C3 unit, in October 1993. The first equipment with RAIM approved for non-precision approach was a Class A1 unit, in February 1994.

4.4.2.5 Since the end of 1991, several civil airframe manufacturers have achieved type certification with a GPS receiver on their aircraft. The first certifications were for Class A2 units (stand-alone GPS). Some aircraft are certified with a GPS receiver integrated in a multi-sensor navigation system (TSO-C129 Class C or equivalent certification criteria). On these aircraft, two GPS receivers are installed using an autonomous architecture or a hybrid architecture. In an autonomous architecture, GPS data are directly provided from the GPS receiver to the flight management system (FMS). In a hybrid architecture, GPS data are mixed with inertial data by the INS or IRS. With this architecture, the FMS generally uses hybrid GPS-Inertial data to navigate.

4.4.2.6 When GPS receivers do not have RAIM (Classes B3, B4, C3, C4), integrity is provided at the aircraft level by the multi-sensor navigation system as described in 4.4.1. If integrity cannot be confirmed by the other navigation sensors, the GPS data are rejected.

4.4.3 GPS/GLONASS equipment

Significant benefits (increased accuracy, integrity, availability and continuity) can be provided by combined use of GPS and GLONASS signals in the same avionics. RTCA is developing avionics minimum operational performance standards (MOPS) for GPS augmented with GLONASS. The Airlines Electronic Engineering Committee (AEEC) has developed Aeronautical Radio, Inc. (ARINC) Characteristic 743A which addresses the form, fit and function for an airline installation of one unit that includes GPS and GLONASS. Several manufacturers have designed equipment that could meet the AEEC requirements and this design could be modified to meet the RTCA draft MOPS requirements. Manufacturers have developed GPS/GLONASS receiver cards that can be used in a portable computer. As a result of the deployment of a complete GLONASS constellation, it is expected that commercial availability of equipment incorporating GLONASS receiving capability will increase significantly.

4.4.4 Primary means — United States FAA approval

4.4.4.1 The United States has developed standards to guide the implementation of GPS primary means oceanic/ remote area operations. The approval would apply initially to areas where 50-mile or greater separation standards apply. This is an extension of the current supplemental approval.

4.4.4.2 The main impetus behind this initiative is the uncertain future of the OMEGA navigation system, which is now used by many operators for navigation over the oceans. It was concluded that GPS could be used as the primary means of navigation in oceanic or remote areas, provided that additional requirements were imposed on receiver design and flight operations, including planning the flight for periods when sufficient satellites are available.

4.4.4.3 In addition to meeting TSO-C129, the receiver must, among other things, track satellites down to at least 5 degrees above the horizon and preferably lower, identify and exclude a bad satellite or satellites, exclude a satellite that causes a step function or steep ramp function errors and exclude a satellite designated unhealthy by the GPS ephemeris health word. Dual receivers will be necessary to ensure loss of function is unlikely. There are also desired performance characteristics, operational requirements and operational restrictions.

4.4.5 Sole means

GPS or GLONASS sole means operations will require augmentation, such as local or wide area augmentation or a combination of GPS and GLONASS. Standards are being developed for avionics that will use local or wide area augmentation system signals to achieve required levels of accuracy, availability, continuity and integrity and are expected to be available in the mid term.

Chapter 5

INTERFERENCE

5.1 POTENTIAL FOR INTERFERENCE

5.1.1 The potential for interference exists to some extent in all radio navigation bands. As with any navigation system, GNSS navigation signals must be protected from harmful interference resulting in the degradation of navigation performance.

5.1.2 Current satellite radio navigation systems feature relatively weak received signal power, meaning that an interference signal could cause loss of service at a somewhat lower receiver power level than with current terrestrial-based systems. Terrestrial system interference typically extends over a local area near a specific installation. Due to the nature of the signal source and to the widespread application being planned for satellite navigation, interference may not be limited to areas near terrestrial installations, but can exist wherever the signal is authorized for use. GNSS, however, is more resistant to misleading navigation errors from interference signals than current systems.

5.1.3 GPS and GLONASS operate within a protected spectrum as allocated by the International Telecommunications Union. States should ensure that their national frequency allocations and assignments in the 1 559-1 610 MHz band do not have the potential to cause interference to GPS or GLONASS operations.

5.1.4 Services operating in bands outside the protected spectrum could also generate harmful interference to GPS or GLONASS. The potential for harmful interference from sources on board an aircraft depends on the individual aircraft, type of transmitting equipment, location of transmitters, antennas, cabling, etc.

5.2 TECHNIQUES THAT ELIMINATE OR MITIGATE INTERFERENCE

5.2.1 ICAO SARPs are being drafted to take into account and mitigate against interference processes as appropriate.

5.2.2 Intentional interference is possible for all radio navigation systems and should be dealt with by appropriate State authorities. The potential for unintentional interference to GNSS should be dealt with via a combination of technical and institutional measures.

5.2.3 Aircraft CNS systems should be designed with the potential for interference in mind. Aircraft certification and installation procedures should require demonstration of protection against on-board harmful interference. It is important to evaluate airspace where aircraft are authorized to fly to identify potential sources of interference.

5.2.4 The principal mitigation techniques include shielding, filtering, receiver design techniques and, especially on larger aircraft, physical separation of antennas, transmitters, and cabling.

5.3 ADDITIONAL INFORMATION

Full information on regulatory aspects, interference mechanisms and mitigation techniques is found in Appendix 2.

Chapter 6

IMPLEMENTATION CONSIDERATIONS

6.1 IMPLEMENTATION TIME-SCALE

6.1.1 Near-term

This time-scale addresses early introduction of satellite-based navigation in some regions of the world.

a) Using the GNSS systems that are already in place,

b) on-board augmentations (e.g., RAIM, AAIM, baro) are used to improve the basic integrity as well as the availability of navigation integrity. Ground-based augmentations (e.g. LADGPS for Special Category I precision approach (see 7.1.2 and Appendix 3, paragraph 4) are used to improve the accuracy; and

c) as a result, existing satellite-based navigation systems can be used in the near term as supplemental means down through non-precision approach. In addition, the improved availability of navigation integrity together with lower availability requirements for en route (oceanic/remote) could allow the use of satellite-based systems as primary means for this phase of flight. Where the required ground-based augmentation is available, satellite-based systems can be used for Special Category I precision approach.

6.1.2 Mid-term

This time-scale addresses existing satellite navigation systems (GPS and GLONASS) with any augmentation or combination of augmentations.

a) Develop augmentations to provide improved integrity, accuracy, availability and continuity of service to bring total system capabilities up to the required level; and

b) as a result, mid-term satellite-based systems could be used as sole means for all phases of flight down through CAT I. Use down through CAT III will still need to be demonstrated.

6.1.3 Long-term

This time-scale applies to future navigation systems.

a) Develop new civil system that is designed to meet the requirements and is under civil control; and

b) all issues, including control, being resolved, long-term satellite-based systems could be used as sole means for all phases of flight.

6.2 IMPLEMENTATION STEPS

6.2.1 The use of GNSS for IFR operations must be authorized by the State civil aviation authority. Prior to approval, there are a number of operational and technical requirements that must be met. The aviation authority will need to consider the following implementation steps:

a) procedures development;

b) aeronautical coordinates referenced to the WGS-84 coordinate system;

c) data base-related issues;

d) certification and operational approvals;

e) ground and flight inspection;

f) trials and demonstrations;

g) GNSS planning and organization;

h) GNSS training;

i) communications;

j) legal issues; and

k) implementation assistance.

These steps in the GNSS implementation process have already been undertaken by some States. The lessons they have learned are incorporated in the following material.

6.2.2 Guidance on institutional issues will be promulgated by the appropriate ICAO body. States, however, should note that some technical implementation issues may be directly linked to, or require institutional decisions. States should consider these issues when implementing operational GNSS systems.

6.3 PROCEDURES DEVELOPMENT

6.3.1 Instrument procedure design criteria and obstruction/terrain criteria need to be developed and approved prior to instrument approach development. The FAA has approved and issued FAA Order 8260.38, Civil Utilization of global positioning system (GPS) (see Appendix 1) which provides the criteria for developing new GPS non-precision approaches.

6.3.2 Procedures are required to provide the maximum gains from satellite navigation and should be based on the anticipated benefits expected from GNSS. States may find it desirable to initiate GNSS operations by initially using overlays of existing ground navigation aid approaches or go directly to designing new approaches. Procedures for issuing Notices to Airmen (NOTAM) concerning the availability of GNSS also need to be developed.

6.3.3 In most cases, en-route procedures will be developed using existing RNAV airway design criteria. Criteria will have to be developed for GNSS non-precision approach design, as will approach documentation. States whose criteria depend upon PANS-OPS will have to assess GNSS performance and develop criteria. In Canada and the United States, terminal instrument procedures (TERPS) criteria have been developed for these approaches. Work is also under way in these States to determine the best location for approach way-points and to derive maximum benefit from GPS. The FAA has developed Advisory Circular AC-90-94 which gives pilots guidance and direction on the use of GPS.

6.3.4 Pilot procedures, contained in aircraft operating manuals, should also be developed to address the characteristics of GNSS and minimize pilot and ATC workload.

6.3.5 Authorities need to develop procedures based on the anticipated or conceptual benefits expected from the GNSS system. Trials provide an opportunity to evaluate procedures in an operational environment. Initial procedures should parallel present procedures and evolve as GPS benefits become available. The development of procedures depends on the levels of approval desired and should be developed commensurate with the milestones outlined in the development plan.

6.4 AERONAUTICAL COORDINATES REFERENCED TO THE WGS-84 COORDINATE SYSTEM

6.4.1 With space-based systems, all air navigation depends on the accurate position of a series of way-points, rather than their positions relative to one another. This means that way-point coordinates, particularly those used for approach and landing, must be of a high quality and based on the same geodetic reference system used by the satellite positioning system.

6.4.2 The successful global implementation of satellite navigation is predicated on the existence of a coordinate and procedures database of a very high quality. This is necessary for all potential aviation applications of advanced navigation systems, including precision area navigation (PRNAV), approach/landing/departure and surface movement guidance and control operations.

6.4.3 Unlike ground-derived coordinates, satellite system-derived coordinates are geocentric or referenced to a model of the Earth whose origin is at the centre of the mass of the planet. The Earth-centred model used by ICAO is known as the World Geodetic System of 1984 (WGS-84). Accurate satellite navigation will only be possible when the ground-derived coordinates, calculated coordinates, and the satellite system-derived coordinates use the same geodetic reference system. Use of an incompatible geodetic reference system could cause operationally significant errors.

6.4.4 In support of evolving satellite-based technology, ICAO adopted WGS-84 as the common geodetic reference datum for civil aviation. The publication of WGS-84-related aeronautical coordinates, with an applicability date of 1 January 1998, was mandated in Annexes 4 and 15 to the Convention. To facilitate the implementation of WGS-84, ICAO is also preparing WGS-84 guidance material for States regarding, among other related topics, the transformation of existing coordinates and reference datums to WGS-84. This is a mathematical process and does not take into consideration the quality and accuracy of the original coordinates. If the accuracy of the original field work in establishing runway threshold coordinates, for example, is in question, mathematical conversion to WGS-84 will not enhance accuracy. Therefore, States should ensure that accuracy of ground-derived co-ordinates are in conformance with specifications provided in Annexes 11 and 14 to the Convention before they are mathematically transformed into WGS-84 reference system.

6.4.5 Implementation programme

6.4.5.1 EUROCONTROL is co-ordinating the implementation of WGS-84 in the ECAC States, where almost forty different geodetic datums are in use. Under the implementation programme, data inventories have now been completed and extensive re-surveys, conforming to a new EUROCONTROL Survey Standard, are now in progress. Phased publication of data is planned to take place throughout 1997. The EUROCONTROL standard calls for the surveys to be carried out under a strict regime of quality control.

6.4.5.2 EUROCONTROL has worked very closely in this field with ICAO, in particular with the Aeronautical Information and Charts (AIS/MAP) Section in Montreal. The co-ordination activities with ICAO have included Annex amendments, guidance material and the harmonization of publication and implementation timetables. Comprehensive training material has been produced by EUROCONTROL in co-operation with ICAO and this has been made available to ICAO for global use.

6.4.5.3 ICAO has prepared Doc 9674, *World Geodetic System — 1984 (WGS-84) Manual* to assist States in the implementation of WGS-84. It is anticipated that this document will be distributed early in 1997.

6.4.5.4 The United States Federal Aviation Administration (FAA) as well as the United States Defence Mapping Agency (DMA), the agency that developed and maintains WGS-84, have also been included in the co-ordination activities with ICAO related to WGS-84 subjects.

6.5 DATABASE-RELATED ISSUES

6.5.1 Aeronautical databases are built and updated through the use of surveys of existing navigation aids, position fixes and runway thresholds and through the design of new routes or approach procedures. Aeronautical information originates with States and States must have systems in place to ensure the quality (accuracy, integrity and resolution) of position data from the time of survey, to the submission of information to the next intended user. States should recognize that aeronautical databases must be updated on a 28-day cycle and that this imposes a cost on aircraft operators. For special situations, such as in domestic operations in some States, it may be possible to find a more flexible solution through a co-operative arrangement.

6.5.2 Instrument approach procedures should not be included in a GNSS database until the data has been verified and validated by the appropriate State authority. An aircraft should not be authorized to fly GNSS-based approaches unless that instrument approach procedure is retrieved from the navigation database in the receiver. It is strongly recommended, for safety reasons, that manual entry/update of approach information in the navigation database not be permitted (in TSO-C129 certified receivers this cannot be done). This would not prevent the storage of ‘‘user-defined data’’ within the equipment for en-route navigation and other purposes.

6.5.3 States may wish to overlay GNSS navigation information on their existing Aeronautical Information Publication (AIP) charts or they may wish to design new routes or approaches using appropriate design criteria. In either case, the navigation database containing the latitude and longitude coordinates for way-points, fixes and navigation aids for non-precision approaches must be codeable for database purposes and safe to fly using normal piloting techniques. The sequence of way-points in the database and those displayed by the equipment for non-precision approach should, as a minimum, consist of the way-points properly representing the selected instrument approach procedure which would include the initial approach fix (IAF) and its associated intermediate fixes (IFs) (when applicable), final approach fix (FAF), missed approach point (MAPt) and the missed approach holding point (MAHP).

6.5.4 States must publish aeronautical charts as part of their AIP and in accordance with specifications defined in ICAO Annexes 4 and 15. They may, however, arrange with a charting company to publish all or some of the required aeronautical charts in their name, but responsibility for the information provided remains with the State. Regardless of the arrangements, these tasks must be performed by qualified personnel so that the required quality of aeronautical data (textual and graphical) is achieved and maintained.

6.5.5 The WGS-84 coordinate information is obtained and stored in databases maintained by data base suppliers and is then made available to all GNSS receiver manufacturers. The media used by different manufacturers for receiver database update are generally incompatible.

6.5.6 RTCA Special Committee 181 (SC-181)/EUROCAE WG 13, Navigation Database Group

6.5.6.1 RTCA SC-181, in co-operation with EUROCAE Working Group 13, has two basic working groups, one of which is the Navigation Database Group. The efforts of the Navigation Database Group will result in two RTCA documents, one defining the ‘‘Requirements for the Aeronautical Data Process’’ (RTCA/DO-200A) and another defining ‘‘Industry Requirements for Aeronautical Information’’ (RTCA/DO-201A). These documents will replace the currently available RTCA/DO-200 and RTCA/DO-201.

6.5.6.2 *RTCA/DO-200A*

6.5.6.2.1 The RTCA/DO-200A is a document that will provide updated requirements for the production, supply and maintenance of aeronautical data used in airborne navigation systems. The requirements are applicable to all stages of the production process, from data originator to the flight deck.

6.5.6.2.2 The document describes all the aeronautical database production processes including the State’s data origination and publication processes, data assembly process, data selection process, data formatting process, data distribution process together with all associated editing, verification, and validation checks. The concept of cyclic redundancy checks (CRC) for data integrity monitoring is introduced including recommended CRC algorithms and tools for maintaining data integrity as it proceeds through the various system processes. The document also defines requirements with respect to configuration management, quality assurance and accountability for aeronautical data.

6.5.6.3 *RTCA/DO-201A*

6.5.6.3.1 While RTCA/DO-200A contains guidelines for the aeronautical data processes, RTCA/DO-201A will specify requirements for aeronautical information that is necessary for computer-based navigation system operations. The document emphasizes aeronautical information requirements to support new concepts and technology such as RNP and RNAV (GNSS) navigation, as well as requirements to enhance navigation with existing technology.

6.5.6.4 The need for quality aeronautical information for navigation systems that rely on navigation data cannot be over-emphasized. Once quality data is developed by a State to meet user requirements, integrity must be maintained as it proceeds through the various processes. The RTCA Special Committee 181 and ICAO have established a task force to evaluate the issues raised in RTCA/DO-201A so the appropriate ICAO Annexes and other technical documents can be amended to support the requirements for computer-based systems. The same approach will be taken with respect to RTCA DO-200A. The Task Force was established at the suggestion of AIS/MAP, ICAO Headquarters and with the concurrence of the RTCA SC-181 Working Groups 2 and 3 and EUROCAE Working Group 13. Once DO-200A and 201A are complete, the issues will again be reviewed and appropriate amendments developed for relevant ICAO documentation.

6.6 CERTIFICATION AND OPERATIONAL APPROVALS

6.6.1 Certification of airborne avionics

6.6.1.1 In order to satisfy the integrity requirement for supplemental means, the FAA developed Technical Standard Order (TSO) C129 to supplement the MOPS for airborne GPS receivers. This TSO requires RAIM or an equivalent means of establishing integrity. Receivers certified according to TSO-C129 also provide an increase in availability by using barometric aiding.

6.6.1.2 Airworthiness requirements governing the installation of approved GPS equipment are detailed in FAA Advisory Circulars AC 20-138 (GPS as stand-alone equipment) and AC 20-130A (GPS as part of a multi-sensor system). Information on these documents can be found in Appendix 1.

6.6.1.3 In the United States, there are two methods for approval of a GPS receiver installation: (1) as part of the original aircraft type design (type certificate) or (2) as a modification to the original type design (supplemental type certificate). The TSO process addresses only the qualification of equipment to a minimum standard. Equipment certified according to a TSO must be evaluated for compatibility with every type of aircraft in which it is installed. Supplements to aircraft flight manuals are part of the installation process and must be approved by the appropriate authority. There are also other requirements (e.g. airworthiness) that must be met before equipment is installed and certified on an aircraft. Canada, the United Kingdom, France, Germany, Switzerland, Kingdom of the Netherlands, Australia and Fiji have issued similar circulars based on FAA criteria.

6.6.1.4 Since many States use FAA or Joint Airworthiness Authority (JAA) standards, States should work together to harmonize these standards. Once a State has set requirements for GPS aircraft equipment, like those above, and has developed GPS operational procedures under VFR and IFR conditions, it may authorize the use of GPS as a means of navigation for en-route, terminal and non-precision approaches. GPS instrument approach operations must be expressly authorized by the appropriate State authority. In any event, each State will have to decide upon what basis it will make its certifications and approvals for installations and operations. Wherever possible, ICAO SARPs should be used; however, in their absence, States may wish to develop their own standards or adopt those of another State.

6.6.2 Operational approvals

6.6.2.1 The aviation authority must issue a document approving the use of GNSS as a means of navigation for oceanic, domestic en-route, terminal, and non-precision approach. The approval should specify any limitations on proposed operations. For example, because the availability of RAIM is less than 100 per cent, the current Canadian and United States operational approvals state that the planned approach at the alternate, if required, must be based on an ICAO standard NAVAID other than GNSS or LORAN-C. This approval can be used only after certification parameters have been met and the necessary documentation and requirements have been complied with.

6.6.2.2 In some States, (e.g. Australia, Fiji) there is a requirement to endorse a pilot’s instrument rating for the types of radio navigation aids he or she is qualified to use, including en-route navigation, position fixing or instrument approach. Individual types of radio navigation aids may be endorsed (e.g. VOR, ADF, ILS). In some States, such as the United States and Canada, there are no requirements for individual navigation aid endorsement as the pilot is certified for IFR operations.

6.7 USE OF UNCERTIFIED GPS RECEIVERS FOR VFR NAVIGATION

6.7.1 There are a number of GPS receivers available that do not meet the requirements for IFR operations stated in TSO-C129. Pilots generally develop a lot of confidence in VFR navigation using GPS receivers. Accurate guidance is provided most of the time but the receivers cannot be relied upon completely. Since they do not use RAIM there will be no warning if a faulty satellite is broadcasting erroneous signals and providing false guidance. Other problems result from poor antenna location with portable receivers and, in some cases, the inability to update receiver databases.

6.7.2 Uncertified GPS receivers may be used to support visual flight rules (VFR) navigation areas where ground-based navigation aids are not available or are unreliable. Standard VFR navigation procedures, or pilot navigation, must continue to be used to ensure safety. Any difference between the GPS-derived position and the navigation data available from other sources must be resolved. This applies where the available navigation data is of questionable accuracy and/or where it has not been transformed to the WGS-84 reference system. It is essential that proper operating procedures are instituted, as necessary, for this usage.

6.7.3 In summary, GPS receivers that are not certified for IFR flight may be used as an accessory to VFR navigation, but the limitations of these receivers must be recognized.

6.8 GROUND AND FLIGHT INSPECTION

6.8.1 Because satellite positions vary as a function of time of day and because multipath and blockage depend on satellite position, ‘‘ground’’ inspections may be necessary to verify the performance of some types of operation.

6.8.2 Flight inspection criteria have not been fully developed for GNSS procedures, although some States have developed draft criteria for non-precision approaches. Several methods are being considered which include:

a) flight inspection of a newly developed procedure followed by an inspection of signals-in-space at a specified interval;

b) routine flight inspection of each procedure;

c) flight inspection of signals-in-space; and

d) inspection of signals by an airport monitoring station or a station specifically placed for such evaluation.

6.8.2.1 More experience with GNSS operations is necessary before authorities can determine the nature and extent of periodic flight inspection of GNSS routes and/or approaches.

6.9 TRIALS AND DEMONSTRATIONS

6.9.1 Proof-of-concept trials and demonstrations serve two purposes. First, they give the civil aviation authorities operational experience with GNSS and an opportunity to gather data and validate the system. Second, they can give users an increase in operational benefits and an early opportunity to gain experience using GNSS.

