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Global Navigation Satellite System (GNSS) Manual

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AMENDMENTS

The issue of amendments is announced regularly in the *ICAO Journal* and in the monthly *Supplement to the Catalogue of ICAO Publications and Audio-visual Training Aids*, which holders of this publication should consult. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

AMENDMENTS		
No.	Date	Entered by

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FOREWORD

The *Global Air Navigation Plan for CNS/ATM Systems* (Doc 9750) recognizes the Global Navigation Satellite System (GNSS) as a key element of the Communications, Navigation, and Surveillance/Air Traffic Management (CNS/ATM) systems as well as a foundation upon which States can deliver improved aeronautical navigation services.

The Standards and Recommended Practices (SARPs) for GNSS were developed by the Global Navigation Satellite System Panel and introduced as part of Amendment 76 to Annex 10 to the *Convention on International Civil Aviation — Aeronautical Telecommunications*, Volume I (*Radio Navigation Aids*) in 2001. The guidance information and material in Attachment D to Annex 10, Volume I provides extensive guidance on the technical aspects and the application of GNSS SARPs.

The primary purpose of this manual is to provide information on the implementation aspects of GNSS in order to assist States in the introduction of GNSS operations. The manual is therefore aimed at air navigation service providers responsible for fielding and operating GNSS elements, and at regulatory agencies responsible for approving the use of GNSS for flight operations. Additionally, it provides GNSS information to aircraft operators and manufacturers.

This manual is to be used in conjunction with the relevant provisions in Annex 10, Volume I.

Comments on this manual would be appreciated from all parties involved in the development and implementation of GNSS. These comments should be addressed to:

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Chapter 1

INTRODUCTION

1.1 GENERAL

This manual describes the concepts of operation that uses the core satellite constellations (i.e. Global Positioning System (GPS) and GLObal NAvigation Satellite System (GLONASS)) and augmentation systems. It includes a basic explanation of satellite navigation technology including satellite systems, augmentations and avionics. It discusses the services provided by Global Navigation Satellite System (GNSS) and describes the implementation considerations that will assist States plan for the orderly introduction of service based on GNSS guidance. Finally, it outlines future prospects for the evolution of GNSS.

1.2 GNSS ELEMENTS

1.2.1 The two core satellite constellations are the GPS and the GLONASS, provided by the United States of America and the Russian Federation, respectively, in accordance with the Standards and Recommended Practices (SARPs). These two systems provide independent capabilities and can be used in combination with future core satellite constellations and augmentation systems. States authorizing GNSS operations remain however responsible for determining if GNSS meets Annex 10 — *Aeronautical Telecommunications* performance requirements in their airspace and for notifying users when performance does not meet these requirements.

1.2.2 The satellites in the core satellite constellations broadcast a timing signal and a data message that includes their orbital parameters (ephemeris data). Aircraft GNSS receivers use these signals to calculate their range from each satellite in view, and then to calculate three-dimensional position and time.

1.2.3 The GNSS receiver consists of an antenna and a processor which computes position, time and, possibly, other information depending on the application. Measurements from a minimum of four satellites are required to establish three-dimensional position and time. Accuracy is dependent on the precision of the measurements from the satellites and the relative positions (geometry) of the satellites used.

1.2.4 The existing core satellite constellations alone however do not meet strict aviation requirements. To meet the operational requirements for various phases of flight, the core satellite constellations require augmentation in the form of aircraft-based augmentation system (ABAS), satellite-based augmentation system (SBAS) and/or ground-based augmentation system (GBAS). ABAS relies on avionics processing techniques or avionics integration to meet aviation requirements. The other two augmentations use ground monitoring stations to verify the validity of satellite signals and calculate corrections to enhance accuracy. SBAS delivers this information via a geostationary earth orbit (GEO) satellite, while GBAS uses a VHF data broadcast (VDB) from a ground station.

1.3 OPERATIONAL ADVANTAGES OF GNSS

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

1.3.2 The first approvals to use GNSS came in 1993, supporting en-route (domestic and oceanic), terminal and non-precision approach (NPA) operations. The approvals, based on ABAS, came with operational restrictions but delivered significant benefits to aircraft operators.