6.9.2 While the information and data collected during GNSS trials and demonstrations is valuable and is needed to pursue GNSS further, it is not a requirement to approve GNSS as a supplemental means. Some States have already completed proof-of-concept trials (e.g. United States and Canada) and have collected a large amount of data which is available on request. This information could be used to substantiate approvals for other States.

6.9.3 One type of demonstration could be called an ‘‘overlay programme’’. This programme is designed to determine approach criteria and to gain operational experience. It also makes available operational benefits of the system to the users. This programme allows GNSS to overlay an existing non precision approach, using the existing approach design and chart. This allows a State to collect data, gain operational experience in approach development and allow users to fly the approach using GNSS receivers.

6.9.4 The overlay programme can be expanded to include existing airway routes, and arrival and departure procedures. Not only does it allow the users to gain GNSS experience, but it can be authorized at minimum cost to the provider. States could consider this type of programme in their developmental stage to gain similar benefits and experience.

6.10 PLANNING AND ORGANIZATION

6.10.1 Implementation planning

Considering the complexity and diversity of the airspace world-wide, planning could best be achieved if it was organized in homogeneous areas of common requirements and interest, taking into account traffic density and level of sophistication required. See Appendix 4, Section 5.

6.10.2 Establishing a GNSS implementation team

6.10.2.1 Experience has shown that the decision to implement GNSS within States should be made at the highest level and co-ordinated regionally within formal planning groups if possible (e.g. the ICAO regional CNS/ATM Implementation Planning Group).

6.10.2.2 Successful implementation programmes usually involve a co-operative effort that includes all departments and/or individuals who:

a) have an interest in the programme;

b) are affected by the possible outcomes;

c) will have a responsibility for committing resources for accomplishment; and

d) have authority or responsibility for assuring completion of all or part of the programme and have the necessary resources.

6.10.2.3 States may wish to consider the need for representation by air carriers, general aviation, and the military during initial meetings centring on the development of a GNSS implementation plan. These users may have capabilities and resources to assist the aviation authority in the implementation of GNSS.

6.10.2.4 A Technical Committee could be formed and given the responsibility for defining requirements and executing the implementation plan. States may differ in their composition of an implementation team. However, it is expected that the core group responsible for the GNSS programme emphasize operational expertise in aviation. Contractor support may be necessary to supplement services where technical or operational expertise is not readily available. The core group could include the following:

a) operations — persons responsible for operational approvals, pilot training, and flight procedures;

b) airworthiness standards — persons responsible for approving avionics and installations;

c) aviation standards;

   1) persons responsible for developing instrument approach procedures; and

   2) persons responsible for developing obstacle clearance criteria, etc.;

d) air traffic control;

   1) persons responsible for developing ATC procedures; and

   2) persons responsible for controller training;

e) engineering — engineers responsible for the design of systems and equipment;

f) airline representatives — flight operations and flight crew training;

g) other user groups — representatives of general, business, commercial aviation, unions, as well as other modes of transport that may use GNSS;

h) other support:

   1) surveyors;

   2) ATC chart designers;

   3) GNSS receiver manufacturing representatives;

   4) other foreign civil aviation or ICAO officials assisting in the process or attending for educational purposes; and

   5) private consultants; and

i) military representatives (if applicable).

6.10.2.5 An important point to consider here is the involvement of the users in this development group. There is a need for the users, including air carriers, general aviation, and the military, to be involved in the development and implementation of GNSS. These users have certain needs and requirements that must be met and they should be identified and addressed during the development of this plan. It is very important that these user groups provide input and have capabilities and resources to assist the aviation authority in the design and development of a GNSS architecture.

6.10.3 Developing a GNSS plan

6.10.3.1 The GNSS plan should include a cost-benefit study. The adoption of CNS/ATM systems has major economic and financial implications for providers of air navigation services and for airspace users. Cost-benefit studies at the State level are therefore essential to determine how they would be affected by the new systems and also to choose the most cost-effective approach to implementation. The Tenth Air Navigation Conference recommended that States perform their own individual cost-effectiveness and/or cost-benefit analyses to determine how they would be affected by the new systems (Recommendation 6/1). To assist States in this exercise, ICAO has developed Circular 257, *Economics of Satellite-based Air Navigation Services* (refer to Appendix 1).

6.10.3.1.1 Further to financial considerations in developing a GNSS plan, in May 1996, the ICAO Air Navigation Services Economics Panel (ANSEP) completed work on a document entitled *Report on Financial and Related Organizational and Managerial Aspects of Global Navigation Satellite System (GNSS) Provision and Operation*. This report is to be published as ICAO Doc 9660. This report makes reference to another document prepared with the assistance of the ANSEP entitled *Manual on Air Navigation Services Economics* which will be published as ICAO Doc 9161/3. Both of these documents will be of use in developing a GNSS plan, particularly where the implementation of ground and/or satellite-based augmentations is envisaged.

6.10.3.2 The plan should identify capabilities that must be in place in order to meet various requirements for each approval stage and steps needed for implementation.

6.10.3.3 To assist implementation teams in their efforts, the following checklist is intended as a guide which can be modified to suit a particular State’s needs.

GNSS implementation checklist (en-route, non-precision approaches)

- — decision to implement GNSS — co-ordinate with regional CNS/ATM implementation planning group
- — initial GNSS meeting
- — identification of technical team — define requirements, develop plan
- — define ATC procedures and GNSS approaches
- — perform GNSS surveys
- — create GNSS database
- — produce chart overlays and/or new approaches
- — define receiver approval basis — obtain approved GNSS receivers with NAV package
- — install receivers
- — perform operational tests/demonstrations
- — train ATC personnel
- — train pilots/operators
- — obtain ICAO advice or assistance as required

6.11 TRAINING

6.11.1 For successful implementation of GNSS, various decision-makers (such as resource providers) must understand GNSS concepts. Orientation briefings should include the basic theory of GNSS operations; its capabilities as well as limitations. More comprehensive training must be provided for controllers, pilots and inspectors. Training is the responsibility of the aviation authority.

6.11.2 The ICAO TRAINAIR programme has been established to upgrade and standardize aviation training available to civil aviation personnel on a global basis. Through this programme, high quality training material is prepared and shared within a network of civil aviation training centres. Several TRAINAIR participants will soon begin preparation of training materials related to GNSS and other CNS/ATM related systems.

6.12 INFORMATION DISSEMINATION

6.12.1 Once the State or aviation authority has decided to implement a GNSS programme it must inform users of the start date and the specifics of the implementation programme.

6.12.2 This may be carried out by the issuance of a NOTAM and supplemented by an Aeronautical Information Circular (AIC). The AIC (see examples in Appendix 4) would provide sufficient information for the aviation community to comply with applicable regulations, procedures and training that the State has imposed.

6.12.3 Due to the rapidly developing nature of the technology, newsletters and other publications are needed to disseminate information about the satellite programme.

6.13 LEGAL ISSUES

6.13.1 Aircraft operators and pilots need to be reassured that the State has the legal authority to implement GNSS while the programme works its way through the ICAO process. In order to protect airlines and pilots from litigation, the State authority needs to ensure that the appropriate law or regulation is in place in order to provide air navigation and air traffic control services using satellite technology. Operators need to ensure that their aircraft are in compliance with applicable airworthiness rules in order to continue insurance coverage.

6.13.2 States usually look to ICAO for guidance on new developments such as GNSS. While Standards and Recommended Practices (SARPs) are being developed, States can realize early benefits from satellite technology using this guidance material.

6.13.3 Articles 28, 29 to 33 and 37 of the *Convention on International Civil Aviation* (Doc 7300) oblige States to provide radionavigation services, to regulate aircraft and to take responsibility for safety. Concern has been raised regarding the liability of using a satellite system owned and operated by another State. These matters are being studied by the Legal Committee of ICAO.

6.14 IMPLEMENTATION ASSISTANCE

6.14.1 States seeking assistance in implementing GNSS or other global CNS/ATM systems should contact their ICAO regional offices.

6.14.2 States are encouraged to take advantage of the expertise and information exchanged in the regional planning and implementation groups and sub-groups. For instance, all regional CNS/ATM implementation co-ordination sub-groups have received a mandate from the ICAO Council to:

a) ensure regional and inter-regional co-ordination on CNS/ATM implementation;

b) provide a forum for the exchange of expertise and information among States and international organizations; and

c) identify technical assistance needs in the region and help arrange the provision of such assistance by States, stakeholders, or the ICAO Technical Co-operation Bureau.

All these efforts are conducted in conjunction with ICAO regional offices.

Chapter 7

EVOLUTION — FUTURE PROSPECTS FOR GNSS

7.1 IMMEDIATE

7.1.1 Current approvals allow the supplemental use of GPS for en-route, terminal and non-precision approach operations. This means that traditional ground aids and avionics must be available to provide integrity when too few satellites are in view for RAIM to operate. Standards and receivers have been developed to allow primary-means oceanic and remote area operations. These standards ensure sufficient availability of RAIM, making possible GPS primary-means operations in airspace with separation minima of 50 NM or greater. The integration of GPS in multi-sensor systems is allowing reductions of separation in some areas where the required levels of surveillance and communications are available.

7.1.2 In the area of precision approach, standards have been developed by some States for ground local differential stations, complementary data link systems and avionics to support Category I operations. The standards are designed to provide early access to this technology on a restricted basis. Approvals should be granted to operators demonstrating compliance with standards. These approaches should not be available to other operators unless they demonstrate compliance with standards. It is expected that these Special Category I (SCAT-I) approvals will be of interest to certain operators who can achieve immediate benefits from precision approach capabilities at airports which do not qualify for traditional precision approach aids due to traffic levels or terrain considerations.

7.2 MEDIUM TERM

7.2.1 The full realization of GNSS benefits requires that space-based systems be certifiable for sole means. One way of achieving sole means use of GNSS would be to use GPS and GLONASS signals together in a receiver to increase the availability of navigation integrity. The full benefits of GNSS will be realized with regional implementation that is consistent with the global CNS/ATM strategy and so that regional plans provide a clear transition path from early implementation strategies to the future GNSS.

7.2.2 Augmentation systems and the data links necessary to implement the augmentation, however, may be peculiar to one region. Maximum benefits are achieved when regional systems are interoperable and aircraft can readily transition from one region to another or from one phase of flight to another. Standards, therefore, need to be common across all regions.

7.2.3 In the case of GPS, augmentation will be required to meet the RNP standards for sole-means operations. A solution that is attractive for the medium term is satellite-based (also called wide area or regional) augmentation. This technique may also be applicable to GLONASS.

7.2.4 The five Inmarsat-3 satellites due to come into operation from early 1996 and the Japanese Multi-Functional Transport Satellite (MTSAT) from 1999 will have navigation transponders. Other entities are also considering putting navigation transponders on satellites of opportunity. These transponders would provide further augmentation to GPS/GLONASS for civil aviation and could be building blocks in the development of a civil internationally operated global navigation system. Figure 7-1 shows the coverage of the Inmarsat-2 satellites. The footprints of the Inmarsat-3s will be substantially the same, with the location of the fifth satellite not yet decided.

7.2.5 The transponders on these satellites will relay their signals on the same frequency as is used by GPS. GPS receivers that have been designed or modified to recognize the signal can receive it and decode the information that it contains. This information could give the status of each of the GPS and GLONASS satellites, provide corrections that would allow more accurate positions to be determined and could be the source of very accurate time. The transponders would also behave, as far as the GPS receiver is concerned, as if they were additional GPS satellites, improving the availability and the confidence that the user could have in the integrity of the user's derived position.

7.2.6 In the United States' development of the Wide Area Augmentation System (WAAS) is under way. The WAAS concept has been proven by trials conducted by the United States and Canada using a WAAS signal transmitted over the Inmarsat-2 Atlantic Ocean West satellite. Accuracies exceeding those required to support operations to CAT 1 ILS limits have been consistently achieved using monitoring stations located as far away as 500 nautical miles from the landing sites, with integrity warning times of about 6 seconds.

7.2.7 The United States FAA has awarded a contract for the development of WAAS which will employ a network of ground monitoring stations to monitor the GPS constellation. Canada is planning a system using six monitoring stations. In Europe, plans are being developed to operate a network known as the European geostationary navigation overlay service (EGNOS). Other countries including Australia, Fiji, India, Italy, China, Japan, New Zealand, the African ASECNA States, Malaysia, Singapore and several South and Central American countries have expressed interest in providing and/or availing of this type of service.

7.2.8 In the United States' plan, a network of about twenty-four ground stations, located throughout the United States, will monitor the GPS satellites and send the information to two or more master stations. These stations will collate the information and send it to an Inmarsat navigation earth station for transmission via the navigation transponders to the user aircraft.

7.2.9 Figure 7-2 illustrates the WAAS technique. Initially, it is planned to use two or three Inmarsat-3 navigation transponders to transmit GPS-related data to aircraft receivers, with transponders on other suitable satellites being added at a later date when they become available.

7.2.10 Satellite-based augmentation will not meet sole-means requirements everywhere as discussed in 4.3.4.3. In such cases, ground-based augmentation may be the solution.

7.3 LONG TERM

The existing satellite navigation systems were originally designed to meet military requirements. It is envisaged that these will ultimately evolve into systems that meet international civil aviation requirements to a greater extent. It is also envisaged that new generation satellite systems will be provided through international co-operation, eliminating any institutional concerns related to military control and monopoly provision of service. The challenge in designing this new GNSS will be to find solutions that overcome known difficulties, while providing sufficient compatibility with first generations systems to allow the user community to continue to benefit from equipment investments and to determine a way to have the system funded on an international basis which is acceptable to all interested parties.

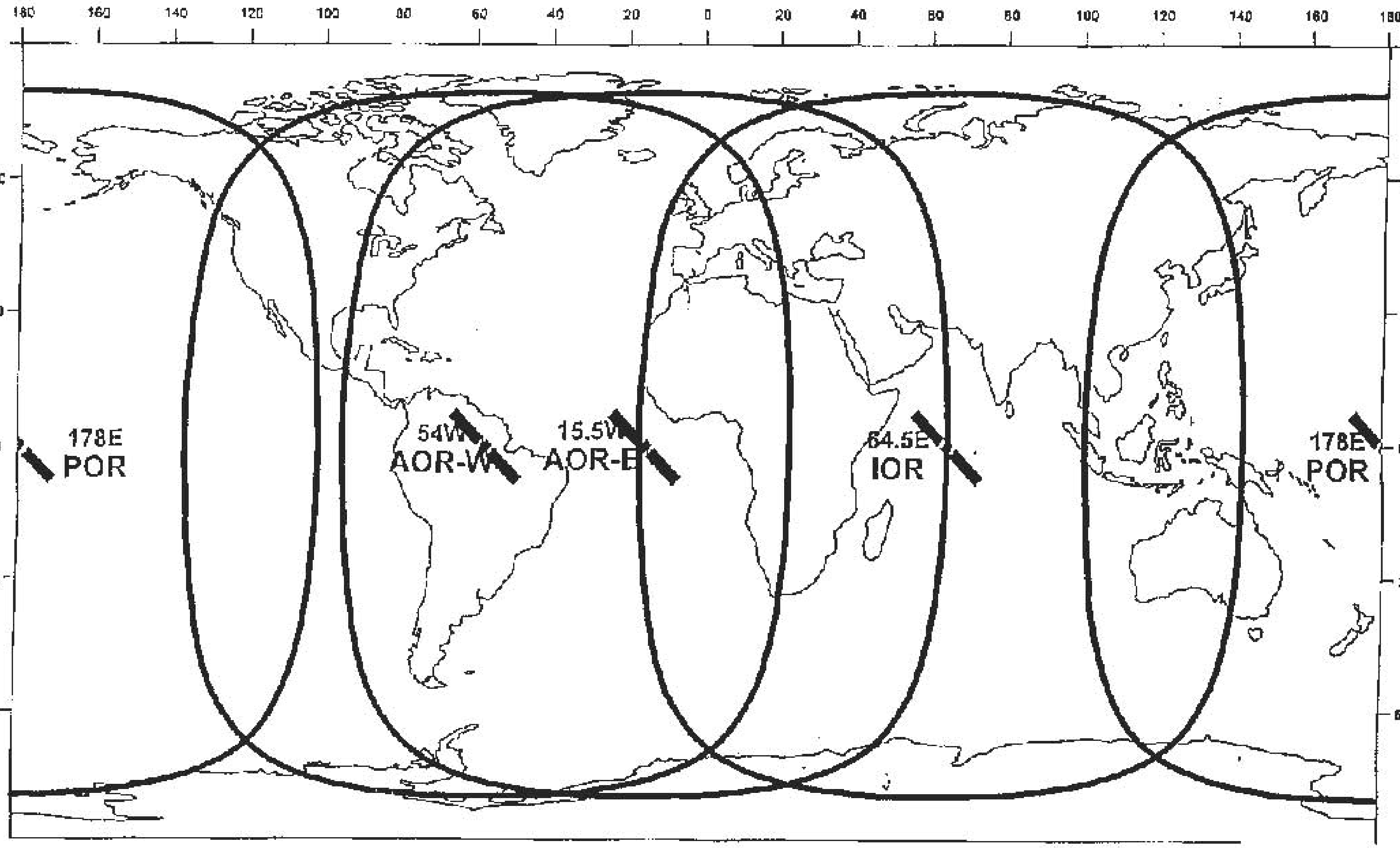
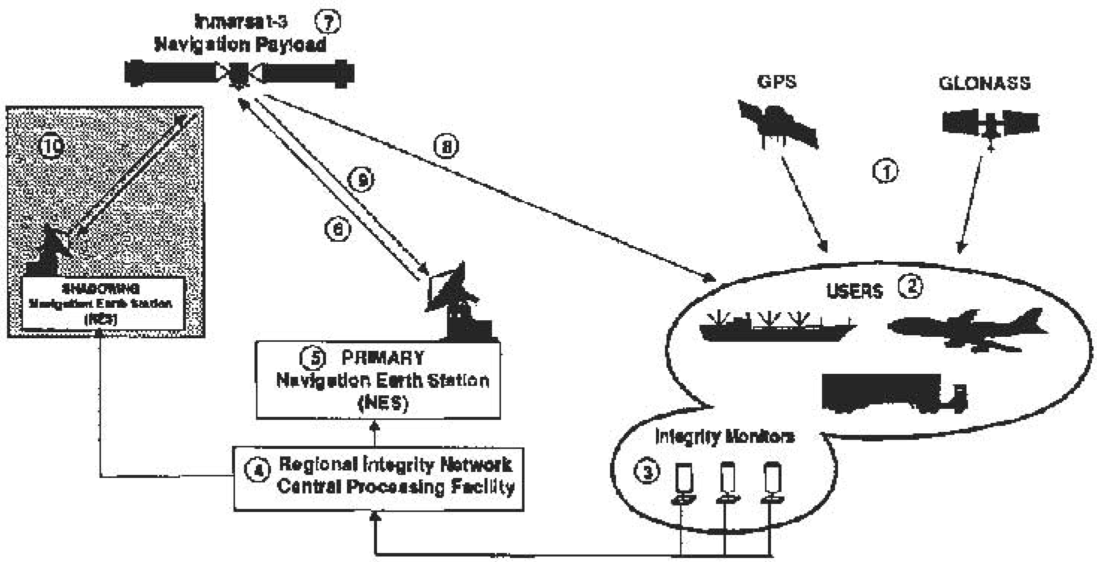


Figure 7-1. Inmarsat-2 satellite coverage

GEOSTATIONARY REGIONAL AUGMENTATION CONCEPT



Navigation signals ① are transmitted from GPS and GLONASS satellites and received by users ②. These signals are also received by Integrity Monitoring Networks ③ operated by governmental agencies. The monitored data are sent to Regional Integrity Network Central Processing Facilities ④. At the central processing facility the data is processed into message types and forwarded to the Navigation Earth Stations (NES) ⑤ & ⑩. At the NES the spread spectrum navigation signal is precisely synchronised to a reference time and the C-band uplink signal ⑥ is modulated with the integrity message data. The spread spectrum navigation signal is frequency translated through the navigation payload on board the Inmarsat-3 satellite ⑦ and transmitted to the user ⑧ in the navigation L-band. An identical signal ⑨ is also transmitted at C-band. This C-band signal is used for maintaining the navigation signal timing loop. The timing of the signal is done in a very precise manner in order for the user to process the signal as though it was generated on board the satellite. The NES and central processing facility may be co-located. The Shadowing NES ⑩ functions as a "Hot Standby" receiving identical data from the central processing facility and maintaining a timing loop to assume operational status in the event of a failure at the Primary NES. It is expected that these functions would alternate on a regular basis.

Figure 7-2. WAAS Technique

Chapter 8

CONCLUSIONS

8.1 The early implementation of GNSS can bring many economic and operational benefits to States and aircraft operators. This technology and the related standards are under continuous development. In the meantime, the use of the principles contained in this document should permit the safe and expeditious introduction of GNSS.

8.2 The full implementation of GNSS requires the co-operation of the world's aviation community. This can be achieved most efficiently through the development of common standards within the ICAO processes.

Appendix 1

LIST OF REFERENCES

PUBLICATIONS

1. General guidelines for GNSS Implementation

   a) FAA Satellite Navigation Program Master Plan — FY 95-00

   Presents the needs, scope, objectives and other requisite planning information for the Federal Aviation Administration's Satellite Navigation Program for the period FY95-FY00.

   Source:
   Federal Aviation Administration
   GPS/Navigation Integrated Product Team, AND-500
   800 Independence Avenue, SW
   Washington, DC 20591, United States
   Telephone number: (202) 358-5485

   b) RTCA Document — RTCA Task Force on the Global Navigation Satellite System (GNSS) Transition and Implementation Strategy —September 1992

   Source:
   RTCA Incorporated
   1140 Connecticut Avenue, NW
   Washington, DC 20036-4001, United States
   Telephone number: (202) 833-9339
   Fax number: (202) 833-9434

   c) 1994 Federal Radionavigation Plan DOT-VNTSC-RSPA-95-1/DOD-4650.5, May 1995

   Sets forth the Federal inter-agency approach to the implementation and operation of Federally provided, common-use radionavigation systems (including GPS).

   Source:
   National Technical Information Service
   Springfield, VA 22161, United States
   Telephone number: (703) 487-4660
   Limited copies: (617) 494-2126

   d) Joint DOD/DOT Task Force Report December 1993 — The Global Positioning System: Management and Operation of a Dual Use System

   Source:
   Department of Transportation
   Radionavigation Staff, P-7
   400 7th Street, SW
   Washington, DC 20590, United States
   Telephone number: (202) 366-5436

   e) FAA Order 6880.1 — U.S. National Aviation Standard for the Global Positioning System Standard Positioning Service — 18 June 1992

   Defines those functional and operational characteristics of the GPS SPS which are necessary to provide compatibility among the GPS components and to satisfy over-all operational use requirements.

   Source:
   Superintendent of Documents
   P.O. Box 37194
   Pittsburgh, PA 15250-7954, United States
   Credit card orders: (202) 512-1800

   f) Interface Control Document GPS (200) — ICD-GPS-200 including changes through IRN-200B-007, July 1993

   Defines the functional characteristics required to exist to assure compatibility between the space segment of the GPS and the navigation user segment of the GPS.

Source:
U.S. Coast Guard
Navigation Information Center
7323 Telegraph Road
Alexandria, VA 22315-3998, United States
Telephone number: (703) 313-5900
Fax number: (703) 313-5920

g) Charter for the Satellite Operational Implementation Team — 7 June 1993

Specifies the scope of authority and objectives of the Satellite Operational Implementation Team (SOIT) .

Source:
Federal Aviation Administration
SOIT Chairman, AFS-440
800 Independence Avenue, SW
Washington, DC 20591, United States
Telephone number: (202) 267-3752
Fax number: (202) 267-5817

h) FAA Order 7100.10 — Air Traffic Implementation Plan for the Use of the Global Positioning System (GPS) — 27 December 1993

Identifies the steps needed to enable the Federal Aviation Administration (FAA) to develop air traffic control (ATC) procedures which will exploit the navigational capabilities of GPS.

Source:
Superintendent of Documents
P.O. Box 37194
Pittsburgh, PA 15250-7954, United States
Credit card orders: (202) 512-1800

i) RTCA/DO-200, Preparation, Verification and Distribution of User-selectable Navigation Databases

Source:
RTCA Incorporated
1140 Connecticut Avenue, NW
Washington, DC 20036-4001, United States
Telephone number: (202) 833-9339
Fax number: (202) 833-9434

j) RTCA/DO-201, User Recommendations for Aeronautical Information Services

Source:
RTCA Incorporated
1140 Connecticut Avenue, NW
Washington, DC 20036-4001, United States
Telephone number: (202) 833-9339
Fax number: (202) 833-9434

k) Charter for Satellite Operations Implementation Team (SOIT)

Source:
Federal Aviation Administration
SOIT Chairman, AFS-440
800 Independence Avenue, SW
Washington, DC 20591, United States
Telephone number: (202) 267-3752
Fax number: (202) 267-5817

l) Boeing Document D240U126 — RNP Capability of FANS 1 FMCS Equipped 747-400

Source:
Boeing Customer Services and Material Support
PO Box 3707
MS 2M-04
Seattle, Washington 98124-2207, United States
Telephone number: (206) 544-9366
Fax number: (206) 544-8838

m) ICAO Document 9623 — *Report of the Fourth Meeting* (1993). FANS (Phase II) — Special Committee for the Monitoring and Co-ordination of Development and Transition Planning for the Future Air Navigation System

Source:
International Civil Aviation Organization
Document Sales Unit
999 University Street
Montreal, Quebec, Canada H3C 5H7
Telephone number: (514) 954-8022
Fax number: (514) 954-6769

n) ICAO Document 9426 — *Air Traffic Services Planning Manual*

Source:
International Civil Aviation Organization
Document Sales Unit
999 University Street
Montreal, Quebec, Canada H3C 5H7
Telephone number: (514) 954-8022
Fax number: (514) 954-6769

o) ICAO Circular 257 — *Economics of Satellite-based Air Navigation Services*

Source:
International Civil Aviation Organization
Document Sales Unit
999 University Street
Montreal, Quebec, Canada H3C 5H7
Telephone number: (514) 954-8022
Fax number: (514) 954-6769

p) ICAO Circular 120 — *Methodology for the Derivation of Separation Minima Applied to the Spacing between Parallel Tracks in ATS Route Structures*

Source:
International Civil Aviation Organization
Document Sales Unit
999 University Street
Montreal, Quebec, Canada H3C 5H7
Telephone number: (514) 954-8022
Fax number: (514) 954-6769

q) ICAO Document 9613 — *Manual on Required Navigation Performance (RNP)*

Source:
International Civil Aviation Organization
Document Sales Unit
999 University Street
Montreal, Quebec, Canada H3C 5H7
Telephone number: (514) 954-8022
Fax number: (514) 954-6769

r) ICAO Document 9660 — *Report on Financial and Related Organizational and Managerial Aspects of Global Navigation Satellite System (GNSS) Provision and Operation*

Source:
International Civil Aviation Organization
Document Sales Unit
999 University Street
Montreal, Quebec, Canada H3C 5H7
Telephone number: (514) 954-8022
Fax number: (514) 954-6769

s) ICAO Document 9161/3 — *Manual on Air Navigation Services Economics*
(Estimated publication date: Fall 1997)

Source:
International Civil Aviation Organization
Document Sales Unit
999 University Street
Montreal, Quebec, Canada H3C 5H7
Telephone number: (514) 954-8022
Fax number: (514) 954-6769

t) ICAO Document 9674 — *World Geodetic System — 1984 (WGS-84) Manual*
(Estimated publication date: Spring 1997)

Source:
International Civil Aviation Organization
Document Sales Unit
999 University Street
Montreal, Quebec, Canada H3C 5H7
Telephone number: (514) 954-8022
Fax number: (514) 954-6769

u) ICAO Document 7300 — *Convention on International Civil Aviation*

Source:
International Civil Aviation Organization
Document Sales Unit
999 University Street
Montreal, Quebec, Canada H3C 5H7
Telephone number: (514) 954-8022
Fax number: (514) 954-6769

2. Guidelines for Implementation of Supplemental Phase

a) RTCA/DO-208 — July 1991 — Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS)

Contains minimum operational performance standards for airborne supplementary navigation equipment (2D and 3D) using GPS inputs.

Source:
RTCA Incorporated
1140 Connecticut Avenue, NW
Washington, DC 20036-4001, United States
Telephone number: (202) 833-9339
Fax number: (202) 833-9434

b) TSO C 129 — Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS) — 10 December 1992

Prescribes the minimum performance standards that airborne supplemental area navigation equipment using the Global Positioning System must meet in order to be identified with the applicable TSO marking.

Source:
Federal Aviation Administration
Aircraft Certification Service
Technical Analysis Branch, AIR-120
800 Independence Avenue, SW
Washington, DC 20591, United States
Telephone number: (202) 267-9546

c) AC 20-138 — Airworthiness Approval of Global Positioning System (GPS) Navigation Equipment for Use as a VFR and IFR Supplemental Navigation System — 25 May 1994

Establishes an acceptable means, but not the only means, of obtaining airworthiness approval of global positioning system (GPS) equipment for use as a supplemental navigation system for oceanic and remote, domestic en-route, terminal and non-precision instrument approach — addresses stand-alone GPS equipment only.

Source:
Superintendent of Documents
P.O. Box 37194
Pittsburgh, PA 15250-7954, United States
Credit card orders: (202) 512-1800

d) AC 20-130 — Airworthiness Approval of Navigation or Flight Management Systems Integrating Multiple Navigation Sensors — 14 June 1995

Establishes an acceptable means, but not the only means, of obtaining airworthiness approval of multi-sensor navigation or flight management systems integrating data from multiple navigation sensors for use as a navigation system for oceanic and remote, domestic en-route, terminal, and non-precision instrument approach — does not address systems incorporating differential GPS capability.

Source:
Superintendent of Documents
P.O. Box 37194
Pittsburgh, PA 15250-7954, United States
Credit card orders: (202) 521-1800

e) Joint AFS/AIR Memo — IFR Approval of Global Positioning System (GPS) Operations — 9 June 1993

Provides approval for United States' civil operators to use GPS equipment to conduct oceanic, domestic en-route and terminal IFR operations — includes approval to fly certain FAR Part 97 VOR, VOR/DME, NDB, NDB/DME, TACAN and RNAV instrument approach procedures.

Source:
Federal Aviation Administration
SOIT Chairman, AFS-440
800 Independence Avenue, SW
Washington, DC 20591, United States
Telephone number: (202) 267-3752
Fax number: (202) 267-5817

f) AC 90-94 — Guidelines for Using Global Positioning System Equipment for IFR En-route and Terminal Operations and for Nonprecision Instrument Approaches in the U.S. National Airspace System — 14 December 1994 (AFS 800/400)

Contains guidance for pilots to use global positioning system equipment during instrument flight rules navigation including operating en-route, in the terminal environment, during non-precision instrument approach procedures in the United States NAS and in oceanic areas — emphasis is placed on the GPS approach overlay programme.

Source:
Superintendent of Documents
P.O. Box 37194
Pittsburgh, PA 15250-7954, United States
Credit card orders: (202) 512-1800

g) FAA Order 8260.38 — Civil Utilization of Global Positioning System (GPS) — December 14, 1993

Terminal Instrument Procedures (TERPS), for establishing GPS procedures at airports — the guidance and criteria prescribed are for nonprecision approaches.

Source:
Superintendent of Documents
P.O. Box 37194
Pittsburgh, PA 15250-7954, United States
Credit card orders: (202) 512-1800

h) AC 97-2 — Database Standardization for the Global Positioning System (GPS) Overlay Program — 19 November 1993

Contains information and guidance to be used by database vendors that develop data for use in the National Airspace System (NAS) for the non-precision GPS overlay programme.

Source:
Department of Transportation
General Services Section, M-45.3
Washington, DC 20590, United States

i) United States Coast Guard — GPS Information Center Pamphlet

Source:
U.S. Coast Guard
Navigation Information Center
7323 Telegraph Road
Alexandria, VA 22315-3998, United States
Telephone number: (703) 313-5900
Fax number: (703) 313-5920

j) RTCA Paper No. 379-93/TMC-99 21 September 1993 — Portable Hand-held GPS Receivers — What You Should Know

Source:
RTCA Incorporated
1140 Connecticut Avenue, NW
Washington, DC 20036-4001, United States
Telephone number: (202) 833-9339
Fax number: (202) 833-9434

k) GPS Implementation Plan

Source:
Federal Aviation Administration
GPS/Navigation Integrated Product Team, AND-500
800 Independence Avenue, SW
Washington, DC 20591, United States
Telephone number: (202) 358-5485

3. Guidelines for Implementation of Primary Use

a) RTCA/DO-217 — Minimum Aviation System Performance Standards DGNSS Instrument Approach System: Special Category I (SCAT-I) — August 27, 1993

Contains minimum aviation system performance standards (MASPS) for a system to support differential GNSS (DGNSS) special instrument approaches — Category I

Source:
RTCA Incorporated
1140 Connecticut Avenue NW
Washington, DC 20036-4001, United States
Telephone number: (202) 833-9339
Fax number: (202) 833-9434

b) FAA Order 8400.11 — IFR Approval for Differential Global Positioning System (DGPS) Special Category I Instrument Approaches Using Private Ground Facilities — 15 September 1994

Identifies specific criteria which shall be satisfied before IFR operations can be authorized using DGPS Special Instrument Approach Procedures that are based on ILS, MLS, LOC, LDA, and SDF criteria.

Source:
Federal Aviation Administration
Flight Standards Service, AFS-400
800 Independence Avenue, SW
Washington, DC 20591, United States

c) AVR-1 Memo — Operational Implementation of Global Positioning System (GPS) as a Primary Means for Oceanic and Remote Operations — 5 December 1994

Initiates action authorizing the use of GPS as a primary means for oceanic and remote operations — forwards the SOIT position paper which proposes minimum performance standards and operational restrictions for using GPS as a primary means of navigation in oceanic and remote areas.

Source:
Federal Aviation Administration
SOIT Chairman, AFS-440
800 Independence Avenue, SW
Washington, DC 20591, United States
Telephone number: (202) 267-3752
Fax number: (202) 267-5817

d) FAA Notice 8110.57 — GPS as a Primary Means of Navigation for Oceanic/Remote Operations — 7 July 1995

Source:
Superintendent of Documents
P.O. Box 37194
Pittsburgh, PA 15250-7954, United States
Credit card orders: (202) 512-1800

e) FAA Bulletin number: FSAT 95-XX Draft Guidelines for Operational Approval of Global Positioning System (GPS) to Provide the Primary Means of Class II Navigation in Oceanic and Remote Areas of Operation. (Estimated publication date: Fall 1995)

Source:
Superintendent of Documents
P.O. Box 37194
Pittsburgh, PA 15250-7954, United States
Credit card orders: (202) 512-1800

f) RTCA Paper No. 396-95/SC 159-661 — Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment (Final draft 24 July 1995 — Estimated publication date: October 1995)

Contains minimum operational performance standards for airborne navigation equipment using GPS augmented by the WAAS — the standards define performance, functions and features for RNAV and, optionally, VNAV equipment to be used for the en-route, terminal area, and non-precision approach phase of flight — also defines performance, functions and features for equipment which satisfies the RNP for Category I precision approach.

Source:
RTCA Incorporated
1140 Connecticut Avenue, NW
Washington, DC 20036-4001, United States
Telephone number: (202) 833-9339
Fax number: (202) 833-9434

g) Global Positioning System, Standard Positioning Service Signal Specification, 2nd edition, June 2, 1995

Source:
U.S. Coast Guard
Navigation Information Center
7323 Telegraph Road
Alexandria, VA 22315-3998, United States
Telephone number: (703) 313-5900
Fax number: (703) 313-5920

h) Required Navigation Performance (RNP) for Precision Approach and Landing with GNSS Application, Journal of the Institute of Navigation, Volume 41, No. 1, Spring 1994.

Source:
The Institute of Navigation
1800 Diagonal Road
Alexandria, VA 22314, United States

i) Beginning the Development of a Global Navigation Satellite System

Source:
Federal Aviation Administration
GPS/Navigation Integrated Product Team, AND-500
800 Independence Avenue, SW
Washington, DC 20591, United States
Telephone number: (202) 358-5485

j) Program Manager's Charter for the Satellite Program — August 31, 1995

Source:
Federal Aviation Administration
GPS/Navigation Integrated Product Team, AND-500
800 Independence Avenue, SW
Washington, DC 20591, United States
Telephone number: (202) 358-5485

Note.— Some documentation is revised regularly. The most current issue will be released at the time of request.

Appendix 2

INTERFERENCE TO GNSS

1. POTENTIAL FOR INTERFERENCE TO GNSS

As with any navigation system, the GNSS navigation signals must be protected from harmful interference. As the electromagnetic spectrum has become more intensely used, the potential for harmful interference to satellite navigation receivers has increased and this trend will probably continue in the future.

1.1 Effects of interference

1.1.1 The potential for interference exists to some extent in all aeronautical radio navigation frequency bands. It is classified as ‘‘harmful interference’’ when it degrades navigation performance. Harmful interference can cause degradation of navigation or complete loss of the navigation function.

1.1.2 Current satellite radio navigation systems feature relatively weak received signal power. This means that an interference signal could cause loss of service at a somewhat lower received power level than with current terrestrial based systems. Terrestrial system interference typically extends over a local area near a specific installation. Due to the nature of the signal source and to the widespread application being planned for satellite navigation, interference may not be limited to areas near terrestrial installations, but can exist wherever the signal is authorized for use. However, one of the features of GNSS is its resistance to misleading navigation errors due to interference signals when compared to other terrestrial aeronautical radio navigation systems.

2. IN-BAND AND OUT-OF-BAND SOURCES

2.1 GPS and GLONASS are internationally registered and protected by the International Telecommunication Union (ITU) as aeronautical radio navigation systems duly operating within spectrum allocated to the aeronautical radio navigation and radio navigation satellite services.

2.2 The current GNSS systems operate in the following frequency bands allocated to aeronautical radio navigation service and aeronautical radio navigation satellite service:

GPS: 1 559-1 610 MHz (GPS operates in segments of this band)
GLONASS: 1 559-1 610 MHz and 1 610-1 626.5 MHz
(GLONASS operates in segments of these bands. After 1998, GLONASS will operate below 1 610 MHz)

2.3 In-band interference sources

2.3.1 A potential source of in-band harmful interference is fixed service operation in certain States. There is a primary allocation to the fixed service for point-to-point microwave links in certain States in the frequency band used by GPS and GLONASS.

2.3.2 It is recommended that States ensure that their national frequency allocations and assignments in the 1 559-1 610 MHz band do not have the potential to cause interference to GPS or GLONASS operations. Although it is recognized that there is pressure to allocate other services to the band, States must ensure that these existing and future frequency assignments in the 1 559-1 610 MHz band with the potential to interfere with the GNSS operations be moved to other frequency assignments or bands where feasible.

2.4 Out-of-band interference sources

Potential sources of interference from services operating in bands outside the 1 559-1 610 MHz band include harmonics and spurious emissions of aeronautical VHF transmitters, VHF and UHF TV broadcast stations and other high power sources. Out-of-band noise, discrete spurious products and intermodulation products from radio services operating near the 1 559-1 610 MHz band can also cause interference problems.

2.5 Intentional jamming and spoofing

2.5.1 Intentional interference (jamming) to GNSS is also a possibility as it is to all radio navigation systems. Such unauthorized interference is illegal and should be dealt with by the appropriate State authorities.

2.5.2 Spoofing of GNSS receivers can be made extremely difficult with proper design of the receiver autonomous integrity monitoring (RAIM) and fault detection and exclusion algorithms for en-route operations being considered by ICAO and States. For approach operations it may be necessary to employ ground based monitoring to detect and anunciate attempted jamming and spoofing of the GNSS. One method to detect intentional jamming and spoofing would be to monitor the spectrum and sound an alarm when a new signal is detected in the spectrum used by the GPS/GLONASS.

3. ON-BOARD SAME AIRCRAFT

3.1 The potential for harmful interference to GPS and GLONASS on an aircraft depends on the individual aircraft, its size and what transmitting equipment is installed. The GNSS antenna location should take into account the possibility of on-board interference (mainly SATCOM).

3.2 On large aircraft, sufficient isolation between a transmitting antenna and a GNSS receiving antenna can usually be obtained to mitigate an interference problem. Transmitters of particular interest are the satellite communications equipment and VHF transmitters. The possible generation of intermodulation products on the aircraft from one transmitter (with multiple carriers) or multiple transmitters is controlled by a combination of transmitter filtering and frequency management. Some on-board interference could be due to harmonics generated by weathered joints and connections. It is recommended that airline operators and State regulatory authorities take action to control such occurrences.

3.3 Avionics must be installed in accordance with certain standards to ensure that they operate properly in the aircraft. These standards require testing for interference with and by other on-board systems. Several States use the United States Federal Aviation Administration Document AC-20-138 (see Appendix 1) as the basis for installation approval.

3.4 The combination of appropriately shielded GPS and GLONASS antenna cabling, separation of antennas and cables and transmitter filters can solve most interference problems on board small aircraft. Transmit equipment should be filtered within its own box or externally as close to the transmit antenna port as possible.

3.5 Some personal electronic devices, when used on board an aircraft, may be capable of generating sufficient in-band energy to interfere with avionics. This topic is the subject of the RTCA SC 177.

4. REGULATORY ASPECTS

4.1 The protection of aeronautical radio navigation safety services is of paramount importance. International regulations state that the aeronautical radio navigation service is afforded special protection. The ITU Radio Regulation (RR) 953 states that:

> ‘‘Members recognise that the safety aspects of radionavigation and other safety services require special measures to ensure their freedom from harmful interference; it is necessary therefore to take this factor into account in the assignment and use of frequencies.’’

4.2 Each State should ensure that regulations are in place to protect aeronautical radio navigation spectrum including satellite navigation.

4.3 At the recent ICAO Special Communications/Operations Divisional Meeting (1995) (SP COM/OPS/95), States were reminded that only International Telecommunication Union (ITU) Member Administrations, normally represented through radio regulatory authorities, have the authority to negotiate for secure and protected spectrum needed for aviation. There is no doubt that there is a critical need to ensure that sufficient spectrum exists for GNSS (including augmentation systems) and that it is properly regulated and protected.

4.4 In this regard, aviation experts from States should participate in a co-operative manner in the ITU Radiocommunications Sector (ITU-R) activities to ensure that ITU-R recommendations are established to protect GNSS. States should be encouraged to develop and adopt suitable radio system electromagnetic compatibility standards using ITU-R recommendations and other available criteria to ensure protection of GNSS. Aviation experts from States should also participate in the ITU World Radio Communication Conferences (now held every two years) where spectrum regulations including allocations of frequency bands are decided.

5. TECHNIQUES THAT ELIMINATE OR MITIGATE INTERFERENCE

5.1 Since there is always the possibility of interference, aircraft CNS systems should be designed with this potential in mind. Aircraft certification and installation procedures should require demonstration of protection against on-board harmful interference.

5.2 The most effective place to deal with interference is at its source. Assuming that suitable performance standards have been implemented by regulatory authorities, filters can be mandated to limit out-of-band emissions.

5.3 It may be possible through improved receiver design that in-band interference may be mitigated. Adaptive filters and cancellation techniques employed in a receiver may potentially improve rejection of narrow in-band interference, and these should be investigated and developed if they are effective, robust and cost-effective and if they improve safety.

5.4 The combined use of GPS and GLONASS in the same receiver provides a more robust design against certain interference than GPS alone and GLONASS alone due to its use of multiple frequencies.

5.5 The integration of an inertial system can provide the ability to coast through short periods of signal outage, including those caused by transient interference. At best it could be considered as an extra margin for unforeseen interference events. It is not recommended that the added benefit of inertial guidance be credited as an interference mitigation technique.

5.6 Where interference is caused by TV transmitters, then control of the harmonic content will be necessary. In one State, it has been found that TV transmitters have harmonics which are over 100 dB less than the carrier. This is 40 dB greater than that required by regulation. If the regulation were changed to be in conformance with what can be achieved and is typical in at least one State in practice, then interference protection from TV transmissions could be assured. Depending upon the adequacy of existing standards and practice, the cost, to the aviation community, of additional filters for TV broadcast stations to protect GNSS operations may be reasonable.

5.7 It is important to evaluate airspace where aircraft are authorized to fly to identify potential sources of interference enumerated in previous paragraphs. If sources interference exist, then consideration should be given to filtering the source transmitter, avoidance of the source where operationally feasible or moving the transmitter to another frequency band.