1.3.3 GNSS provides accurate guidance in remote and oceanic areas where it is impractical or too costly or impossible to provide reliable and accurate traditional NAVAID guidance. Many States employ GNSS to deliver improved service to aircraft operators while at the same time avoiding the cost of fielding traditional NAVAIDs.

1.3.4 Even in areas well served by traditional NAVAIDs, GNSS supports area navigation operations, allowing aircraft to follow more efficient flight paths. GNSS brings this capability within the economic reach of all aircraft operators. This allows States to design en-route and terminal airspace for maximum capacity and minimum delays.

1.3.5 The availability of accurate GNSS-based guidance on departure supports efficient noise abatement procedures. It allows greater flexibility in routings, where terrain is a restricting factor, providing the possibility of lower climb gradients and higher payloads.

1.3.6 GNSS can improve airport usability, through lower minima, without the need to install a NAVAID at the airport. GNSS may support approach procedure with vertical guidance (APV) on all runways, with proper consideration of aerodrome standards for physical characteristics, marking and lighting (see 5.7.4). When a landing threshold is displaced, the flexibility inherent in GNSS can allow continued operations with vertical guidance to the new threshold. GNSS may also be used to support surface operations.

1.3.7 In suitably equipped aircraft, the availability of accurate GNSS position, velocity and time may be used additionally to support such functions as automatic dependent surveillance (ADS) and controller-pilot data link communications (CPDLC).

1.3.8 The availability of GNSS guidance will allow the phased decommissioning of some or all of the traditional NAVAIDs. This will decrease costs in the longer term, resulting in savings for airspace users. Even in the early stages of GNSS implementation, States may be able to avoid the cost of replacing existing NAVAIDs. Planning for the decommissioning of traditional NAVAIDs depends on the availability of GNSS service in a particular airspace and on the proportion of aircraft equipped for GNSS. There are a number of issues affecting availability, which are discussed in Chapter 4 of this manual.

1.3.9 GNSS can be implemented in stages, providing increasing operational benefits at each stage. This allows aircraft operators to decide, based on weighing of operational benefits against cost, when to equip with GNSS avionics.

1.4 GNSS LIMITATIONS AND ASSOCIATED ISSUES

1.4.1 While GNSS offers significant benefits, the technology has its limitations and brings with it a number of institutional issues. In approving GNSS operations, States should take account of these limitations and issues.

1.4.2 A transition to GNSS represents a major change for all members of the aviation community. It affects aircraft operators, pilots, air traffic services (ATS) and regulatory personnel. States should therefore plan such a transition carefully and in close consultation with all involved parties. The global nature of GNSS also dictates close coordination with other States. These considerations, coupled with the pace of development of GNSS technology and applications, challenge air navigation service providers to dedicate resources, move quickly and retain flexibility in order to meet the demands of their customers for GNSS services.

1.4.3 A challenge for GNSS is the achievement of a high availability of service. The first GNSS approvals relied on traditional NAVAIDs as a back-up when insufficient satellites were in view. SBAS and GBAS are designed to enhance, *inter alia*, GNSS performance in terms of availability.

1.4.4 Interference with GNSS signals directly affects availability. While it is possible to interfere with signals from traditional NAVAIDs, these aids have limited service volumes when compared with GNSS, so interference with GNSS signals can affect more aircraft simultaneously. States should assess the likelihood of unintentional and intentional interference, including the effects of such occurrences on aircraft operations. If necessary, special measures have to be implemented to minimize these effects as discussed in 5.8.

1.4.5 While GNSS has the potential to support better approaches to more runways at relatively low cost, approach minima also depend on the physical characteristics of the aerodrome and on infrastructure such as lighting. States should therefore consider the cost of meeting aerodrome standards when planning for new GNSS-based approaches or approaches with lower minima.

1.4.6 The safety of GNSS navigation depends on the accuracy of navigation databases. States should therefore ensure data integrity when developing new procedures. Additionally, procedures and systems should be in place to ensure the integrity of the data as they are processed for use in avionics.

1.5 THE GNSS PLANNING PROCESS

1.5.1 With GNSS, States will be less involved in the design and acquisition of ground-based infrastructure. Their efforts will focus on developing procedures and air traffic management based on operational requirements, the capabilities of GNSS and operational approvals.