6. OTHER FACTORS

Airframe shielding of the top-mounted GNSS antenna from ground-based transmitters can offer additional mitigation against interference. The radiation pattern of the antenna and the antenna's position on the aircraft is important in rejecting ground-based interference.

7. FLIGHT CHECKING AND LOCATION OF INTERFERENCE SOURCES

Airframe shielding has been used by one State to help locate the source of ground-based interference. When ground-based interference is experienced, aircraft banking/circling while observing GNSS performance will have the following effect: as the aircraft banks, higher gain portions of the top-mounted GNSS antenna pattern become exposed to the surface of the Earth, while other areas remain shielded. If GNSS performance degrades, then the source may be in the direction of the bank; if performance improves, then the opposite may be true. By using this technique it may be possible to estimate the interfering source location.

8. SUMMARY

8.1 It is acknowledged that the potential for unintentional interference to GNSS should be dealt with via a combination of technical and institutional measures. Intentional interference is possible for all radio navigation systems and should be dealt with by appropriate State authorities.

8.2 Operators should be encouraged to use GNSS receivers that are approved for aviation use with the ability to monitor for hazardous and misleading information including that resulting from interference, however caused, through use of the integrity function.

8.3 States should actively participate, through the appropriate international bodies, to formally protect the frequency spectrum required for satellite navigation.

8.4 States should ensure that SARPs drafted for GNSS by the GNSSP take into account and mitigate against the interference process as appropriate.

Appendix 3

EXAMPLES OF AVIONICS AND GROUND SYSTEMS THAT PROVIDE OPERATIONAL CAPABILITY USING GPS

1. TECHNICAL STANDARD ORDER (TSO) C-129 AVIONICS

1.1 Receivers that comply with United States FAA Technical Standard Order (TSO) C-129 support one or more of the following phases of flight depending on the class of the receiver: en-route, terminal and non-precision approach. These receivers provide virtually the same position accuracy as the GPS SIS (100 m 95th percentile). These receivers either provide the RAIM fault detection function or must be used with an integrated navigation system that provides performance equivalent to RAIM. If a GPS horizontal position error larger than the protection limit exists, RAIM will detect it with a probability of 0.999 when RAIM exists. When RAIM does not exist, an indication to this effect is provided by the equipment. Given the current United States guarantee on the frequency of major service failures (horizontal position errors larger than 500 m when PDOP does not exceed 6), and under the assumption that one-third of users are affected by erroneous data from a malfunctioning satellite, the probability with which a given user will experience undetected errors larger than the protection limit will be approximately 1.1×10^{-7} per flight hour when RAIM exists. This probability is computed as ((3/year × 1/3) / (365 days/year) × (24 hours/day)) x 0.001 missed detection probability.

1.2 The availability of RAIM depends on the particular RAIM algorithm used, the number of operating satellites, satellite mask angle, latitude and other factors. TSO C-129 requires that the receiver accept pressure-altitude input to augment RAIM to improve RAIM availability. Approach-capable avionics are required to have two types of altimeter aiding, termed ‘‘altimeter aiding with GPS calibration’’ and ‘‘altimeter aiding with local pressure correction’’. Availabilities are highest for en-route protection limit of 2 NM and lowest for the non-precision approach protection limit of 0.3 NM. Typical availabilities of the RAIM fault detection function are roughly 99 per cent for en-route flight and 90-95 per cent for non-precision approach for mid-latitudes, depending on the factors cited above.

1.3 Because the availability of RAIM with altimeter aiding is less than 100 per cent, equipment complying with TSO C-129 were intended for supplemental use, i.e. a backup navigation method is required to be present on the aircraft. In addition, TSO C-129 requires a predictive RAIM capability to allow a pilot to determine whether or not RAIM will exist at future locations at the estimated time of arrival. This capability is intended to be used to plan flights to ensure the availability of approach guidance at arrival time. To maintain safety, current guidance states that an alternate airport, if required, must be based on an ICAO standard navigation aid other than GPS or LORAN-C.

2. FANS 1

2.1 The 747-400 ‘‘FANS-1’’ avionics package uses GPS as an input to a multi-sensor area navigation (RNAV) system. The system has been designed to use GPS in the RNAV solution for oceanic/remote, en-route, terminal, and instrument approach procedures (to MDA/DA).

2.2 Navigation performance is specified using the ICAO RNP concept and includes accuracy, integrity, availability of signals in space, and availability of avionics equipment for a particular area, airspace, route, procedure, or operation. Performance is further specified in terms of the number of healthy GPS satellites that are anticipated to be available for a particular operation. For example, for RNP 4, an accuracy of 4.0 NM (95 per cent probability) will be available 99.999 per cent of the time with 23 healthy satellites. Integrity associated with this particular example is such that an 8.0 NM containment radius will be protected to a probability level of 1×10^{-7} per flight hour. (Stated differently, integrity as used in FANS 1 is the probability level of 1×10^{-7} that the actual position is outside the containment radius.) This level of availability is defined as primary navigation for FANS-1. FANS-1 is expected to provide primary navigation to larger and smaller RNPs depending on the number of healthy satellites and the availability of VHF navigation radios.

2.3 FANS-1 performance has been specified for RNP levels of 0.15, 0.5, 1.0, 2.0, 4.0 and 12.0. It may be possible to associate an RNP level with existing procedure types (VHF omnidirectional radio range (VOR), VOR/distance measuring equipment (DME) etc.) so that FANS-1 can be evaluated for use in non-RNP environments. For example, an RNP of 12.0 could be associated with MNPS airspace, an RNP of 4.0 with en-route domestic airspace, RNP 0.5 for VOR or VOR/DME non-precision approaches, and RNP 0.3 for RNAV non-precision approaches.

2.4 For certain RNPs, the current satellite navigation system (GPS) will not support primary operations due to lack of ability to compute RAIM. FANS-1 integration of the GNSS receiver with a flight management system and inertial reference units provides enhanced integrity to increase the availability of the GPS-supplied accuracy levels. If desired, airline operations departments may predict the availability of the GPS integrity monitoring function (RAIM) to determine if a particular RNP can be achieved during an operation at times when nominal FANS-1 performance guarantees (based on world-wide satellite availabilities) state that it could not be met.

2.5 A complete description of FANS-1 navigation capability including assumptions regarding accuracy, integrity, availability, and RNP is contained in Boeing Document D240U126, ‘‘RNP Capability of FANS-1 FMCS Equipped 747-400’’ (source information may be found in Appendix 1).

2.6 While the 747-400 is the first FANS-1 aeroplane, similar updates are under development for the MD-11 and MD-90. The performance for these systems is also specified using the ICAO RNP concept. All three airplanes use similar architectures (triple inertial reference systems, dual flight management systems, dual GNSS, dual DME) and should be able to demonstrate similar levels of RNP. It will be interoperable with the Boeing FANS-1 and Airbus FANS A.

3. FANS A

3.1 The FANS A package is being developed for implementation in a phased and evolutionary manner. The first part of the FANS A package will enable GPS to be used as a ‘‘primary’’ means of navigation and will be available on all current Airbus aircraft — A310, A320 and A330/A340 families — in 1996.

3.2 The FANS A GNSS Function has been designed with two main objectives:

a) FANS A operation will be based on a total navigation system concept. It uses GPS accuracy and on-board autonomous integrity monitoring techniques, augmented by the built-in integrity checking capability of the FMS, should there be GPS outages; to take advantage of the GPS performance as long as possible the integrity checking takes into account the current satellite coverage.

b) FANS A is also designed to integrate GPS navigation smoothly into the cockpit. Since GPS is already certified as a supplementary means of navigation on the A320 and A330/A340 families of aircraft, that initial experience will allow early introduction of GPS as a primary means of navigation without the need for extensive pilot training or retraining. Significant operational benefits should accrue very quickly. Annunciations have been designed to highlight the use of GPS navigation (instead of radio or inertial navigation) and incorporate the required navigation performance (RNP) concept.

3.3 The FANS A GPS functions are designed to be compliant with the FAA multi-sensor certification document AC 20-130A and the TSO C129 receiver certification document. FANS A is also functionally interoperable with the Boeing FANS-1 and the McDonnell Douglas FANS-1.

3.4 Use of the on-board RAIM-type functions for integrity checking will permit certification to RNP levels of RNP 0.3 (certification will be as ‘‘GPS Primary’’)

3.5 In terms of availability, the current GPS constellation should allow RNP 4 operations in most parts of the world outside of radio coverage. For RNP 1 operations, it is envisioned that the routes will be based on DME/DME coverage until the GPS is augmented with additional satellites. The FANS A system is designed to support these satellites without modification.

3.6 For non-precision approach operations, including ‘‘GPS only approaches’’, the ‘‘GPS Primary’’ function includes an on-board ‘‘predictive RAIM-type’’ function to determine integrity and availability.

3.7 Use of the on-board integrity monitoring functions, based on the GPS/IRS configuration or, for the A320/A330/A340 families, the GPS/ADIRS[1] configuration, will assure compliance with accuracy, integrity and availability criteria sufficient to meet RNP requirements without the need for radio coverage nor predictive RAIM.

4. SPECIAL CATEGORY I

4.1 Special Category I (SCAT-I) avionics and ground systems are local differential GPS systems, not for public use, intended to achieve CAT I precision approach minima. See United States FAA Order 8400.11, RTCA DO-217 and Transport Canada Aviation Document TP11907. They perform continuous integrity monitoring as well as transmitting differential corrections. SCAT-I requirements may be summarized as follows:

a) *Integrity*. The probability of undetected hazardously misleading information (HMI) due to all causes (ground system, airborne system, data link) is less than 10^{-7} per approach;

b) *Continuity*. The probability of loss of approach capability after an approach is initiated is no greater than 10^{-4} per approach due to all causes;

c) *Availability.* 0.95; and

d) *Accuracy.* Unlike other precision approach systems, accuracy is specified in terms of total system error (TSE) rather than navigation system error (NSE). SCAT-I requirements include 95th percentile TSE and a $1 - 10^{-7}$ outer containment surface, both of which vary as a function of nominal height above threshold. See RTCA D0-217 for further information.

1. The GPS/ADIRS is the GPS coupled with the Air Data Inertial Reference System, a system that uses all available navigation sources to monitor the GPS to assure the highest levels of accuracy, integrity and availability.

4.2 The achievement of SCAT-I TSE depends on the magnitude of flight technical error (FTE). Demonstration of FTE is required to assure that performance is adequate to support decision heights as low as those of CAT I ILS.

5. ENHANCED TSO C-129 RECEIVERS FOR PRIMARY USE IN OCEANIC AND REMOTE AIRSPACE

5.1 The United States FAA is developing guidance for the use of receivers complying with TSO C-129 with enhanced capabilities as a primary means of navigation in oceanic and remote airspace. This development was motivated by the possible loss of Omega stations. The principal additional required receiver capability is fault detection and exclusion (FDE). The FDE function enables avionics to automatically exclude the source of erroneous information when a fault is detected and continue navigation with the remaining ranging sources, all without pilot involvement. Receiver performance is otherwise not different from that described in 1.1 above. The ability to support a protection (alert) limit of 4 NM is desirable, however, because it increases the availability of RAIM and FDE functions. Because the loss of these functions is a probable event without dispatch requirements, guidance being developed requires that predictions of navigation, RAIM, and FDE functions be performed under certain conditions. These limit the probability and/or duration of outages of these functions to prevent the need for extended dead reckoning. The durations are chosen consistent with the ability to dead-reckon and remain within protected airspace.

Appendix 4

CASE STUDIES AND RELATED INFORMATION

This appendix contains information on the early application of GPS technology in some ICAO Contracting States. It also provides a methodology for identifying homogeneous areas for implementation of GNSS.

This appendix contains the following sections:

Section 1. Information on Australia’s early application of GPS technology
Section 2. Information on Canada’s early application of GPS technology
Section 3. Information on Fiji’s early application of GPS technology
Section 4. Information on the United Kingdom’s early application of GPS technology
Section 5. Methodology for identifying homogeneous areas for implementation of GNSS

The foregoing information is being updated by the States concerned and promulgated in their Aeronautical Information Publications (AIPs).

Section 1
Information on Australia's Early Application of GPS Technology

Requirements for Use of Global Positioning System (GPS) as an Approved Primary Means IFR Navigation Aid

1. PURPOSE

1.1 The purpose of this AIP Supplement (SUP) is to detail the Civil Aviation Safety Authority's requirements for the use of GPS as:

a) an approved en-route and area IFR primary means navigation aid; and

b) a navigation aid approved for the purpose of ''GPS Arrivals'' and ''DME or GPS Arrivals'' as published in AIP DAP.

1.2 This SUP constitutes the Civil Aviation Safety Authority (CASA) approval for the use of a GPS system, fitted and operated in accordance with the provisions of this SUP, within Australian domestic airspace only, for the purpose of:

a) position fixing, as required in AIP RAC, paragraph 44;

b) long range navigation in accordance with AIP RAC, paragraph 44.1 b, including operations on designated RNAV routes;

c) deriving distance information, for en-route navigation, traffic information and ATC separation;

d) en-route IFR descent below LSALT/MSA — GPS Arrivals;

e) en-route IFR descent below LSALT/MSA — DME or GPS Arrivals (substituting GPS-derived distance information); and

f) application of RNAV-based separation.

1.3 *GPS must not be used as a sole-means navigation system, or for instrument approaches other than ''GPS Arrivals'' or ''DME or GPS Arrivals'' until further authorization is issued.*

1.4 GPS may continue to be used as an en-route supplemental navigation aid under the provisions of AIP SUP H 18/94.

2. BACKGROUND

2.1 GPS was approved for IFR en-route supplemental navigation use in Australia in 1994. As further information has become available on the accuracy, integrity, availability and continuity of GPS, and following United States DoD declaration of Full Operational Capability (FOC) in April 1995, CASA has determined that the use of GPS for IFR navigation can be extended, in accordance with the provisions of this SUP.

2.2 Additionally, as a result of non-aviation demands for the 200 MHz frequency band, Australian DME (DMEA) will be withdrawn with effect 7 December 1995, and instrument arrivals based on DMEA will no longer be available. CASA has determined that GPS-derived distance information, in lieu of DME, may be used, as specified in this SUP.

2.3 Instrument arrival procedures using GPS-derived distance, combined with NDB or VOR azimuth information, will be introduced and will be known as ‘‘GPS Arrival’’ procedures.

2.4 DME Arrival procedures based on international DME will be retained. Approved GPS systems may be used to provide the distance element of International DME Arrival procedures, in accordance with the provisions of this SUP. These procedures are identified in AIP DAP as ‘‘DME or GPS arrivals’’.

3. DEFINITIONS

Sole-means navigation system. A navigation system that, for a given phase of flight, must allow the aircraft to meet all four navigation system performance requirements — accuracy, integrity, availability and continuity of service.

Primary-means navigation system. A navigation system that, for a given operation or phase of flight, must meet accuracy and integrity requirements, but need not meet full availability and continuity of service requirements. Safety is achieved by either limiting flights to specific time periods or through appropriate procedural restrictions and operational requirements.

Supplemental-means navigation system. A navigation system that must be used in conjunction with a sole-means navigation system.

Integrity. That quality which relates to the trust which can be placed in the correctness of information supplied by a system. It includes the ability of a system to provide timely warnings to users when the system should not be used for navigation.

Receiver autonomous integrity monitoring (RAIM). A technique whereby an airborne GPS receiver/processor autonomously monitors the integrity of the navigation signals from GPS satellites.

Note.— Systems for providing integrity, other than RAIM, may be approved for use. Where reference to RAIM occurs in this SUP, it includes other approved equivalent integrity monitoring systems.

4. GPS SIGNAL INTEGRITY

4.1 System integrity is an essential element of the approval for use of GPS as a primary-means navigation system. GPS receivers certified to TSO-C129 provide integrity through the use of RAIM or an approved equivalent integrity system. When RAIM is lost or not available, the accuracy of the system cannot be assumed to meet the required standard for navigation or for the application of ATC separation standards.

4.2 GPS integrity is also dependent on the number of operational satellites in view or available for use. Loss of one or more satellites can result in degraded system availability (see 5).

4.3 RAIM availability is greatly improved through the use of barometric aiding.

4.4 *Except as provided in this SUP, GPS must not be used to fix position, provide distance information or provide primary navigation, unless RAIM is available.*

5. GPS SATELLITE CONSTELLATION

5.1 The approvals contained in this SUP are based on the availability of the United States DoD GPS Standard Positioning Service (SPS) operating to its defined Full Operational Capability (FOC). This service does not meet the requirements of a sole means navigation system.

5.2 Disruption to the SPS may result in degradations in GPS service to such a level that some or all of the operational approvals for the IFR primary use of GPS contained in this SUP may need to be withdrawn. When known, these changes or restrictions will be advised by NOTAM.

5.3 Prior knowledge of RAIM availability will enable operators to use the system more efficiently, by allowing operations to be planned around gaps in RAIM coverage (RAIM holes). To achieve these efficiencies, CASA recommends that appropriate RAIM prediction capabilities be available at dispatch locations. Flights should be planned to ensure the safe completion of flight in the event of loss of GPS integrity.

6. AIRWORTHINESS REQUIREMENTS

The following airworthiness requirements must be satisfied:

a) GPS navigation equipment must have United States FAA Technical Standard Order (TSO) C-129 (or CASA approved equivalent) authorization; and

b) GPS receivers must be installed in Australian civil registered aircraft in accordance with AAC No. 6-26; and

c) automatic barometric aiding function, as provided by TSO C-129, must be connected.

Note 1.— Operators should be aware that not all TSO C-129 receivers will meet the requirements for non-precision approaches, other than ‘‘GPS Arrivals’’ and ‘‘DME or GPS Arrivals’’.

Note 2.— Operators should also be aware that TSO-C129 receivers may not be able to take advantage of future enhanced GPS capabilities, such as Wide Area or Local Area Augmentation Systems (WAAS or LAAS).

7. PILOT TRAINING

The following pilot training requirements must be satisfied.

a) Prior to using GPS in IFR operations for any of the purposes specified in this SUP, the holder of an instrument rating must, unless exempted by CASA, have completed a course of ground training based on the syllabus contained in Annex A. The course must be conducted by, or on behalf of, an approved IFR check and training organization or approved instrument training school, or by CASA.

b) Satisfactory completion of the course and demonstration of competence in operation must be certified in the pilot's log book by either a Flying Operations Inspector (FOI), or by the Chief Pilot or the Chief Flying Instructor (or their nominated representative) of an organization approved to conduct such a course. The certification entered in the pilot's personal log book shall be in the form specified below:

> Form: XY Jones has satisfactorily completed a course of ground instruction in GPS principles and operation in accordance with the syllabus contained in CAO 40.2.1 Appendix IV and I consider him or her competent in the operation of . . . . type of GPS equipment for the purposes specified in CAO 40.2.1 para 13.5(a).
>
> . . . .
>
> AB Smith (ARN . . . .) 7 December 1995.

c) The course must cover both general information and procedures applicable to all types of GPS equipment, as well as the essential operating procedures for a specific type of aircraft equipment. Pilots who have completed the course and who wish to use a different type of GPS aircraft equipment must ensure that they are familiar with and competent in the operating procedures required for that type of equipment, before using it in flight for any of the purposes approved in this SUP.

8. OPERATIONAL REQUIREMENTS

The following operational requirements must be satisfied.

a) Operating instructions for GPS navigation equipment must be:

1) carried on board; and

2) incorporated into the Company Operations Manual for commercial operations.

b) GPS navigation equipment must be operated in accordance with the operating instructions and any additional requirements specified in the approved aircraft flight manual or flight manual supplement.

c) In addition to GPS, aircraft must be equipped with serviceable radio navigation systems as specified at AIP RAC paragraph 44.6 or the Minimum Equipment List (MEL).

d) GPS must not be used to satisfy any of the alternate requirements of RAC paragraph 38.3.1.

e) When within rated coverage of ground-based navigation aids, pilots must monitor the ground-based system, and maintain track as defined by the most accurate ground-based radio navigation aid (VOR or NDB) available. If there is a discrepancy between the GPS and ground-based system information, pilots must use the information provided by the ground-based navigation system.

f) ATC may require GPS-equipped aircraft to establish on, and track with reference to, a particular VOR radial or NDB track for the application of separation.

g) *GPS must not be used as a navigation reference for flight below the LSALT/MSA,* except as provided in paragraph 11 of this SUP, or as otherwise authorized by CASA.

9. OPERATIONS WITHOUT RAIM

9.1 GPS systems normally provide three modes of operation:

a) Navigation (Nav) Solution with RAIM;

b) 2D or 3D Nav Solution without RAIM; and

c) Dead Reckoning (DR) or Loss of Nav Solution.

9.2 ATS services and, in particular, ATC separation standards, are predicated on accurate navigation and position fixing. If RAIM is lost, the accuracy of the system is assumed not to meet the required standard for both navigation and application of ATC separation. Accordingly, when RAIM is lost, the following procedures must be adopted:

a) Aircraft tracking must be closely monitored against other on-board systems.

b) *In controlled airspace, ATC must be advised if:*

1) RAIM is lost for periods greater than ten minutes, even if GPS is still providing positional information; or

2) RAIM is not available when ATC requests GPS distance, or if an ATC clearance or requirement based on GPS distance is imposed; or

3) the GPS receiver is in DR mode, or experiences loss of navigation function, for more than one minute; or

4) indicated displacement from track centre line is found to exceed 2 NM.

ATC may then adjust separation.

c) If valid position information is lost (2D and DR Mode), or non-RAIM operation exceeds ten minutes, the GPS information is to be considered unreliable and another means of navigation should be used until RAIM is restored and the aircraft is re-established on track.

d) Following re-establishment of RAIM, the appropriate ATS unit should be notified of RAIM restoration, prior to using GPS information. This will allow ATC to reassess the appropriate separation standards.

e) When advising ATS of the status of GPS, the phrases ‘‘RAIM FAILURE’’ or ‘‘RAIM RESTORED’’ must be used.

10. GPS DISTANCE INFORMATION TO ATS UNITS

10.1 When a DME distance is requested by an ATS unit, DME-derived distance information should normally be provided. Alternatively, GPS-derived distance information may be provided to an ATS unit, unless RAIM is currently unavailable and has been unavailable for the preceding ten minutes.