Cost-benefit analysis

1.5.2 In deciding whether to proceed with approvals of GNSS-based operations or fielding of a GNSS augmentation system, a State or group of States may wish to develop a business case. An analysis should be conducted to consider all the costs and benefits from the perspectives of the service provider and of the user. It would be useful for service providers, regulators and users to work together on the analysis to ensure that it is as complete and valid as possible. The analysis should consider such elements as cost recovery, revenue policy and extra costs during a transition period. In some cases the analysis may not be conclusive or it may not be positive for one of the parties. In such a case participants should examine various options to find the best solution.

Safety considerations

1.5.3 By approving GNSS operations, a State accepts responsibility to ensure that such operations can be completed safely. This is the case irrespective of whether the operations are based on a non-augmented satellite navigation system, aircraft-based augmentation system or an augmentation system provided by a service provider in another State.

Role of ICAO

1.5.4 In making appropriate GNSS implementation decisions, States are encouraged to take advantage of the expertise and information available at the ICAO planning and implementation regional groups (PIRGs) and their subgroups. ICAO has a mandate to contribute to this process by:

a) ensuring regional and interregional coordination;

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

c) identifying technical assistance needs in the region and arranging for the provision of such assistance.

Chapter 2

OVERVIEW OF GNSS-BASED OPERATIONS

2.1 GENERAL

2.1.1 GNSS service can be introduced in stages as the technology and operational procedures develop. The implementation of GNSS service by stages may however be affected by various factors, including:

a) the existing navigation services;

b) availability of design criteria for GNSS procedures;

c) level of air traffic services supporting GNSS operations;

d) aerodrome infrastructure;

e) extent of aircraft equipage; and

f) completeness of relevant regulations.

2.1.2 Depending upon these factors, States may adopt different implementation strategies and derive different benefits from the various stages of implementation.

2.1.3 The introduction of augmentation systems enhances service and eliminates most limitations. Depending on traffic volume and airspace structure, States can choose their level of involvement in the development and implementation of satellite-based augmentation system (SBAS) and/or ground-based augmentation system (GBAS). These implementation efforts require a high level of cooperation among States in order to deliver maximum operational advantages to aircraft operators.

2.2 OPERATIONS USING AIRCRAFT-BASED AUGMENTATION SYSTEM (ABAS)

2.2.1 In the early 1990s, many aircraft operators were quick to adopt GNSS because of the availability of relatively inexpensive Global Positioning System (GPS) receivers. Operators used these early receivers as an aid to visual flight rules (VFR) and instrument flight rules (IFR) navigation. They quickly saw the benefits of having global area navigation (RNAV) capability, and demanded avionics that could be used for IFR navigation.

2.2.2 The core satellite constellations were not developed to satisfy the strict requirements of IFR navigation. For this reason, GNSS avionics used in IFR operations should augment the GNSS signal to ensure, among other things, its integrity. ABAS augments and/or integrates GNSS information with information available on-board the aircraft to enhance the performance of the core satellite constellations.

2.2.3 The most common ABAS technique is called receiver autonomous integrity monitoring (RAIM). RAIM requires redundant satellite range measurements to detect faulty signals and alert the pilot. The requirement for redundant signals means that navigation guidance with integrity provided by RAIM may not be available 100 per cent of the time. RAIM availability depends on the type of operation; it is lower for non-precision approach than for terminal, and lower for terminal than for en-route. It is for this reason that GPS/RAIM approvals usually have operational restrictions. Another ABAS technique involves integration of GNSS with other airborne sensors such as inertial navigation systems.

2.2.4 Many States have taken advantage of GPS/ABAS to improve service without incurring any expenditure on infrastructure. The use of GPS/ABAS is a worthwhile first stage in a phased transition to GNSS guidance for all phases of flight.

2.2.5 The initial approvals to use GNSS had covered en-route, terminal and non-precision approach operations. Many service providers have designed new GPS stand-alone approaches that offer significant benefits because they can be designed to provide the most effective flight path to the runway, do not require a course reversal and provide the pilot with precise position information throughout the procedure. Most GPS stand-alone approaches provide straight-in guidance, so they are considerably safer than circling approaches.