10.2 Notwithstanding 10.1, if an ATC unit has issued a clearance or requirement based upon GPS distance (e.g. a requirement to reach a certain level by a GPS distance), pilots must inform ATC if RAIM is not available.

10.3 When a DME distance is not specifically requested, or when the provision of a DME distance is not possible, distance information based on GPS-derived information may be provided. When providing GPS distance, transmission of distance information must include the source and point of reference — e.g. 115 GPS ML VOR, 80 GPS CTM NDB, 267 GPS BEEZA, etc.

10.4 If a GPS distance is provided to an ATC unit and RAIM is not currently available but has been available in the preceding 10 minutes, the distance report should be suffixed ‘‘NEGATIVE RAIM’’ — e.g. 26 GPS LT NEGATIVE RAIM.

10.5 Databases sometimes contain way-point information which is not shown on published AIP charts and maps. Distance information must only be provided in relation to published way-points unless specifically requested by an ATS unit.

10.6 Where GPS distance is requested or provided from an NDB, VOR, DME or published way-point, the latitude and longitude of the navigation aid or way-point must be derived from a validated data base which cannot be modified by the operator or crew (refer to 1.1 and 1.2).

11. GPS ARRIVALS

11.1 Provided that primary azimuth guidance is provided by an associated NDB or VOR, and subject to the restrictions in 11.2, GPS systems meeting the requirements of this SUP may be used to conduct en-route IFR descent below LSALT/MSA in accordance with the ‘‘GPS Arrival’’ and ‘‘DME or GPS Arrival’’ procedures published in AIP DAP.

11.2 In addition to the general limitations and restrictions in this SUP, the following specific restrictions apply to ‘‘GPS Arrivals’’ and ‘‘DME or GPS Arrivals’’:

a) the coordinates of the destination VOR or NDB, to which the descent procedure relates, must not be capable of modification by the operator or crew;

b) the database medium (card, chip, etc.) must be current, and of a kind endorsed by the receiver manufacturer;

c) RAIM must be available before descending below the LSALT/MSA when conducting a ‘‘GPS Arrival’’ or ‘‘DME or GPS Arrival’’;

d) the destination aid (VOR or NDB) nominated in the ‘‘GPS Arrival’’ or ‘‘DME or GPS Arrival’’ chart must be used to provide primary track guidance during the arrival procedure;

e) in the event of a significant disparity between the NDB or VOR track, and the GPS track indication, the pilot must discontinue the arrival procedure;

Note.— Significant disparities (from AIP RAC 44.5) are:

a) NDB: > 6.9 degrees and

b) VOR: > 5.2 degrees.

f) if at any time during the approach there is cause to doubt the validity of the GPS information (e.g. RAIM warning) or if RAIM is lost, the pilot must:

1) maintain flight to the Missed Approach Point (MAPt) at the last level at which the pilot was satisfied with the accuracy of the GPS system; or

2) climb to the en-route LSALT/MSA and use an alternative approach, or hold or divert.

Note.— Where significant aberrations in GPS information are observed, pilots are requested to advise ATS of any suspected errors. If interference is suspected, an interference report should be submitted (refer Annex B).

12. DATA INTEGRITY

12.1 As a significant number of data errors, in general applications, occur as a result of manual data entry errors, navigation aid and way-point latitude and longitude data should be derived from a database, if available, that cannot be modified by the operator or crew.

12.2 When data is entered manually, data entries must be cross-checked by at least two crew members for accuracy and reasonableness or, for single pilot operations, an independent check (e.g. GPS computed tracks and distances against current chart data) must be made.

12.3 Both manually entered and database derived position and tracking information should be checked for reasonableness (confidence check) in the following cases:

a) prior to each compulsory reporting point;

b) at or prior to arrival at each en-route way-point;

c) at hourly intervals during area type operations when operating off established routes; and

d) after insertion of new data — e.g. creation of new flight plan.

12.4 *Only data from a validated database may be used for navigation below the LSALT/MSA. Manually entered data must not be used for navigation by civil aircraft below the LSALT/MSA, unless authorized by CASA.*

13. INTEGRITY AND INTERFERENCE DATA SHEETS

13.1 Coincident with the approvals contained in this SUP, and in order to build up the database on GPS integrity in Australia, a system validation period has been established to verify operationally the availability of RAIM and the quality of navigation provided by GPS at other times.

13.2 The validation period will be reviewed prior to 1 December 1996, with a view to possibly extending GPS use approvals and revising ATC separation minima.

13.3 Operators or pilots using GPS for the purposes stated at 1.2 of this SUP are requested to provide GPS system information, as detailed below:

a) *Private operators.* Private operators are requested to submit information on GPS interference as it occurs; and

b) *Commercial operators.* Commercial operators are requested to submit integrity reports for the first 30 flights after installation of approved GPS equipment. After this period, operators are requested to monitor and record the performance of GPS, and provide details of the system accuracies and reliabilities from time to time. In addition to these reports, operators are requested to submit information on GPS interference as it occurs.

13.4 Pilots should particularly note cases of GPS degradation/interference around airports, over populated areas, near radio or television transmission towers and during radio or SATCOM transmit operations.

13.5 Information about the additional types of data required is detailed on the data sheet. This data will be used to verify the predicted integrity of the GPS system in Australian airspace, and will, in part, form the basis for future extension of GPS approvals and revisions to ATC separation minima.

13.6 Data should be entered on System Verification Data Sheets, which may be obtained from a CASA District Office, or by copying the attached Annex B.

14. FLIGHT PLAN NOTIFICATION

Pilots of aircraft equipped with GPS systems that comply with the requirements of this SUP should insert the following in flight plans:

a) Domestic Flight Plan: ‘‘N’’ in the NAV section, and ‘‘NAV/GPSRNAV’’ in the OTHER INFORMATION section.

b) Standard IFR Flight Plan: ‘‘N’’ in the NAV section, and ‘‘NAV/GPSRNAV’’ in the OTHER INFORMATION section.

c) ICAO Flight Plan: ‘‘Z’’ in field 10, and ‘‘NAV/GPSRNAV’’ in field 18.

15. CANCELLATION

15.1 This SUP remains valid until its provisions are incorporated into AIP and MATS.

16. DISTRIBUTION

All Pilot Licence holders (except students)	last issue H48/95
All AIP holders	last issue H48/95
All MATS holders	last issue H47/95

Annex:

A. Syllabus of Training — GPS as Primary-means Navigation
B. System Verification Data Sheet

ANNEX A TO SUP H50/95
SYLLABUS OF TRAINING — GPS AS PRIMARY MEANS NAVIGATION

1. GPS SYSTEM COMPONENTS AND PRINCIPLE OF OPERATION

Demonstrate an understanding of the GPS system and its principles of operation:

- GPS system components, constellation, control and user
- Aircraft equipment requirements
- GPS satellite signal and pseudo random code
- Principle of position fixing
- Method of minimizing receiver clock error
- Minimum satellites required for navigation functions
- Masking function
- Performance limitations of various equipment types
- GPS use of WGS-84 coordinate system

2. NAVIGATION SYSTEM PERFORMANCE REQUIREMENTS

Define the following terms in relation to a navigation system and recall to what extent the GPS system meets the associated requirements:

- Accuracy
- Integrity: Means of providing GPS integrity; RAIM; procedural systems integration.
- Availability
- Continuity of service

3. AUTHORIZATION AND DOCUMENTATION

Recall the requirements applicable to pilots and equipment for GPS operations:

- Pilot training requirements
- Log book certification
- Aircraft equipment requirements
- GPS NOTAM

4. GPS ERRORS AND LIMITATIONS

Recall the cause and magnitude of typical GPS errors:

- Ephemeris
- Clock
- Receiver
- Atmospheric/ionospheric
- Multipath
- SA
- Typical total error associated with C/A code
- Effect of PDOP/GDOP on position accuracy
- Susceptibility to interference
- Comparison of vertical and horizontal errors
- Tracking accuracy and collision avoidance

5. HUMAN FACTORS AND GPS

Be aware of the human factors limitations associated with the use of GPS equipment. Apply GPS operating procedures which provide safeguards against navigational errors and loss of situational awareness due to these causes:

- Mode errors
- Data entry errors
- Data validation and checking including independent cross-checking procedures
- Automation-induced complacency
- Non-standardization of the GPS/pilot interface
- Human information processing and situational awareness

6. GPS EQUIPMENT — SPECIFIC NAVIGATION PROCEDURES

Recall and apply knowledge of appropriate GPS operating procedures to typical navigational tasks using a specific type of aircraft equipment.

- Select appropriate operational modes
- Recall categories of information contained in the navigational database
- Predict RAIM availability
- Enter and check user defined waypoints
- Enter/retrieve and check flight plan data
- Interpret typical GPS navigational displays LAT/LONG, distance and bearing to waypoint, CDI
- Intercept and maintain GPS-defined tracks
- Determine TMG, GS, ETA, time and distance to WPT, WV in flight
- Indications of waypoint passage
- Use of direct to function
- Use of nearest airport function
- Use of GPS in GPS and DME/GPS arrival procedures

7. GPS EQUIPMENT CHECKS

For the specific type of aircraft equipment, carry out the following GPS operational and serviceability checks at appropriate times:

- TSO status
- Satellites acquired
- RAIM status
- PDOP/GDOP status
- IFR Database currency
- Receiver serviceability
- CDI sensitivity
- Position indication

8. GPS WARNINGS AND MESSAGES

For the specific type of aircraft equipment, recognize and take appropriate action for GPS-warnings and messages, including the following:

- Loss of RAIM
- 2D navigation
- In dead reckoning mode
- Database out of date
- Database missing
- GPS fail
- Barometric input fail
- Power/battery fail
- Parallel offset on
- Satellite fail

ANNEX B TO SUP H50/95

Global Positioning System (GPS)
System Verification Data Sheet

A. GENERAL

Name: . . . . Company: . . . .

Address:. . . . .

. . . .

Telephone:. . . . . Facsimile: . . . .

(Address is used only in the event clarification is needed.)

Please report each occurrence separately.

Make and type of receiver and any special features in use at the time that may have affected its performance:

. . . .

. . . .

B. INTERFERENCE REPORT

Purpose for which GPS was being used (survey, navigation, etc.) and its mode of use (e.g. stationary vehicle, at sea, aircraft in flight, etc.):

. . . .

Location of receiver antenna (e.g. remote mounted on vehicle):

. . . .

Date, time and nature of GPS malfunction and variation with time/distance travelled:

. . . .

Geographical location of malfunction (map reference or Lat/Long):

. . . .

. . . .

Description of location (e.g. town, airfield) noting any potential sources of interference (e.g. satellite signals shadowed from rising ground, reflections from other sources):

. . . .

. . . .

Did you try to establish a cause for the malfunction? If so, what did you do, and what were your conclusions?

. . . .

. . . .

C. INTEGRITY/RAIM LOSS REPORT

RAIM/mode: Enroute/terminal/approach	*Date and time*	*Period of loss*	*Location*

COMMENTS:

Please forward completed forms to:

Ian Mallett
Airservices Australia
P.O. Box 367
CANBERRA ACT 2601
Fax: 06 - 268 4141

Section 2

Information on Canada's Early Application of GPS Technology

INTRODUCTION

Aircraft provide the only means of transport in Canada's vast sparsely-populated remote areas, where providing reliable navigation aids is difficult and expensive. Many operators in these areas have discovered GPS, see its benefits and want to move away from traditional aids to a system based entirely on GPS. In response, Transport Canada Aviation is exploring the potential of GPS and augmentation systems to meet the safety standards for all phases of flight in all areas of the country.

BENEFITS OF GPS

The global implementation of all CNS/ATM components is required to bring major benefits to international airlines. GPS approvals, however, will bring many benefits to domestic operators. Much of Canada's northern airspace is uncontrolled and traditional NAVAIDS do not support the most efficient routes. With GPS, operators can fly direct to destination, saving fuel and time. Many airports in remote areas are served by circling non-precision approaches. Straight-in GPS non-precision approaches will lower minima, increasing airport availability and improving the safety of operations, particularly for turbojet aircraft. In summary, the early approval of GPS operations in Canada will bring significant safety and efficiency benefits.

GOAL AND STRATEGY

Transport Canada Aviation's goal is to bring the benefits of GPS to users as soon as it is proven safe. This involves learning about GPS and granting approvals incrementally, rather than waiting for a satellite-based system that meets all requirements. This requires a broadly-based approach, in which all offices responsible for granting approvals move forward together in the learning process. Other key elements of the strategy include co-operating internationally to avoid duplication of effort and seeking support from Canadian users in other disciplines. It is also important to work closely with operators, to ensure that standards and approvals meet their needs.

TRIALS AND STUDIES

Under an agreement with the United States FAA, Transport Canada Aviation has completed GPS en-route, non-precision approach and WAAS precision approach trials with its flight inspection fleet of Challenger and Dash 8 aircraft. In addition, other agencies and operators in Canada have completed LAAS precision approach trials and theoretical studies, all with the support of Transport Canada Aviation. This experience with GPS fosters the confidence necessary to grant approvals and move forward with development.

SUPPLEMENTAL APPROVAL

Based on non-precision approach trials completed by TC Aviation in Canada and the FAA in the United States, Canada issued its first GPS approval in June 1993. The Special Aviation Notice, issued 22 July 1993, was revised on 2 February 1995. The revised notice is attached. Non-precision approaches are being introduced in two phases. In the first phase, about 150 existing VOR and NDB straight-in approaches have been overlaid with GPS approaches. Pilots can use existing approach charts to fly these approaches while monitoring the traditional aids. In the second phase, stand-alone approaches will be introduced. This depends on completing runway surveys and developing flight inspection standards, procedures, equipment and software.

To develop the experience necessary to design approaches and develop training and testing standards, TC Aviation is purchasing TSO C129 Class A1 receivers and using them in a departmental Cessna 182. In addition, the department's Cessna Citation II aircraft are being fitted with TSO C129 sensors integrated with the FMS and certified for non-precision approach.

Surveys of most candidate runways in the country were completed using relatively inexpensive GPS survey receivers, which provided about 5 metre accuracy. Regional offices have set priorities for approach development based on traffic levels, increased airport usability and by consulting users. Software has been acquired to allow all approach design to be completed by computer, effectively eliminating possible data base errors introduced in the design process.

SPECIAL CATEGORY I (SCAT-I) PRECISION APPROACH

There are a significant number of runways in Canada served by jet transport aircraft where traditional precision approach aids are not economically viable. The lower cost of LDGPS systems makes it feasible to provide better service at these airports. To meet user demand for early access to GPS precision approach capability, TC Aviation developed a Canadian version of the FAA SCAT-I standards document. Approvals to use SCAT-I systems will be restricted to operators who demonstrate that all components of the system meet requirements. They must also demonstrate, through flight tests, that the aircraft can meet Category I accuracy requirements using the integrated system. It is expected that the first Canadian SCAT-I system will be approved in 1996.

CONCLUSION

GNSS will bring many benefits to the world's aircraft operators. Operators in countries like Canada can benefit immediately through the incremental introduction of GPS. Much can be learned about the use of this global technology from States who have already explored its capabilities and approved its use.

SPECIAL AVIATION NOTICE — CANADA

IFR CONDITIONAL APPROVAL OF GLOBAL POSITIONING SYSTEM (GPS) OPERATIONS

INTRODUCTION

On July 22, 1993, the use of GPS for IFR operations was approved under the conditions described in a Special Aviation Notice. Developments since that time, most notably the declaration of Initial Operational Capability (IOC) of the GPS constellation, require updating the approval document. This was done in part through a NOTAM issued in February, 1994. This Special Aviation Notice replaces the one issued in 1993 and incorporates the February 1994 NOTAM. It specifies the conditions and limitations associated with the approval to use GPS for certain IFR operations in Canada and for Canadian-registered aircraft in North Atlantic Minimum Navigation Performance Specification (NAT MNPS) airspace.

The avionics requirements for IFR flight are described in Air Navigation Order, Series V, Number 22 — IFR Flight Instruments and Equipment Order. An exemption to this Order, allowing a GPS receiver to replace a VOR or ADF receiver, was issued as Aeronautical Information Circular 5/94.

At this point, GPS is considered a supplemental navigation system, meaning it is approved for use in conjunction with a sole means of navigation system, such as VOR. This approval allows GPS to be used most of the time as the primary source of guidance, with the understanding that pilots will back up GPS with sole means systems in accordance with the terms of this approval.

OCEANIC, DOMESTIC EN ROUTE AND TERMINAL OPERATIONS

GPS may be used as the primary IFR flight guidance for oceanic, domestic en route and terminal operations if the following provisions and limitations are met:

a) The GPS navigation equipment must be approved in accordance with the requirements specified in TSO C-129 (Classes A1, A2, B1, B2, C1 or C2), installed and approved in accordance with the appropriate sections of the Airworthiness Manual, and operated in accordance with the approved flight manual or flight manual supplement.

b) Aircraft using GPS equipment under IFR must be equipped with another approved and operational means of navigation. Should GPS navigation capability be lost, this equipment must allow navigation along the planned route or suitable alternate route. Monitoring of the traditional navigation equipment is necessary when there are insufficient satellites in view for Receiver Autonomous Integrity Monitoring (RAIM) to operate.

c) For flight plan purposes other than for operations described in d), the suffix *R* must be used to indicate RNAV capability.

d) For Canadian-registered aircraft in NAT MNPS airspace, a GPS installation with TSO C-129 authorization in Classes A1, A2, B1, B2, C1 or C2 may be used to replace one of the other approved means of long-range navigation (INS, IRS or OMEGA). For flight within Canadian Minimum Navigation Performance

Specifications (CMNPS) airspace or Required Navigation Performance Capability (RNPC) airspace, GPS may serve as the long-range navigation system. CMNPS and RNPC airspace are depicted in RAC 12.2.1, Figure 12.1.

NON-PRECISION APPROACH

GPS non-precision approaches will be introduced in two stages. In the first stage, 147 existing VOR, VOR/DME, NDB and NDB/DME approaches, listed in a notice in the Canada Air Pilot, can be flown using GPS guidance. These *overlay* approaches will provide pilots with operational experience flying GPS approaches while monitoring traditional NAVAIDs. Overlay approaches will use the existing approach plate and name.

In the second stage, *stand-alone* approaches will be published. These will be new GPS approaches that do not overlay traditional approaches. They will be provided for runways which currently have no approach, runways served by circling approaches or runways which have straight-in approaches where the use of GPS will significantly reduce minima. New approach plates, with GPS in the name, will be provided for stand-alone approaches.

GPS may be used as the primary IFR flight guidance during a non-precision instrument approach if the provisions and limitations in a), b) and c) below are met.

a) General provisions

1) The GPS avionics must meet TSO C-129 (Classes A1, B1, B3, C1, C3) requirements or equivalent criteria, must be installed and approved in accordance with the appropriate sections of the Airworthiness Manual, and operated in accordance with the flight manual or flight manual supplement. The avionics database must be current and must contain the non-precision approaches to be flown. All associated databases and charted GPS instrument approach procedures used must contain co-ordinates relative to the World Geodetic System 1984 (WGS-84).

2) An approach using GPS shall not be flown unless it is retrieved from the avionics database. The GPS avionics must store the location of all waypoints required to define the approach and present them in the order depicted on the published non-precision instrument approach procedure chart.

b) GPS overlay approaches

1) The appropriate ground NAVAID(s) (e.g. VOR, NDB, DME) which define the published approach being flown must be operating, and the avionics required to fly that approach must be operating and monitored by the flight crew.

2) The approach must be requested and approved by its published name, (e.g. NDB RWY 24, VOR RWY 24).

Note.— Assuming the underlying NAVAID(s) and related avionics continue to function, the pilot must revert to traditional means of navigation if there is a discrepancy between GPS and the traditional NAVAID(s).

c) GPS stand-alone approaches

1) RAIM must be available at the final approach fix to provide integrity for the navigation guidance used during the approach.

2) Any required alternate aerodrome must have an approved instrument approach procedure, other than GPS, which is anticipated to be operational at the estimated arrival time. The avionics to fly that approach must be installed and operational. The avionics required to receive the traditional NAVAID(s) that may be used to fly from the departure to the destination and to any required alternate aerodrome must also be installed and operational.

3) The published approach must be identified and requested as a GPS approach (e.g. GPS RWY 24).

Note.— Air Carrier and commercial operators conducting GPS IFR operations shall meet the appropriate provisions of their Operating Certificates and Operations Specifications. An Air Carrier Advisory Circular has been published with more detailed information and guidance concerning training requirements and approval procedures.

David Wightman
Assistant Deputy Minister
Aviation

Section 3
Information on Fiji’s Early Application of GPS Technology

SUMMARY

This paper provides information on why and how Fiji introduced the use of GPS into its domestic aviation environment. Implementation issues, the problems encountered and the lessons learned are described.

INTRODUCTION

This paper is presented to enable those States with a domestic aviation environment similar to Fiji’s to implement GNSS technology using the United States’ global positioning system (GPS).

The paper outlines the initial steps taken, the trials and demonstrations undertaken and being planned, the implementation of the different phases of operations, problems encountered and lessons learnt.

WHY GPS IS NEEDED

Fiji consists of 300 islands (mostly volcanic) scattered over 200 000 square miles of ocean. Of these, only 100 are inhabited. There are nineteen airfields, plus seven that are privately owned, but only five of the nineteen have NDBs and one has VOR-DME.

This means that 80 per cent of the area is without any form of navigation aid. There are also helicopter and seaplane operations. Navigation has been accomplished primarily through visual flight rules or dead reckoning.

Domestic operations consist of about fifteen aircraft and about forty pilots, operated by two airlines, as well as one helicopter and seaplane operator. Inter-island air services for outer islands are provided by Twin Otter and Islander type aircraft. It is not uncommon for an aircraft to fly up to 150 miles across water to an island without a navigation aid.

Fiji’s islands are volcanic and quite high. Over the two main ones, the minimum safe altitudes are higher than 5 000 feet, and over the rest of the group they are rarely below 3 000 feet. During the rainy season, Fiji can expect a typical cloud base of 2 000-3 000 feet, often accompanied by thunderstorm activity and torrential rainfall.

In adverse weather, the pilots used to fly to an area they thought was safe, then descend over the sea and search for the island.