2.2.6 In some States, pilots are authorized to fly suitable VHF omnidirectional radio range (VOR), VOR/distance measuring equipment (DME), non-directional beacon (NDB) and NDB/DME non-precision approach (NPA) procedures using GPS guidance. These are termed “GPS overlay” approaches and allow operators to benefit from better accuracy and situational awareness without the need for the service provider to design a new approach. This is seen as an interim step to bring early benefits to users. Using GPS guidance, pilots follow the path defined by the traditional navigation aids (NAVAIDs), and comply with the visibility and minimum descent altitude associated with the traditional approach. Some VOR and NDB-based procedures are however not suited to the overlay programme because certain approach legs cannot be adapted to the RNAV data coding system. GPS overlay approaches are not ideal from the pilot’s perspective, because the original NPA procedures were not intended to be flown using an RNAV system.

2.2.7 An overlay approach should be removed from the State Aeronautical Information Publication (AIP) when a GPS stand-alone approach is designed for the same runway in order to avoid the potential for confusion between two approaches to the same runway.

2.2.8 Certain operational restrictions are deemed necessary for the implementation of GPS-based NPA procedures. The reasons for and nature of these restrictions vary from State to State and include: the effects of GPS outages in large regions; the availability of traditional NAVAIDs as a back-up; traffic density; and regulations for avionics redundancy. A common operational restriction is that the pilot shall not take credit for GPS approaches at an alternate aerodrome when determining alternate weather minima requirements.

2.2.9 Some States have also approved the use of GPS as the only navigation service in oceanic and remote areas. In this case avionics should not only have the ability to detect a faulty satellite (through RAIM), but it should also exclude that satellite and continue to provide guidance. This feature is called fault detection and exclusion (FDE). Under such approval, aircraft carry dual systems and operators perform pre-flight predictions to ensure that there will be enough satellites in view to support the planned flight. This provides operators with a cost-effective alternative to inertial navigation systems in oceanic and remote airspace.

2.2.10 Some aircraft with existing inertial navigation systems have used another ABAS technique which involves the integration of GNSS with the inertial data. The combination of GNSS fault detection (FD), or FDE, along with the short-term accuracy of modern inertial navigation systems, provides enhanced availability of GNSS integrity for all phases of flight.

2.2.11 Annex 15 — *Aeronautical Information Services* requires a Notice to Airmen (NOTAM) service for navigation systems. In the case of GNSS, some States have NOTAM or advisory systems to inform pilots when and where the RAIM function will not be available.

2.2.12 Many operators use GPS as an aid to VFR navigation. As long as pilots rely on map reading and visual contact with the ground, this use of GPS can increase efficiency and safety. Some States require IFR certification of the avionics for certain VFR operations.

2.3 OPERATIONS USING SATELLITE-BASED AUGMENTATION SYSTEM (SBAS)

2.3.1 An SBAS augments core satellite constellations by providing ranging, integrity and correction information via geostationary satellites. The system comprises:

a) a network of ground reference stations that monitor satellite signals;

b) master stations that collect and process reference station data and generate SBAS messages;

c) uplink stations that send the messages to geostationary satellites; and

d) transponders on these satellites that broadcast the SBAS messages.

2.3.2 By providing differential corrections, extra ranging signals via geostationary satellites and integrity information for each navigation satellite, SBAS delivers much higher availability of service than the core satellite constellations with ABAS alone. In certain configurations, SBAS can support approach procedures with vertical guidance (APV). There are two levels of APV: APV I and APV II. Both use the same lateral obstacle surfaces as localizers; however APV II may have lower minima due to better vertical performance. There will nonetheless be only one APV approach to a runway end, based on the level of service that SBAS can support at an aerodrome. The two APV approach types are identical from the perspective of avionics and pilot procedures.

2.3.3 In many cases, SBAS will support lower minima than that associated with non-precision approaches, resulting in higher airport usability. Almost all SBAS approaches will feature vertical guidance, resulting in a significant increase in safety. APV minima (down to a decision height (DH) of 75 m (250 ft) approximately) will be higher than Category I minima, but APV approaches would not require the same ground infrastructure, so this increase in safety will be affordable at most airports. SBAS availability levels will allow operators to take advantage of SBAS instrument approach minima when designating an alternate airport. An SBAS approach does not require any SBAS infrastructure at an airport.

2.3.4 SBAS can support all en-route and terminal RNAV operations. Significantly, SBAS offers the promise of affordable RNAV capability for a wide cross section of users. This will allow States to reorganize airspace for maximum efficiency and capacity, allowing aircraft to follow the most efficient flight path between airports. High availability of service will permit States to decommission traditional NAVAIDs, resulting in lower costs.

2.3.5 There are four SBASs being developed: the European Geostationary Navigation Overlay Service (EGNOS); the Indian GPS and Geostationary Earth Orbit (GEO) Augmented Navigation (GAGAN) System; the Japanese Multi-functional Transport Satellite (MTSAT) Satellite-based Augmentation System (MSAS); and the United States Wide Area Augmentation System (WAAS).

2.3.6 Geostationary satellite footprints define the coverage area of an SBAS. Within this coverage area, States may establish service areas where SBAS supports approved operations. Other States can take advantage of the signals available in the coverage area in two ways: by fielding SBAS components integrated with an existing SBAS, or by authorizing the use of SBAS signals. The first option offers some degree of control and improved performance. The second option lacks any degree of control, and the degree of improved performance depends on the proximity of the host SBAS to the service area.

2.3.7 In either case, the State, which has established an SBAS service area, should assume responsibility for the SBAS signals within that service area. This requires the provision of NOTAM information, as described in 5.6.5.

2.3.8 If ABAS-only operations are approved within the coverage area of SBAS, SBAS avionics will also support ABAS operations and in fact better meet availability-of-service requirements.

2.3.9 Although the architectures of the various SBASs are different, they broadcast the standard message format on the same frequency (GPS L1) and so are interoperable from the user's perspective. It is anticipated that these SBAS networks will expand beyond their initial service areas. Other SBAS networks may also be developed. When SBAS coverage areas overlap, it is possible for an SBAS operator to monitor and send integrity and correction messages for the geostationary satellites of another SBAS, thus improving availability by adding ranging sources. This system enhancement should be accomplished by all SBAS operators.

2.4 OPERATIONS USING GROUND-BASED AUGMENTATION SYSTEM (GBAS)

2.4.1 GBAS ground sub-systems are intended to provide a precision approach service and optionally, they may also provide a GBAS positioning service. The precision approach service is intended to provide deviation guidance for final approach segments, while the GBAS positioning service provides horizontal position information to support two-dimensional RNAV operations in terminal areas. A ground station at the airport broadcasts locally relevant corrections, integrity parameters and approach data to aircraft in the terminal area in the 108 – 117.975 MHz band.

2.4.2 A GBAS installation will typically provide corrections that support approaches to multiple runways at a single airport. In some cases, the data may be used for nearby airports and heliports as well. GBAS infrastructure includes electronic equipment, which can be installed in any suitable airport building, and antennas to broadcast data and receive the satellite signals. Antenna location is independent of the runway configuration, but requires the careful evaluation of local sources of interference, signal blockage, and multipath. Siting of the VHF data broadcast antenna should ensure that the coverage area is sufficient for the intended operations.

2.4.3 The complexity and redundancy of GBAS ground station installation depends on the service provided.

2.4.4 The cost and flexibility of GBAS will lead to more runway ends being equipped with qualified electronic precision approach guidance, resulting in significant safety and efficiency benefits. Such runways however should meet the relevant standards for physical characteristics and infrastructure.

Chapter 3

GNSS SYSTEM DESCRIPTION

3.1 GENERAL

3.1.1 Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS) have the capability to provide accurate position and time information worldwide. The accuracy provided by both systems meets aviation requirements for en-route through non-precision approach, but not the requirements for precision approach. Augmentation systems can be used to meet the four basic GNSS navigation operational performance requirements that are stated in the GNSS SARPs in Annex 10 — *Aeronautical Telecommunications*, Volume I (*Radio Navigation Aids*), Chapter 3, Table 3.7.2.4-1 and discussed in Chapter 4. Integrity, availability and continuity can be provided by using on-board, ground- or satellite-based augmentation techniques. Accuracy can be enhanced by using differential techniques. The total system, including core satellite constellations (i.e. GPS and GLONASS), and all augmentation systems, is referred to as GNSS. Efforts to bring the full benefits of satellite navigation to users are focused on developing these augmentations and certifying them for operational use.

3.1.2 According to Annex 10, any change in the SARPs that will require the replacement or update of GNSS equipment requires a six-year advance notice. Similarly, a six-year notice is required of a core or augmentation system provider who plans to terminate the service provided.