Many times, approaches to domestic airfields have to be aborted, the flights diverted to alternate airports. Some flights are even cancelled

There are many States in the Pacific Region and elsewhere with a situation very similar to Fiji's, that is, a few islands scattered over a large oceanic area, with few or no navigation aids. Fiji has already provided familiarization assistance to Tonga, Solomon Islands, Indonesia, Mongolia and Nepal. Australia and New Zealand were invited to Fiji to observe the initial stages of Fiji's GPS programme.

It is not financially possible to install an NDB at each one of the nineteen airfields, as each NDB would cost about U.S. $100 000 to install and maintain. For this amount, a GPS receiver could be fitted in every domestic aircraft in Fiji enabling accurate navigation to any location. The GPS is far superior to the NDB and is not subject to interference caused by thunderstorms or damage by cyclones.

Present day longitudinal standards using NDB or VOR is 10 degrees for NDB and 6 degrees for VOR on either side of track with an additional 5 mile buffer zone. With GPS, routes are separated by a buffer of only 5 miles either side of track.

HOW FIJI STARTED

Fiji became involved in FANS and GPS in 1990/91 through briefings given by CAA Australia, and became convinced of the safety and cost benefits to be gained. Ad hoc trials, including long distance oceanic flights with a hand-held GPS receiver convinced Fiji of the potential of the GPS.

At that time, the full GPS constellation of satellites was not in place nor were procedures and standards issued by the United States Federal Aviation Administration (FAA). Several countries were approached for advice as to how Fiji could utilize GPS. The FAA responded positively in exchange for the knowledge to be gained by setting up the system now in place.

Under a Memorandum of Co-operation (MOC) the United States FAA provided equipment and operational and technical support to carry out trials and demonstrations. GPS receivers were provided for installation in all domestic IFR aircraft. These early receivers were not certified, and special procedures were developed to ensure that all the information provided by the GPS was confirmed by other navigation sources.

Since Fiji was the first, procedures had to be developed and tested, and data collection systems had to be developed. Training manuals had to be prepared, and training had to be conducted for pilots and controllers. Airlines signed a Memorandum of Agreement with CAA Fiji to participate in the trials.

There were thirteen months of hard work before the trials started. The trials lasted seven months and were conducted using scheduled flights with fare paying passengers.

Many countries allow GPS receivers to be installed but not to be used for navigation. The Fiji approach has been to promote the use of GPS under controlled conditions (e.g. specifying equipment type, procedures and training required). This approach enables a free exchange of knowledge gained by pilots, operators, air traffic controllers and the flight standards section.

SAVINGS

Fiji's experience has shown that using the system, flying time is significantly reduced. The extremely accurate tracking capability of GPS enables an aircraft to fly a straight line to any destination. (GPS routes and guidelines are shown in Figure A4-1.) For example, on the Nausori-Rotuma route (340 NM) flying time of approximately three hours is reduced by as much as 15 minutes one way. Previously, it was mandatory for pilots to carry enough fuel for the return trip because at times the island could not be located. With GPS aircraft this requirement is no longer imposed. See Figure A4-2.

The fuel savings that result are estimated to pay for the cost of installing the GPS receiver unit in about three months of usage. The savings to be gained by Fiji's domestic airlines and the aviation industry are estimated to be several million dollars, e.g.

— $2 million — no NDBs
— $20 000 per annum — reduced airline operating costs

A GPS stepped descent similar to DME stepped descent into an aerodrome can save five minutes of a flight. This is costed at U.S. $50 per flight (U.S. $600.00 per hour).

GPS TRIALS AND DEMONSTRATIONS

The trials were conducted prior to IOC (initial operational capability) of GPS.

Some of the main features are listed here.

- GPS routes had been designed to all nineteen aerodromes. The GPS route charts show GPS airways and GPS way-points at the intersections.

- GPS checkpoints were established and surveyed on all the aerodromes, initially using a GPS receiver but now these have been resurveyed by an outside contractor to WGS-84.

- Outside areas of VOR/DME coverage, the pilot DR is now replaced by GPS procedures.

- Cloud break procedures were also designed to enable pilots to descend below cloud and make visual contact with the island, so that in most cases they leave a pilot at 1 000 ft above obstructions, five miles out, on the extended centre line. This information together with way-points were entered into the GPS receivers via data cards, by the CAA Fiji.

- Pilots and controllers were trained and examined on the rules and procedures. Pilots also had to undergo a practical test before being approved and pilots may not use the GPS unless they are approved.

- Based on this initial experience, the charts have been further simplified so that pilots can now select, on the GPS receiver, straight-in approach or cloud break, when this was needed.

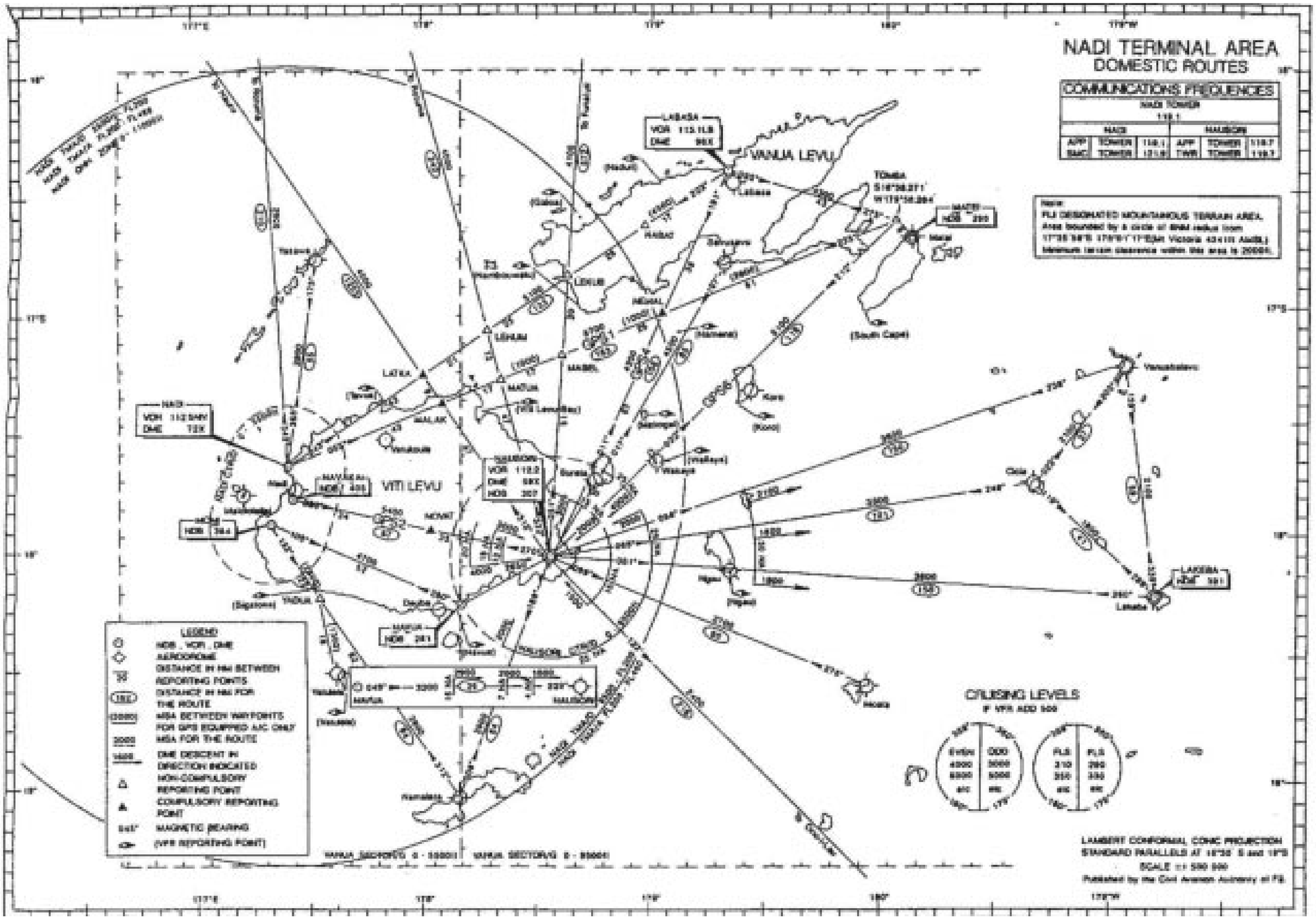


Figure A4-1. Fiji GPS routes and guidelines

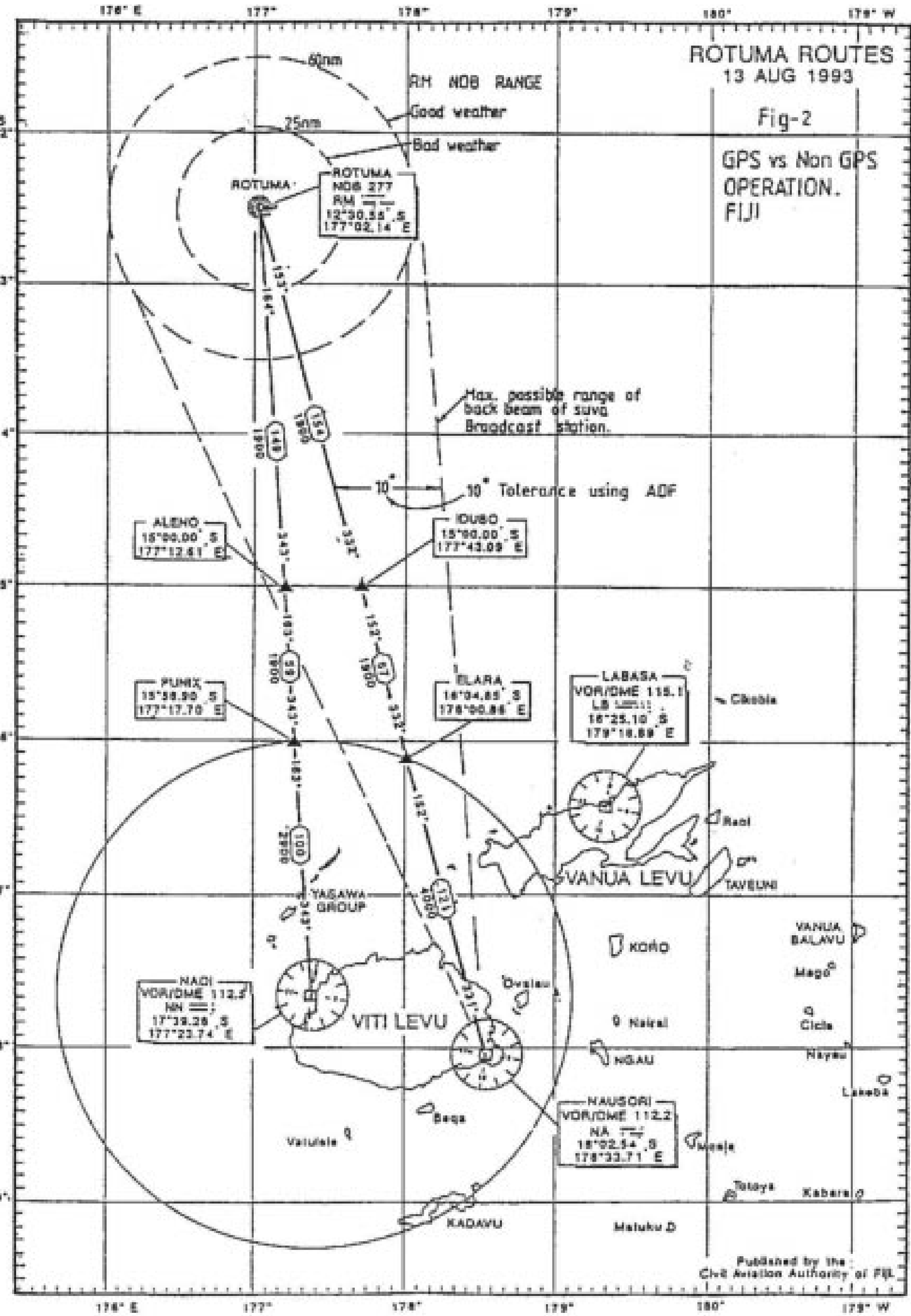


Figure A4-2. GPS vs. non-GPS operation on Rotuma routes

LESSONS LEARNED

The trials helped pilots and controllers to gain confidence in the accuracy, reliability, availability and integrity of the system.

- Accuracy was confirmed by comparing DME distances with GPS distances and VOR bearings with GPS positions.
- Data recorded by pilots after taxiing over aerodrome checkpoints indicated an accuracy better than 120-metres for 98 per cent of the time. The largest error recorded was 130 metres.
- Fiji is in a good latitude for satellite coverage. There are no fewer than six satellites and frequently nine are in view simultaneously. Therefore, coverage and availability problems are non-existent. The integrity issue also does not apply with RAIM fitted receivers.
- There has been only one satellite failure since the monitor was installed over two years ago. It was identified by both the monitor and the airborne receivers.
- Pilots and controllers appreciate the greater knowledge they have of the positions of all the traffic in the vicinity and traffic management has become easier. Controllers are now asking pilots for an ETA for the next way-point, which gives them more timely advice than ‘‘report passing the 011 radial’’, or ‘‘report 10 DME’’. Separation standards are still VOR/DME standards, but GPS position reporting is easier to use.
- A GPS way-point can be treated in the same way as a VOR. Air traffic controllers now separate aircraft using GPS bearings and distances in the same way they now use VOR/DME bearings and distances.
- The area of procedures design will also benefit from GPS. The time consuming process of an aircraft tracking to a point source navaid near the airport, then carrying out a procedural turn and teardrop approach or similar, will be replaced by a smooth transition from the en-route track to the final approach track via one or more way-points. With each aircraft spending less time in the approach phase, the flow of traffic should improve.
- For outer island airports non-precision approaches (NPA) will be all that is ever needed for domestic operations as minimas of about 400 feet have been established to all airports. These are usually lower than current MSAs without GPS; e.g. MSA 5700 (GPS 4800).
- Only the two international airports will need differential GPS.
- Because of the confidence gained in the use of GPS, two NDBs have been decommissioned.

SUPPLEMENTAL USE

Fiji accepted GPS for ‘‘Supplemental Use’’ for en-route and terminal operations on 15 April 1994, after DoD & FAA declared an Initial Operational Capability (IOC) of the GPS system and the receivers had been upgraded to the TSO-C129, A2 standard, for en-route and terminal area operations. The A2 standard is the first level and the TSO-C129, A1 standard is for non precision approaches. GPS is used as a supplemental aid in areas with navigation aids and as a primary navigation reference in areas without navigation aids.

FUTURE GPS PROGRAMME

NON-PRECISION APPROACH

GPS approach procedures to remote aerodromes are being drawn up using the FAA TERPS standards and selected pilots are evaluating them in visual meteorological conditions (VMC).

This stage of using GPS for NPA will take place when the GPS receivers are further upgraded to TSO A1 standard.

DIFFERENTIAL GPS TO REPLACE ILS?

The ILS at Nadi International Airport is due for replacement by 1996 at the latest. One thing is certain: Fiji does not have an operational requirement for MLS. CAT I ILS is all that will ever be needed.

A full differential GPS landing system (with main standby) has been quoted at U.S. $120 000. This is about 10 per cent the cost of a new ILS system, without the installation cost. There is an additional cost of U.S. $5 000 for modification of each GPS airborne receiver to receive the DGPS correction signal. The GPS signals are used to drive the normal ILS indicators.

The issue of ILS replacement at Nadi International Airport for international traffic is quite vexing as DGPS will still need to go through the ICAO processes before being approved for international use, at present not envisaged until beyond 1998. Fiji cannot wait that long and of necessity is required to purchase another ILS.

Fiji carried out brief trials and demonstrations to familiarize pilots and others on the accuracy and integrity of the system, using a GPS set fitted in a light aircraft.

Fiji is negotiating with another party for assistance in the supply of DGPS equipment. With a DGPS, any runway at an airport with an appropriate ground station can be used for CAT I approaches. At Nadi Airport, this could be equivalent to four ILS systems.

INTERNATIONAL USE OF GPS

The recent announcement by FAA to approve primary means navigation over oceanic areas is another step in progressive use of GPS that Fiji is keen to achieve. The Informal South Pacific Air Traffic Co-ordinating Group (ISPACG) would be requested to consider international airlines using GPS in the Nadi FIR and DGPS in Nadi.

ADS/PSEUDO RADAR

Consideration is also being given to tracking GPS-fitted aircraft in the domestic environment using some form of VHF data link.

Discussions are being held with others to provide a ‘‘proof of concept’’ study for the domestic operation using three ground stations and fitting fifteen aircraft with data linking capability.

Success in this area may eliminate the need for a radar system and consequently save several million dollars.

ISSUES ENCOUNTERED IN GETTING ORGANIZED

LEGAL ISSUES

In order for the trials to commence it was necessary for CAAF to establish safe procedures and issue appropriate aeronautical information circulars to sanction the use of GPS.

The Civil Aviation Authority of Fiji Act empowered the CAA Fiji to provide air navigation services and to issue directions and appropriate circulars. The appropriate AIC on GPS are therefore official and legal documents in accordance with the laws of Fiji.

A Memorandum of Agreement was also signed with the two airline operators participating in the trials. A schedule was included to authorize only those pilots trained and approved by CAA Fiji to use the GPS and certain conditions were laid down, e.g. AIC.

In doing so, the airlines had also to obtain the approval of their insurers that their insurance is still valid when using the GPS.

DATA CARD UPDATES

Fiji has encountered a problem with the renewal of data cards used with the GPS receivers. The data cards supplied with the GPS receivers were configured by the database manufacturer using information supplied by CAA Fiji and contain world-wide information as well. However, these cards have a validity date inserted on them and operators will need to subscribe to the database manufacturer for the renewal every twenty-eight days. This is a recurrent cost. After twenty-eight days the card would display ‘‘Database Expired’’ yet the information related to Fiji domestic airspace for GPS has not been changed since the cards were issued two years ago.

The receivers can be programmed such that only information on Fiji can be displayed. ‘‘The Aeroplane Flight Manual Supplement’’ issued by CAAF stipulates that the information on GPS must be verified before use.

The above is only an interim measure. In the longer term a more flexible and cost-effective solution will be introduced.

MANAGING CHANGE — THE HUMAN ELEMENT

The progress Fiji has made so far can be attributed to the facts below.

- States in the Pacific Region such as Australia, United States and New Zealand have provided valuable assistance.

- New technology that brings about improvements is readily accepted.

- To gain support of the Government and the Board of CAA Fiji, regular briefings were made.

- The staff were sent to attend seminars on CNS/ATM.

- CAA Fiji joined up with regional groups.

- An in-house CNS/ATM committee was formed.

- Pilots and airlines were briefed on the trials and demonstrations.

- A cost-benefit analysis was carried out.

It is inevitable that in a technological leap such as this some resistance to change would be encountered. While the GPS is widely supported by the CAA Fiji and by the industry, some local pilots have complained to their association regarding aspects of the programme and the air traffic controllers association recently requested changes to the programme. As a result, CAA Fiji has issued a new chart to overlay GPS approaches on existing routes based on ground-based aids.

An industry user group is being formed to provide a forum whereby the views of all parties be taken into account in future implementation programmes.

SUMMARY

1. GPS has changed the way airlines and CAA Fiji operate. Savings have been made both in the air and on the ground and safety greatly enhanced.

2. Managing change is always difficult and all the players should be thoroughly briefed so that they can understand and support the changes being made.

3. Fiji reiterates the offer it made at the recent Asia/Pacific Air Navigation Planning and Implementation Regional Group (APANPIRG) to assist any State with advice and information on the implementation of GPS in their country.

PROPOSED AIC 7/95
USE OF GPS IN FIJI

1. OBJECTIVE

The purpose of this AIC is to detail the current CAAF policy relating to the use of GPS in Fiji domestic airspace. It updates the information contained in AICs 6/94 and 3/95.

2. DEFINITIONS

Fiji has adopted the ICAO definitions relating to the approval of GPS. These are:

> ‘‘Primary-Means Navigation System — A navigation system approved for a given operation or phase of flight that must meet accuracy and integrity requirements, but need not meet full availability and continuity of service requirements. Safety is achieved by limiting flights to specific time periods and through appropriate procedural restrictions.
>
> There is no requirement to have a sole-means navigation system on board to support a primary means system.’’
>
> ‘‘*Sole-means navigation system* — A sole-means navigation system approved for a given operation or phase of flight must allow the aircraft to meet, for that operation or phase of flight, all four navigation system performance requirements: accuracy, integrity, availability and continuity of service.
>
> *Note.— This definition does not exclude the carriage of other navigation systems. Any sole-means navigation system could include one (stand-alone installation) or several sensors, possibly of different types (multi-sensor installation).’’*
>
> ‘‘*Supplemental-means navigation system* — A navigation system that must be used in conjunction with a sole-means navigation system. Approval for supplemental-means for a given phase of flight requires that a sole-means navigation system for that phase of flight must be on board. Amongst the navigation system performance requirements for a given operation or phase of flight, a supplemental-means navigation system must meet the accuracy and integrity requirements for a given operation or phase of flight; there is no requirement to meet availability and continuity requirements.
>
> *Note.— Operationally, while accuracy and integrity requirements are being met, a supplemental-means system can be used without any cross-check with the sole-means system. Any navigation system approved for supplemental-means could involve one (stand-alone installation) or several sensors, possibly of different types (multi-sensor installation).’’*

3. APPROVAL FOR USE

3.1 GPS receivers meeting the requirements of TSO C-129 A1 may be used as a *Primary Navigation System* to fly any en route or terminal non-directional radio beacon (NDB), VOR, DME or GPS procedure and any GPS approach, in Fiji domestic airspace.

3.2 GPS receivers meeting the requirements of TSO C-129 A2 may be used as a *Primary Navigation System* to fly any en route or terminal NDB, VOR, DME or GPS procedure and any GPS approach, *but only as far as the final approach waypoint in Fiji domestic airspace.*

4. CERTIFICATION OF GPS RECEIVERS AND INSTALLATIONS

4.1 Stand alone equipment must comply with FAA TSO C-129 class A and meet the installation requirements defined in FAA notice N8110.47.

4.2 Multi-sensor equipment must comply with FAA TSO C-129 class B or C and meet the installation requirements defined in FAA Notice N8110.48.

5. APPROVAL OF INSTALLATIONS

5.1 Installations of GPS receivers are modifications as defined in ANR 13(10), and require approval.

5.2 Approval will only be granted where:

a) the receiver has already been through a TC or STC procedure in a similar aircraft; and

b) the interface with autopilot, flight director, flight displays and other aircraft equipment is of a simple nature.