3.1.3 Satellite systems providing navigational functions to the international civil aviation community are required to comply with the ICAO-approved common geodetic reference datum, i.e. the World Geodetic System 1984 (WGS-84). GPS utilizes WGS-84 as the reference datum; however, GLONASS utilizes PZ-90 (parameters of the Earth 1990 coordinate system). GNSS SARPs provide a transformation algorithm to convert PZ-90 into WGS-84 coordinates (see 5.6.3).

3.2 EXISTING SATELLITE-BASED NAVIGATION SYSTEMS

3.2.1 Global Positioning System (GPS)

3.2.1.1 GPS is a satellite-based radio navigation system which utilizes precise range measurements from GPS satellites to determine position and time anywhere in the world. The system is operated for the government of the United States by the United States Air Force. In 1994, the United States offered the GPS standard positioning service (SPS) to support the needs of international civil aviation and the ICAO Council accepted the offer.

3.2.1.2 The design GPS space segment is comprised of 24 satellites in six orbital planes. The satellites operate in near-circular 20 200 km (10 900 NM) orbits at an inclination angle of 55 degrees to the equator; each satellite completes an orbit in approximately 12 hours. The GPS control segment has five monitor stations and four ground antennas with uplink capabilities. The monitor stations use a GPS receiver to passively track all satellites in view and accumulate ranging data. The master control station processes this information 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.

3.2.1.3 The GPS SPS, which utilizes a coarse acquisition (C/A) code on the L1 frequency (1 575.42 MHz), is designed to provide an accurate positioning capability for civilian users throughout the world. A precise positioning service (PPS), which utilizes the Precise Code (P-code) on a second frequency L2 (1 227.6 MHz), provides a more accurate positioning capability, but is encrypted to restrict its use to authorized agencies.

3.2.1.4 On 1 May 2000, the United States discontinued the use of GPS selective availability (SA). The discontinuation of SA resulted in an immediate improvement of GPS SPS accuracy; however, the ability of a user application to take full advantage of the removal of SA depends on certain assumptions within the receiver and on the nature of the navigation system integration. Most Technical Standard Order TSO-C129 avionics do not see improvements in the availability of receiver autonomous integrity monitoring (RAIM) because they assume SA is present. The RAIM/fault detection and exclusion (FDE) functionality in satellite-based augmentation system (SBAS) avionics does however take advantage of the discontinuation of SA.

3.2.1.5 Elimination of the SA error component does not eliminate other errors. Therefore, no changes are expected for either SBAS or ground-based augmentation system (GBAS) augmentations.

3.2.1.6 The GPS SPS performance standard defines the level of performance that the United States Government commits to provide to all civilian users. The Interface Control Document (ICD) GPS 200C details the technical characteristics of the SPS L-band carrier and the C/A code as well as the technical definition of requirements between the GPS constellation and SPS receivers. Additional information concerning GPS can be found on the United States Coast Guard's Navigation Center (NAVCEN) website (www.navcen.uscg.gov).

3.2.2 Global Navigation Satellite System (GLONASS)

3.2.2.1 GLONASS provides three-dimensional position and velocity determinations based upon the measurement of transit time and Doppler shift of radio frequency (RF) signals transmitted by GLONASS satellites. The system is operated by the Ministry of Defence of the Russian Federation. In 1996, the Russian Federation offered the GLONASS channel of standard accuracy (CSA) to support the needs of international civil aviation and the ICAO Council accepted the offer.

3.2.2.2 The nominal GLONASS space segment consists of 24 operational satellites and several spares. GLONASS satellites orbit at an altitude of 19 100 km (10 310 NM) 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.

3.2.2.3 A navigation message transmitted from each satellite consists of satellite coordinates, velocity vector components, corrections to GLONASS system time, and satellite health information. Measurements from a minimum of four satellites are required to establish three-dimensional position and time. A minimum of three satellite measurements is required to determine a two-dimensional position and time, if altitude is known. The user's receiver may track these satellites either simultaneously or sequentially. GLONASS satellites broadcast in two L-band portions of the RF spectrum and have two binary codes, namely, 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 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-code and C/A code.

3.2.2.4 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 referenced to Coordinated Universal Time (UTC).