5.3 Application for approval should be made to the Authority on form AD 261 and procedures should follow FAA Notice N810.47 Appendix 1, Paragraph 2.

5.4 In addition to the ground and flight testing specified in the FAA notice, the following tests must be conducted to verify adequate isolation from possible harmonic interference caused by VHF transmissions.

5.4.1 Tests shall be conducted by tuning each VHF transmitter to the frequencies listed below and transmitting for about 30 seconds while observing the signal status of one or more satellites.

121.150 MHz	121.175 MHz	121.200 MHz
131.250 MHz	131.275 MHz	131.300 MHz

5.4.2 If excessive degradation of signal strength occurs, isolation or filter techniques must be included in the installation or appropriate limitations must be included in the aeroplane flight manual supplement.

6. INSTRUMENT FLIGHT PROCEDURES

6.1 En route, terminal, and approach procedures for use with GPS are being produced by the Authority.

6.2 These procedures are designed in compliance with FAA publication DOC 8260.3b Terminal Instrument Procedures (TERPs).

7. OPERATION CONDITIONS

7.1 The use of GPS on instrument flight rules (IFR) flight may only take place over promulgated routes.

7.2 Operations in instrument meteorological conditions (IMC) below the promulgated MSA are not permitted except in compliance with a procedure which has been approved by the Authority.

7.3 The aircraft must be equipped with an approved and operational alternative navigation system for use in the event of the failure of the GPS system. It is not necessary for this system to be monitored unless the GPS system fails.

7.4 Where GPS is used for navigation to a destination not equipped with a ground-based navigation aid, an aerodrome so equipped must be nominated as an alternate.

8. AIR TRAFFIC CONTROL REQUIREMENTS

8.1 Pilots intending to operate over GPS routes should insert ‘‘GPS’’ in section 18 (other information) of flight plan form CAAF 316A.

8.2 Pilots intending to use GPS on training or other flights should advise ATC when establishing contact prior to taxiing.

8.3 Aircraft may be cleared for a GPS step descent provided:

a) the aircraft is on track;
b) the request is initiated by the pilot; and
c) traffic permits.

8.4 GPS bearings and distances will be treated in the same way as VOR radials and DME distances by ATC for separation purposes. These are detailed in ICAO DOC 4444.

8.5 Aircraft may be cleared for a GPS approach at Nadi or Nansori, but it is the pilot’s responsibility to commence the missed approach from the final approach waypoint if the GPS receiver has only a C-129 A2 certification.

This AIC supersedes AICs 6/94 and 3/95 which are hereby cancelled.

Section 4
Information on the United Kingdom's Early Application of GPS Technology

Aeronautical Information Circular
AIC 16/1994

Interim Policy for the Use of Global Positioning System (GPS) Navigation Equipment when Flying under Instrument Flight Rules (IFR)

1. INTRODUCTION

1.1 This Circular sets out the airworthiness criteria and operational matters associated with the use of GPS when flying under IFR. The Circular considers the current status of GPS, the classes of airborne equipment, their use and the limitations prevailing. At present, these limitations restrict the use of GPS equipment only as a Supplemental Air Navigation System.

1.2 Definitions of terms used and reference documents are at Annex A.

2. DESCRIPTION OF GPS

2.1 The Navstar Global Positioning System (GPS) of the United States Department of Defence (DOD) is a satellite-based radio navigation system. Today, twenty-four satellites are in various orbits approximately 11 000 NM above the surface of the Earth. Each satellite broadcasts a timing signal and data message. A portion of the data message gives a GPS receiver the orbital details of each satellite. The receiver measures the time taken for the signal to arrive from the satellites in view and from this information computes a position and velocity.

2.2 Three satellites are needed to determine a two-dimensional position and four for a three-dimensional position. The elevation and geometry of each satellite relative to the receiver must satisfy certain criteria before the designed system accuracy can be achieved. Accuracy in predictable horizontal positions of 100 m or better should be available on 95 per cent of occasions and 300 m or better on 99.99 per cent of occasions.

2.3 The figures quoted for accuracy are based on the assumption that the position given is referenced to the World Geodetic System 1984 (WGS-84) Datum. This datum relates position on the earth's surface or in space to a mathematically defined ellipsoid that approximates the complex shape of the Earth. The point of origin of the WGS-84 Datum is the Earth's centre of mass. This allows position information to be derived for the world from one reference. ICAO is proposing to adopt WGS-84 as a world standard, to be in use by 1998.

2.4 Currently, position information throughout the world is derived from local or regional datums, for example, European Datum 1950 and Nouvelle Triangulation de France (NTF) 1970. These datums use different ellipsoids that approximate the shape of the Earth over a selected area, but are not valid on a global scale. Conversion between datums is possible, but inherent inaccuracies present in national datums can result in large residual errors.

2.5 Consequently, a given position today could be referenced to one of many datums and that position may be significantly displaced from the co-ordinates of the same position when measured against WGS-84. Differences of several hundred metres are not uncommon. With the accuracy provided by today's ground-based navigation aids — other than precision approach aids — these discrepancies in position between datums are of little importance. The introduction of position information provided by satellites for more precise navigation changes this situation, but only when all positions world-wide are based on one datum can the full potential of satellite navigation be realized. Until this stage is reached it is necessary to place some restrictions on the airborne use of the Navstar GPS constellation.

3. LIMITATIONS OF THE GPS CONSTELLATION AND EQUIPMENT

3.1 At the time of writing, January 1994, the United States DOD has declared Initial Operational Capability (IOC) for the constellation. This declaration has not yet been formally endorsed by the United States Department of Transportation (DOT)/Federal Aviation Administration (FAA). Currently, the interim policy stated in this Circular parallels the use of GPS as authorized by the FAA. Following the endorsement of IOC by the DOT/FAA the FAA proposes extending the conditions of use of GPS for certain phases of flight. This will not be applicable outside the U.S. National Airspace System (NAS), due to the limitations discussed below.

3.2 Full operational capability will probably be declared by the DOD in 1995. Even then, when flying under IFR, the system will not provide the coverage, availability and integrity needed for a sole-means air navigation system. Coverage and availability can be forecast, but determining the integrity of the signals requires other means.

3.3 Most existing ground-based navigation aids are flight calibrated and can signal an alarm if erroneous signals are being radiated. For example, VOR signal characteristics are monitored and where the set tolerances are not met the VOR automatically stops transmitting. The GPS constellation is monitored from the ground and it may take considerable time before users become aware of a malfunction within the system. Several possibilities for providing signal integrity equivalent to that obtained from conventional navigation aids are under consideration, but it will be some years before these possibilities are realized. At present, two methods exist within airborne equipment to provide the integrity of navigation when using GPS signals: receiver autonomous integrity monitoring (RAIM) and that given by an integrated navigation system where other sensors are used in addition to GPS.

3.4 In airborne equipment incorporating both the GPS sensor and navigation capability, determination of a 3D position requires four satellites with adequate elevation and suitable geometry. An additional satellite is needed to perform the RAIM function. A sixth satellite is required to isolate any faulty satellite and remove it from contributing to the navigation solution. Where a GPS receiver uses barometric altitude as an augmentation to RAIM, the number of satellites needed for the receiver to perform the RAIM function may be reduced by one, given appropriate geometry. Not all GPS receivers possess RAIM, but in stand-alone GPS equipment this function is essential for airborne use when flying under IFR.

3.5 In airborne equipment where a GPS sensor provides data to an integrated navigation system, e.g. FMS or a multi-sensor navigation system, either the GPS sensor is required to provide RAIM, or the multi-sensor navigation system should possess a level of integrity equivalent to that provided by RAIM. This level of integrity is required when flying under IFR.

3.6 The availability of six satellites is less than 100 per cent of all occasions. Consequently, the RAIM function may be interrupted.

3.7 The limitations discussed above make GPS suitable for use only as a Supplemental Air Navigation System for certain phases of flight.

4. USE OF GPS

4.1 When the airborne navigation equipment using GPS is CAA approved as satisfying the relevant technical criteria, then operators may be approved to conduct flights when flying under IFR in oceanic, domestic en-route and terminal airspace subject to the conditions detailed below and in paragraph 7.

4.2 A stand-alone GPS-based supplemental air navigation system may not be used for any GPS non-precision approach procedure until the database for the navigation system contains those procedures as depicted in the relevant published approach plates and referenced to WGS-84.

4.3 The use of GPS in any form for any type or part of any precision approach is not permitted.

4.4 The criteria presently specified may be superseded by airworthiness and operational standards promulgated by the Joint Aviation Authorities (JAA).

5. COMPOSITION AND APPROVAL OF A SUPPLEMENTAL AIR NAVIGATION SYSTEM USING GPS

A GPS supplemental air navigation system may comprise:

a) a stand-alone GPS equipment; or

b) a multi-sensor system where at least one sensor is GPS.

6. AIRWORTHINESS APPROVAL

6.1 To gain airworthiness approval for a GPS supplemental air navigation system, the equipment and its installation will need to satisfy the following criteria:

a) stand-alone equipment:

   1) approved by the CAA as complying with FAA TSO-C129, Class A, or equivalent, and meeting the intent of the associated FAA Notice N8110.47; and

   2) an approved sole-means navigation system suitable for the route to be flown is fitted to the aircraft;

b) multi-sensor equipment using GPS:

   1) approved by the CAA as complying with FAA TSO-C129, Classes B or C, or equivalent, and meeting the intent of the associated FAA Notice N8110.48; and

   2) an approved sole-means navigation system suitable for the route to be flown is fitted to the aircraft; and

c) existing GPS installations:

1) when a GPS sensor has been approved and installed in an aircraft as one component of an integrated navigation system on a ‘‘no-credit’’ basis, that system may be classed as a supplemental air navigation system where it can be shown that a level of integrity to that given by RAIM is provided.

6.2 Approvals for the installation and use of this type of equipment as required by the United Kingdom Air Navigation Order (ANO) must be obtained using the current certification procedures of British Civil Airworthiness Requirements (BCAR).

7. OPERATIONAL MATTERS

7.1 Operation of GPS equipment will require use in accordance with the limitations stated in the approved flight manual or flight manual supplement. Furthermore, multi-sensor navigation systems employing GPS may be used for standard instrument departures (SIDs) and standard terminal arrivals (STARs) only when the operator has an operational approval to fly such procedures using an FMS. The following conditions also apply.

a) Stand-alone equipment:

1) the approved sole-means navigation system not using GPS to determine position must be serviceable and continuously displayed to and monitored by the flight crew when the GPS equipment is in use; and

2) the GPS equipment is used during a non-precision approach only where an approved procedure has been published by the national regulatory authority; and

3) the criteria stated in Annex B are met.

b) Multi-sensor equipment using GPS:

1) the criteria stated in Annex B must be met for flying a non-precision approach.

c) Existing GPS installations:

1) where these systems have received airworthiness approval for use as a supplemental air navigation system they may be used for flying a non-precision approach provided the criteria stated in Annex B are met.

7.2 Due to satellite coverage and their elevation and geometry relative to the receiver, the RAIM function will not always be available and may be lost for significant periods of time. Where this occurs then the primary means of navigation must be by reference to other approved navigation systems.

8. THE FUTURE

8.1 At present, GPS is the only satellite-based system capable of giving a usable service to aviation. GLONASS, the Russian global navigation satellite system, is some way from reaching an operational capability. Combinations of GPS and GLONASS plus other civil satellites and ground augmentation facilities are possible components for a civil global navigation satellite system (GNSS). ICAO has established working groups to develop the principles governing the operation of GNSS.

8.2 It is evident that a GPS-based system is potentially capable of achieving aeronautical navigation performance requirements for en-route, terminal area and precision landing. Many technical and institutional issues require resolution before GPS can be used in other than a supplemental role.

ANNEX A to AIC 16/1994

1. DEFINITIONS

Receiver autonomous integrity monitoring (RAIM). A technique whereby a GPS receiver/processor determines the integrity of the GPS navigation signals using only GPS signals or GPS signals augmented with barometric altitude.

Sole-means air navigation system. An approved navigation system that can be used for specified phases of operations without the need for any other navigation system.

Stand-alone GPS navigation system. A GPS navigation system that is not combined with other navigation sensors or navigation systems.

Supplemental air navigation system. An approved navigation system that can be used in conjunction with a sole-means air navigation system.

2. REFERENCES

EUROCAE Edition 58
Minimum Operational Performance Specification for Area Navigation Equipment using Multi-sensor inputs.

EUROCAE Edition 72
Minimum Operational Performance Specification for Airborne GPS Receiving Equipment.

FAA TSO-C115 a
Airborne Area Navigation Equipment using Multi-sensor inputs.

FAA TSO-C129
Airborne Supplemental Navigation Equipment using the Global Positioning System (GPS).

RTCA DO 208
Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment using Global Positioning System (GPS).

FAA NOTICE N8110.47
Airworthiness Approval of Global Positioning System (GPS) Navigation Equipment for use as a VFR and IFR Supplemental Navigation System.

FAA NOTICE N8110.48
Airworthiness Approval of Navigation or Flight Management Systems integrating Multiple Navigation Sensors.

Note.— The two FAA Notices are time limited. They are due to expire in April 1994, by which time the FAA intends to replace them with Advisory Circular material.

ANNEX B

USE OF APPROVED GPS-BASED EQUIPMENT FOR NON-PRECISION APPROACHES

1. The use of GPS-based navigation equipment as a supplemental air navigation system to fly any part of any instrument non-precision approach will be permitted when the following general and specific conditions are satisfied.

1.1 General

a) The GPS equipment must be approved by the CAA as complying with FAA TSO-Cl29, Classes Al, B1, B3, C1 or C3, or equivalent, and be installed to meet the intent of the applicable FAA Notice (N8110.47 or N8110.48); and

b) the navigation database must contain current information on the non-precision approach to be flown; and

c) all approach plates and databases must have position information in WGS-84 coordinates, or equivalent; and

d) the approach to be flown must be retrievable from the database, which must have stored:

1) the location of all navigation aids required to define the approach; and

2) the location of all way-points and intersections; and

3) present the information in the order depicted on the published non-precision approach plate;

e) if required, the nominated alternate airfield must have an approved non-GPS instrument approach procedure expected to be available at ETA; and

f) the use of GPS equipment to fly non-precision approaches is initially restricted to approaches based on VOR, VOR/DME, NDB, NDB/DME and RNAV let-downs.

1.2 Specific

1.2.1 For the approach used:

a) the operator must be authorized by the national authority in whose airspace the approach procedure is promulgated; and

b) the appropriate ground based navigation aid(s) must be serviceable; and

c) the appropriate navigation equipment, in addition to the GPS equipment, must be installed and operational in the aircraft.

ADDENDUM TO AIC 16/1994 (PINK 100) — INTERIM POLICY FOR THE USE OF GLOBAL POSITIONING SYSTEM (GPS) NAVIGATION EQUIPMENT WHEN FLYING UNDER INSTRUMENT FLIGHT RULES (IFR)

1. In AIC 16/1994 (Pink 100), Annex B, paragraph 1.1(c), it is stated that all approach plates and databases must have position information expressed in WGS-84 coordinates or equivalent. This statement was made recognizing that some States are already producing the appropriate data.

2. However, the United Kingdom and EUROCONTROL are following the decision taken by ICAO that WGS-84 will be adopted as the single geodetic reference system for civil aviation from 1 January 1998. The United Kingdom will not be making available data suitable for approach plates and databases to commercial organizations until early 1997 to meet the proposed implementation date in 1998.

3. Consequently, non-precision approaches to airfields in the United Kingdom will not be possible until 1 January 1998, at the earliest, but may be possible at foreign airfields where all the relevant criteria are met.

Section 5

Methodology for Identifying Homogeneous Areas for Implementation of GNSS

(Presented by Spain)

INTRODUCTION

The Special European Regional Air Navigation Meeting (SP EUR RAN) took place in Vienna from 5 to 16 September 1994. One of the main tasks of the Meeting was to develop a communications, navigation, surveillance and air traffic management (CNS/ATM) plan for the European Region.

Considering the complexity and diversity of the European Region, the Meeting agreed that planning could best be achieved if it was organized in homogeneous areas of common requirements and interest, taking into account traffic density and level of sophistication required. In order to do so, a methodology based on the following steps was established:

Step 1. To compile a list of desired benefits/improvements affecting operations in the EUR Region.

Step 2. To identify homogeneous areas within the EUR Region — in terms of traffic density and air navigation facilities and services consequently required.

Step 3. To analyse the list of benefits/improvements at Step 1 in order to establish:

a) costs, e.g. — additional ATS capability;
— additional aircraft capability;

b) financial benefits/operational advantages;

c) relative priority;

d) desired implementation date of the various features for each homogeneous area within the EUR Region.

Step 4. To establish small sub-groups, each tasked with the detailed analysis of the requirements of a homogeneous area within the EUR Region.

Step 5. To develop the work of the sub-groups into draft Regional planning material as an input to the bodies which are active in developing European CNS/ATM plans.

IDENTIFICATION OF HOMOGENEOUS AREAS

Based partly on the recommendation made above and in order to identify homogeneous areas for GNSS implementation planning, airspace world-wide could be divided into two different types of areas.

a) *Areas where GNSS is not required in the near term.* This includes areas where siting of navigation aids has been physically and economically possible, and where their deployment to cover the existing fixed route structure and foreseeable RNAV routes is adequate and even in some cases considered excessive.

In this type of airspace the current navigation system has adequate levels of accuracy, integrity and availability and therefore meets the traffic demand. Until GNSS can provide the same or better levels, it will not be used in this type of airspace.

Although GNSS, once EGNOS or WAAS has been fully implemented, will meet the above requirements and will even bring significant improvements in terms of accuracy and route flexibility *(Note.— a good amount of flexibility can already be achieved with the current system by means of RNAV)* the main reason to switch to satellite navigation will be economical, since the major benefits will be the cost savings from withdrawal of existing ground-based facilities. Apart from the mentioned economical reason, there is no urgent need to switch to satellite navigation in these areas.

b) *Areas where GNSS is required in the near term.* This includes areas where an adequate siting of proper navigation aids has not been physically or economically possible due to a variety of reasons, and consequently the current route structure is not adequate or cannot be used optimally (reduced longitudinal separations cannot be applied, etc.). Although the current navigation system in these areas does not fully meet the requirements, it is being used, in conjunction with proper, sometimes very restrictive operational procedures, which maintain an adequate level of safety. Different kinds of traffic restrictions are the consequence of this.

In these areas there is a clear and pressing need for a better navigation system that would at least relieve some restrictions. That better navigation system could be, without needing to wait for EGNOS or WAAS, GPS augmented by on-board systems such as RAIM or AAIM, or by the ground-based surveillance system, in order to provide integrity. Proper operational procedures should be developed to provide for safety and match the different possible solutions.

In some of these areas where GNSS would bring benefits in the near term, the early implementation of GNSS could be possible. Feasibility will mainly depend on the number of good geometry satellites simultaneously in view for that area. If satellite availability is not enough to provide a 24-hour service, it might be possible to provide instead a part-time (twelve hours for instance) service. That should be taken into account by the operational procedures. In other areas, either the early implementation of GNSS is not possible or a part-time SATNAV service would not bring any significant benefit.

In order to proceed with the orderly implementation of GNSS world-wide, homogeneous areas would need to be identified. This would allow States within the same homogeneous area or from other similar homogeneous areas to join efforts for better and more efficient GNSS implementation planning.

THE CANARY ISLANDS CASE

Traffic transiting between the Spanish Peninsula and the Canary Islands go through a part of airspace where the proper siting of navigation aids has not been possible. As a consequence the route structure is not most adequate and cannot be used optimally (longitudinal separation between aircraft is ten minutes or more). For instance, the A857 airway is 100 NM wide. UA857 and UA873 are both 50 NM wide.

Recently four RNAV routes have been established (UN866, UN873, UN858 and UN857). This has helped to mitigate the problems but has not solved them completely, since many aircraft are not RNAV-equipped and the ground aids geometry is not the most adequate. The longitudinal separation between aircraft is still ten minutes or more. Clearly, this is an area where the early implementation of GNSS would bring a lot of benefits.

Aeropuertos Españoles y Navegación Aérea (AENA) has carried out a ‘‘number of good geometry satellites simultaneously in view’’ study for the area, which demonstrates that most of the time (99 per cent) there is always a minimum of six satellites in sight. Clearly this is an area where the early implementation of GNSS could be possible.

Appendix 5

EXPLANATION OF GNSS-RELATED TERMS

Note 1.— The following explanations of terms have been compiled from a number of different sources. The reader should note that some GNSS-related issues are still under development and these explanations of terms are provisional.

Note 2.— In some cases, terms used to describe specific programmes in individual States have also been used in a ‘‘generic’’ sense (e.g. ‘‘wide area augmentation system’’). To establish consistency in terminology for augmentation systems, it has been agreed within the GNSS Panel that the term ‘‘satellite-based augmentation system (SBAS)’’ will be used as the generic term to describe wide coverage augmentation systems such as WAAS, EGNOS and MTSAT which will use satellites to transmit augmentation signals to the user. Similarly, the term ‘‘ground-based augmentation system (GBAS)’’ will be used to describe limited coverage augmentation systems which will use ground facilities to transmit augmentation signals to the user.

Accuracy (Doc 9613). The degree of conformance between the estimated or measured position and/or velocity of a platform at a given time and its true position and/or velocity. Radio navigation system accuracy is usually presented as a statistical measure of system error and is specified as:

a) *Predictable.* The accuracy of a position with respect to the geographic or geodetic coordinates of the Earth;

b) *Repeatable.* The accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigation system; and

c) *Relative.* The accuracy with which a user can determine one position relative to another position regardless of any error in their true positions.

Active way-point. (RTCA/DO-208) A way-point to or from which navigational guidance is being provided. For a parallel offset, the active way-point may or may not be at the same geographical position as the parent way-point. When not in the parallel offset mode (operating on the parent route), the active and parent way-points are at the same geographical position.

Alert limit (FANS(II)/4). For the phase of operation in progress, the distance which the GNSS position error cannot exceed without a GNSS integrity alert being given to the user.

Along-track distance (ATD) (RTCA/DO-208). The distance along the desired track from the way-point to the perpendicular line from the desired track to the aircraft.

Along-track error (ATRK) (Doc 9613). A fix error along the flight track resulting from the total error contributions.

Altimetry aiding (RTCA/TF GNSS) The process of using altitude data to simulate a GNSS satellite directly over the receiver antenna (i.e. it reduces, by one, the number of satellites required for a given function).

Area navigation (RNAV) (Doc 9613). A method of navigation which permits aircraft operation on any desired flight path.

Area navigation route (Annex 11) An ATS route established for the use of aircraft capable of employing area navigation.

Augmentation (of GNSS) (ICAO/FANS). A technique of providing the system with input information, extra to that derived from the main constellation(s) in use, which provides additional range/pseudo-range inputs or corrections to, or enhancements of, existing pseudo-range inputs. This enables the system to provide a performance which is enhanced relative to that possible with the basic satellite information only.

Availability (RTCA/DO-208). The availability of a navigation system is the percentage of time that the services of the system are usable. Availability is an indication of the ability of the system to provide usable service within the specified coverage area. Signal availability is the percentage of time that navigational signals transmitted from external sources are available for use. Availability is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities.

Barometric altitude (RTCA/DO-208). Geopotential altitude in the Earth's atmosphere above mean standard sea level pressure datum plane, measured by a pressure (barometric) altimeter.

Carrier phase tracking GNSS receiver (FANS(II)/4). A receiver which, in addition to using normal GNSS data processing techniques all or part of the time, continuously tracks the carrier phases of GNSS navigational satellites and uses the resulting measurements to calculate its navigational solution.

Circular error probable (CEP) (RTCA/DO-208). In a circular normal distribution (the magnitudes of the two one-dimensional input errors are equal and the angle of cut is 90 degrees), circular error probable is the radius of the circle containing fifty per cent of the individual measurements being made, or the radius of the circle inside of which there is a fifty per cent probability of being located.

Coordinate conversion (RTCA/DO-208). The act of changing the coordinate values from one system to another; e.g. from geodetic coordinates (latitude and longitude) to Universal Transverse Mercator grid coordinates.

Course setting error (CSE) (RTCA/DO-208). The difference between the desired course setting and the course that is actually set.

Coverage (Doc 9613). The coverage provided by a radionavigation system is that surface area or space volume in which the signals are adequate to permit the user to determine position to a specified level of accuracy. Coverage is influenced by system geometry, signal power levels, receiver sensitivity, atmospheric noise conditions and other factors that affect signal availability.

Cross-track error (Doc 9613). The perpendicular deviation that the airplane is to the left or right of the desired track.

Differential GNSS (DGNSS) (FANS(II)/4). An augmentation, the purpose of which is to determine position errors at one or more known locations and subsequently to transmit information derived to other GNSS receivers to enhance the accuracy of the position estimate.

Distance root mean square (drms) (RTCA/DO-208). The root-mean-square value of the distances from the true location point of the position fixes in a collection of measurements. The confidence level depends on the elongation of the error ellipse. As the error ellipse collapses to a line segment, the 2 drms confidence level approaches 95 per cent (95.4 per cent); as the error ellipse becomes circular, the confidence level approaches 98 per cent (98.2 per cent). In navigation system analysis, a 95 per cent confidence level is assumed, thus all error budgets are conservative with respect to the actual obtainable accuracy.

Earth-referenced navigation (ERN) (Doc 9613). Navigation which is dependent on an external navigation source or inertial reference system (IRS) but is not dependent on a single fixed site. ERN may use either time or phase differences from hyperbolic radionavigation systems or satellite sources with geodetic datums to determine position (normally converted latitude and longitude) on the surface of the earth. OMEGA, LORAN-C and GPS are different forms of ERN.

Fix dimension (Doc 9613). A characteristic which defines whether the navigation system provides a linear, one-dimensional line of position or a two- or three-dimensional position fix. The ability of the system to derive a fourth dimension (i.e. time) from the navigational signals is also included.

Fix rate (Doc 9613). The number of independent position fixes available from the system per unit of time.

***Flight management system* (FMS)** (Doc 9613). An integrated system, consisting of airborne sensor, receiver and computer with both navigation and aircraft performance databases, which provides performance and RNAV guidance to a display and automatic flight control system. (RTCA/DO-208)

Flight technical error (FTE) (Doc 9613). The accuracy with which the aircraft is controlled as measured by the indicated aircraft position with respect to the indicated command or desired position. It does not include blunder errors.

Geocentric (RTCA/DO-208). Relative to the Earth as a centre, measured from the centre of the earth.

Geometric dilution of precision (GDOP) (RTCA/DO-208). The ratio of position error of a multilateration system. More precisely, it is the ratio of the standard deviation of the position error to the standard deviation of the measurement errors, assuming all measurement errors are statistically independent and have a zero mean and the same standard distribution. GDOP is the measure of the ‘‘goodness’’ of the geometry of the multilateration sources as seen by the observer; a low GDOP is desirable, a high GDOP undesirable. Applied to Loran-C, GDOP is a measure of horizontal accuracy, while with satellite navigation systems it is a measure of over-all positional and temporal accuracy. (See also PDOP, HDOP and VDOP.)

Geostationary (RTCA/DO-208). An equatorial satellite orbit that results in a constant fixed position of the satellite over a particular earth surface reference point. (GPS satellites are not geostationary.) Some proposed integrity schemes use geostationary satellites.

Global navigation satellite system (GNSS) (FANS(II)/4). A world-wide position and time determination system, that includes one or more satellite constellations, aircraft receivers, and system integrity monitoring, augmented as necessary to support the required navigation performance for the actual phase of operation.

GNSS accuracy (FANS(II)/4). The degree of conformance between the GNSS output of position and time and the true position and time.

GNSS continuity (FANS(II)/4). The probability that the GNSS will be available for the duration of a phase of operation, presuming that the GNSS was available at the beginning of that phase of operation.

GNSS fault detection and isolation (FDI) (FANS(II)/4). A combination of internal and external integrity monitoring which will identify any source of error in GNSS navigation signals and negate the effect within the system.

GNSS integrity (FANS(II)/4). The assurance that all functions of the system perform within GNSS operational performance limits.

GNSS integrity monitoring (FANS(II)/4). A GNSS sub-system which enables the timely detection and indication of malfunctions in GNSS operations to ensure the user is aware whether or not the system is operating within its specified performance limits.

GNSS performance (FANS(II)/4). The performance defined by the instantaneous GNSS accuracy of position and time for a defined phase of operation.

GNSS planned non-availability (FANS(II)/4). The proportion of time that the signals-in-space service of the GNSS is not usable taking into consideration scheduled outages only.

GNSS random non-availability (FANS(II)/4). The proportion of time and space over the area of interest when the services of the GNSS are not usable to support the required navigation performance.

Note 1.— When referred to a selected point, rather than a defined area, GNSS random non-availability is the portion of time that the services of GNSS are not usable to support the required navigation performance at the selected point.

Note 2.— GNSS random non-availability excludes planned non-availability.

GNSS reliability (FANS(II)/4). The probability that the GNSS will perform within defined performance limits for a specified period of time under given operating conditions.

GNSS time-to-alert (FANS(II)/4). The maximum allowable time interval between GNSS system performance going outside of operational performance limits and the GNSS integrity monitoring system providing an alert.

Ground-based augmentation system (GBAS). A limited coverage augmentation system in which the user receives augmentation information directly from a ground-based transmitter.

Horizontal dilution of precision (HDOP) (RTCA/DO-208). The ratio of user-referenced horizontal position error to measurement error of a multilateration system. (See GDOP for a more detailed description.)

Integrity (Doc 9613). The ability of a system to provide timely warnings to users when the system should not be used for navigation.

Local area differential GNSS (FANS(II)/4). Local area differential GNSS is differential GNSS in which the differential corrections are usable for the supported phases of operation within a limited geographical area.

Mask angle (FANS(II)/4). A fixed elevation angle referenced to the user's horizon below which satellites are ignored by the receiver software. Mask angles are used primarily in the analysis of GNSS performance and are employed in some receiver designs. The mask angle is driven by the receiver characteristics, the strength of the transmitted signal at low elevations, receiver sensitivity and acceptable low elevation errors.

Minimum usable elevation angle (RTCA/DO-208). The minimum satellite elevation, above the user's local horizon, that the satellite can be reliably used in the calculation of a navigation solution. The minimum usable elevation angle varies depending on the environment, the antenna design and placement, aircraft altitude and attitude.

Nodal regression rate (RTCA/DO-208). The rotation of the orbit plane about the Earth's polar axis due to the effect of the Earth's oblateness together with the average effect of moon and sun perturbations on GPS orbits.

Parallel offset path (Doc 9613). A desired track parallel to and left or right of the ''parent'' track specified in nautical miles of offset distance.

Parent way-point (RTCA/DO-208). A way-point used for route definition and/or progress reporting. The geographical position of a parent way-point is not altered when RNAV equipment is operated in a parallel offset mode.

Phase of operation (FANS(II)/4). A period of navigation with a constant required navigation performance (RNP).

Note.— Traditionally, the term ''phase of flight'' has related to periods of navigation with different procedures/ criteria such as en-route (continental, oceanic), terminal, approach and landing. As the RNP concept is introduced, ''phase of operation'' will relate more to a particular RNP. For example, in the future, the continental en-route phase of flight may be divided into more than one phase of operation, since several RNPs may be included as an aircraft transits a continental area.

Position determination error (RTCA/DO-208). The accuracy with which a navigation sensor can calculate and provide an output of actual location in an operational environment.

Position dilution of precision (PDOP) (RTCA/DO-208). The ratio of user-referenced three-dimensional position error to measurement error of a multilateration system. PDOP is the root-sum-square of HDOP and VDOP.

Position fixing error (RTCA/DO-208). The accuracy with which a navigation sensor in combination with a navigation computer can calculate and provide an output of actual location in relation to desired location in an operational environment.

Primary-means navigation system (GNSSP). A navigation system approved for a given operation or phase of flight that must meet accuracy and integrity requirements, but need not meet full availability and continuity of service requirements. Safety is achieved by limiting flights to specific time periods and through appropriate procedural restrictions.

Note.— There is no requirement to have a sole-means navigation system on board to support a primary means system.

Propagation delay (RTCA/DO-208). The time delay of a signal created as the signal travels between antennas through a propagation medium.

Pseudolite (FANS(II)/4). A ground-based GNSS augmentation which provides, at GNSS satellite signal-in-space radio frequencies, an additional navigation ranging signal. The augmentation may include additionally differential GNSS corrections.

Pseudorange (RTCA/DO-208). The distance from the user to a satellite plus an unknown user clock offset distance. With four satellite signals it is possible to compute position and offset distance. If the user clock offset is known, three satellite signals would suffice to compute a position.

Receiver autonomous integrity monitoring (RAIM) (FANS(II)/4). A technique whereby an airborne GNSS receiver/processor autonomously monitors the integrity of the navigation signals from GNSS satellites.

Reliability (Doc 9613). A function of the frequency with which failures occur within the system. The probability that a system will perform its function within defined performance limits for a specified period under given operating conditions. Formally, reliability is one minus the probability of system failure.

Required navigation performance (RNP) (Annex 11). A statement of the navigation performance accuracy necessary for operation within a defined airspace.

Satellite-based augmentation system (SBAS). A wide coverage augmentation system in which the user receives augmentation information directly from a satellite-based transmitter.

Selective availability (SA) (RTCA/DO-208). A set of techniques for denying the full accuracy and selecting the level of positioning and time accuracy of GPS available to SPS users.

Signal-derived position error (RTCA/DO-208). That part of the horizontal position error at the user location attributable to signal-in-space errors from the GPS control segment, space segment and propagation effects; does not include receiver-induced errors.

Signal-derived range accuracy (RTCA/DO-208). Measured pseudorange error on a particular satellite as observed by a ground monitor station. SRA includes the sign of the error.

Sole-means navigation system (GNSSP). A sole-means navigation system approved for a given operation or phase of flight must allow the aircraft to meet, for that operation or phase of flight, all four navigation system performance requirements: accuracy, integrity, availability and continuity of service.

Note.— This definition does not exclude the carriage of other navigation systems. Any sole-means navigation system could include one (stand-alone installation) or several sensors, possibly of different types (multi-sensor installation).

Spherical error probable (SEP) (RTCA/DO-208). The radius of a sphere within which there is a 50 per cent probability of locating a point or being located. SEP is the three-dimensional analogue of CEP.

Station-referenced navigation (Doc 9613). Position determination which is referenced to a particular source.

Supplemental-means navigation system (GNSSP). A navigation system that must be used in conjunction with a sole-means navigation system. Approval for supplemental-means for a given phase of flight requires that a sole-means navigation system for that phase of flight must be on board. Amongst the navigation system performance requirements for a given operation or phase of flight, a supplemental-means navigation system must meet the accuracy and integrity requirements for that operation or phase of flight; there is no requirement to meet availability and continuity requirements.

Note.— Operationally, while accuracy and integrity requirements are being met, a supplemental-means system can be used without any cross-check with the sole-means system. Any navigation system approved for supplemental-means could involve one (stand-alone installation) or several sensors, possibly of different types (multi-sensor installation).

Time navigation (TNAV) (RTCA/DO-208). A function of RNAV equipment that provides the capability to arrive/depart at a way-point at a specified time. When added to a 3D system, TNAV is called 4D.

Time to recover navigation (Doc 9613). The time required for restoration of navigation service after signal interruption.

User range accuracy (URA) (RTCA/DO-208). The one-sigma estimate of user range errors in the navigation data for each individual satellite. It includes all errors for which the space or control segment is responsible. It does not include any errors introduced at the user set.

Vertical deviation (VDEV) (RTCA/DO-208). The deviation of the aircraft above or below the vertical profile as displayed on an indicator such that deflection is up when the aircraft is below the vertical profile.

Vertical dilution of precision (VDOP) (RTCA/DO-208). The ratio of user-referenced vertical position error to measurement error of a multilateration system (see GDOP for a more detailed description).

Vertical navigation (VNAV) (RTCA/DO-208). A function of RNAV equipment which calculates, displays and provides guidance to a vertical profile or path.

Way-point (W/P) (Annex 11). A specified geographical location used to define an area navigation route or the flight path of an aircraft employing area navigation.

Way-point displacement area (RTCA/DO-208). The rectangular area formed around the plotted position of the way-point. The rectangle is oriented along the desired track with the way-point at its centre. Its dimensions are two times the appropriate plus-or-minus along-track and cross-track displacement error values.

Appendix 6

GLOSSARY OF ACRONYMS

AAIM	Aircraft autonomous integrity monitoring
ACC	Area control centre
ADS	Automatic dependent surveillance
AEEC	Airlines Electronic Engineering Committee
AIP	Aeronautical Information Publication
AIS	Aeronautical information services
AMS(R)S	Aeronautical mobile-satellite (route) service
AMSS	Aeronautical mobile-satellite service
ANC	Air Navigation Commission
AOR-E/W	(Inmarsat) Atlantic Ocean Region East/West
ARINC	Aeronautical Radio, Inc.
ASECNA	Agency for the Security of Aerial Navigation in Africa and Madagascar
ATC	Air traffic control
ATM	Air traffic management
ATN	Aeronautical telecommunication network
ATS	Air traffic service
C/A code	Coarse acquisition code
CCIR	International Radio Consultative Committee
CDI	Course deviation indicator
CEP	Circular error probable
CNS	Communications, navigation and surveillance
CASITAF	CNS/ATM Implementation Task Force
CPDLC	Controller/pilot data link communications
CSA	Channel of standard accuracy
DGNSS	Differential GNSS
DGPS	Differential GPS
DH	Decision height
DMA	Defence Mapping Agency
DME	Distance measuring equipment
DOP	Dilution of precision
EATCHIP	European Air Traffic Control Harmonization and Integration Programme
ECAC	European Civil Aviation Conference
EGNOS	European Geostationary Navigation Overlay Service
ESA	European Space Agency
EUROCAE	European Organization for Civil Aviation Equipment
EUROCONTROL	European Organization for the Safety of Air Navigation
FAA	Federal Aviation Administration
FANS (Phase II)	Special Committee for the Monitoring and Co-ordination of Development and Transition Planning for the Future Air Navigation System
FIR	Flight information region
FMS	Flight management system
FTE	Flight technical error
GBAS	Ground-based augmentation system
GDOP	Geometric dilution of precision
GEO	Geostationary satellite
GES	Ground earth station
GIC	GNSS integrity channel
GLONASS	Global orbiting navigation satellite system
GNE	Gross navigational error
GNSS	Global navigation satellite system

GNSSP	Global Navigation Satellite System Panel
GPS	Global positioning system
GRS	Ground reference station
HDOP	Horizontal dilution of precision
HUD	Head-up display
IAF	Initial approach fix
IALA	International Association of Lighthouse Authorities
IAOPA	International Council of Aircraft Owner and Pilot Associations
IAP	Initial approach point
IATA	International Air Transport Association
IBAC	International Business Aviation Council
ICAO	International Civil Aviation Organization
ICCAIA	International Co-ordinating Council of Aerospace Industries Associations
IFALPA	International Federation of Airline Pilots' Associations
IFATCA	International Federation of Air Traffic Controllers' Associations
IFR	Instrument flight rules
ILS	Instrument landing system
IMC	Instrument meteorological conditions
IMO	International Maritime Organization
INS	Inertial navigation system
IMS	Integrity monitoring system
IOC	(GPS) initial operational capability
IOR	(Inmarsat) Indian Ocean Region
IRS	Inertial reference system
ISO	International Organization for Standardization
ITU	International Telecommunication Union
KLADGNSS	Kinematic local area differential GNSS
LADGNSS	Local area differential GNSS
LADGPS	Local area differential GPS
LEO	Low earth orbit(ing satellite)
MAPt	Missed approach point
MAHP	Missed approach holding point
MASPS	Minimum aviation system performance standards
MCS	Master control station
MDA	Minimum descent altitude
MLS	Microwave landing system
MMALS	Multi-mode approach and landing system
MMR	Multi-mode receiver
MNPS	Minimum navigation performance specification
MOPS	Minimum operational performance standards
MTSAT	Multi-Functional Transport Satellite
NAT SPG	North Atlantic Systems Planning Group
NDB	Non-directional beacon
NM	Nautical mile(s)
NOTAM	Notices to Airmen
NSE	Navigation system error
OSI	Open systems interconnection
PANS-OPS	Procedures for Air Navigation Services — Aircraft Operations
PDOP	Position dilution of precision
P-code	(GPS/GLONASS) precision code
PDE	Path definition error
PE-90	Parameters of the Earth 1990
PET	Pacific Engineering Trials
PHARE	Programme for harmonized ATM research in Eurocontrol
POR	(Inmarsat) Pacific Ocean Region
PPS	(GPS) precise positioning service
RAIM	Receiver autonomous integrity monitoring
R&D	Research and development

RDT&D	Research, development, trials and demonstrations
RF	Radio frequency
RFI	RF interference
RGIC	Ranging GNSS integrity channel
RMS	Remote monitoring station
RNAV	Area navigation
RNP	Required navigation performance
RTCM	Radio Technical Commission for Maritime Services
RVR	Runway visual range
SA	(GPS) selective availability
SARPs	Standards and Recommended Practices
SATCOM	Satellite communication
SBAS	Satellite-based augmentation system
SCAT-I	Special Category I (approach system)
SIS	Signal-in-space
SITA	International Society for Aeronautical Telecommunications
SMGCS	Surface movement guidance and control systems
SPS	(GPS) standard positioning service
SV	Space vehicle
SVN	Space vehicle number
TDMA	Time division multiple access
TDOP	Time dilution of precision
TLS	Target level of safety
TSE	Total system error
TSO	(FAA) technical standard order
UHF	Ultra high frequency
UTC	Universal time co-ordinated
VDL	VHF digital link
VDOP	Vertical dilution of precision
VFR	Visual flight rules
VHF	Very high frequency
VMC	visual meteorological conditions
VOR	VHF omnidirectional range
VSM	Vertical separation minimum
WAAS	Wide area augmentation system (U.S.)
WADGNSS	Wide area differential GNSS
WADGPS	Wide area differential GPS
WGS-84	World geodetic system 1984

— END —

ICAO TECHNICAL PUBLICATIONS

The following summary gives the status, and also describes in general terms the contents of the various series of technical publications issued by the International Civil Aviation Organization. It does not include specialized publications that do not fall specifically within one of the series, such as the Aeronautical Chart Catalogue *or the* Meteorological Tables for International Air Navigation.

International Standards and Recommended Practices are adopted by the Council in accordance with Articles 54, 37 and 90 of the Convention on International Civil Aviation and are designated, for convenience, as Annexes to the Convention. The uniform application by Contracting States of the specifications contained in the International Standards is recognized as necessary for the safety or regularity of international air navigation while the uniform application of the specifications in the Recommended Practices is regarded as desirable in the interest of safety, regularity or efficiency of international air navigation. Knowledge of any differences between the national regulations or practices of a State and those established by an International Standard is essential to the safety or regularity of international air navigation. In the event of non-compliance with an International Standard, a State has, in fact, an obligation, under Article 38 of the Convention, to notify the Council of any differences. Knowledge of differences from Recommended Practices may also be important for the safety of air navigation and, although the Convention does not impose any obligation with regard thereto, the Council has invited Contracting States to notify such differences in addition to those relating to International Standards.

Procedures for Air Navigation Services (PANS) are approved by the Council for world-wide application. They contain, for the most part, operating procedures regarded as not yet having attained a sufficient degree of maturity for adoption as International Standards and Recommended Practices, as well as material of a more permanent character which is considered too detailed for incorporation in an Annex, or is susceptible to frequent amendment, for which the processes of the Convention would be too cumbersome.

Regional Supplementary Procedures (SUPPS) have a status similar to that of PANS in that they are approved by the Council, but only for application in the respective regions. They are prepared in consolidated form, since certain of the procedures apply to overlapping regions or are common to two or more regions.

The following publications are prepared by authority of the Secretary General in accordance with the principles and policies approved by the Council.

Technical Manuals provide guidance and information in amplification of the International Standards, Recommended Practices and PANS, the implementation of which they are designed to facilitate.

Air Navigation Plans detail requirements for facilities and services for international air navigation in the respective ICAO Air Navigation Regions. They are prepared on the authority of the Secretary General on the basis of recommendations of regional air navigation meetings and of the Council action thereon. The plans are amended periodically to reflect changes in requirements and in the status of implementation of the recommended facilities and services.

ICAO Circulars make available specialized information of interest to Contracting States. This includes studies on technical subjects.

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