3.2.2.5 Ephemeris information includes the three-dimensional Earth-centred Earth-fixed position, velocity and acceleration for every half-hour epoch of each satellite. 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.

3.2.2.6 The GLONASS control segment performs satellite monitoring and control functions, and determines the navigation data to be modulated on the coded satellite navigation signals. The control segment includes a master control station and 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, the master control station provides the clock correction parameters.

3.2.2.7 Additional information concerning GLONASS can be found in the *GLONASS Interface Control Document*, published by the Scientific Co-ordination Information Centre of the Ministry of Defence of the Russian Federation, Moscow and available on the Centre's website: http://www.glonass-center.ru.

3.3 AUGMENTATION SYSTEMS

3.3.1 General

Three augmentation systems, namely aircraft-based augmentation system (ABAS), satellite-based augmentation system (SBAS) and ground-based augmentation system (GBAS), have been designed and standardized to overcome inherent limitations in GPS and GLONASS. Descriptions of the avionics used with the GNSS augmentations are provided in 3.4.

3.3.2 Aircraft-based Augmentation System (ABAS)

3.3.2.1 The purpose of ABAS is to augment and/or integrate information obtained from GNSS with on-board aircraft information. This augmentation or integration is required to ensure that performance meets the requirements of Annex 10, Volume I, Chapter 3, Table 3.7.2.4-1.

3.3.2.2 RAIM algorithms require a minimum of five visible satellites in order to perform fault detection and detect the presence of an unacceptably large position error for a given mode of flight. FDE uses a minimum of six satellites not only to detect a faulty satellite but also to exclude it from the navigation solution so that the navigation function can continue without interruption.

3.3.2.3 A barometric altimeter may be used as an additional measurement so that the number of ranging sources required for RAIM and FDE can be reduced by one. Baro aiding can also help to increase availability when there are enough visible satellites, but their geometry is not adequate to perform integrity function. Basic GNSS receivers require the use of baro aiding for non-precision approach operations.

3.3.2.4 The inputs to the RAIM and FDE algorithms are the standard deviation of the measurement noise, the measurement geometry, as well as the maximum allowable probabilities for a false alert and a missed detection. The output from the algorithm is the horizontal protection level (HPL), which is the radius of a circle centred at the true aircraft position that is guaranteed to contain the indicated horizontal position within the specified integrity requirement.

3.3.2.5 For receivers that cannot take advantage of the discontinuation of SA, the average RAIM availability is 99.99 per cent for en-route and 99.7 per cent for non-precision approach operations with a 24-satellite GPS constellation. FDE availability ranges from 99.8 per cent for en-route to 89.5 per cent for non-precision approach operations. For receivers that can take advantage of the discontinuation of SA (e.g. SBAS receivers), the availability of RAIM is increased to 100 per cent for en-route and to 99.998 per cent for non-precision approach operations. FDE availability ranges from 99.92 per cent for en-route to 99.1 per cent for non-precision approach operations.

3.3.2.6 The availability of RAIM and FDE will be slightly lower for mid-latitude operations and slightly higher for equatorial and high latitude regions due to the nature of the orbits. The use of satellites from multiple GNSS elements (e.g. GPS + GLONASS) or the use of SBAS satellites as additional ranging sources can improve the availability of RAIM and FDE.

3.3.3 Satellite-based Augmentation System (SBAS)

3.3.3.1 As defined in the SARPs, SBAS has the potential to support en-route through Category I precision approach operations. Initial SBAS architectures will typically support operations down to approach procedures with vertical guidance (APV).

3.3.3.2 SBAS monitors GPS and/or GLONASS signals using a network of reference stations distributed over a large geographic area. These stations relay data to a central processing facility, which assesses signal validity and computes corrections to the broadcast ephemeris and clock of each satellite. For each monitored GPS or GLONASS satellite, SBAS estimates the errors in the broadcast ephemeris parameters and satellite clock, and then broadcasts the corrections.

3.3.3.3 Integrity messages and corrections for each monitored GPS and/or GLONASS ranging source are broadcast on the GPS L1 frequency from SBAS satellites, typically geostationary earth orbit (GEO) satellites in fixed orbital slots over the equator. The SBAS satellites also provide ranging signals similar to GPS signals; however, these ranging signals cannot be received by Basic GNSS receivers. SBAS messages ensure integrity, improve availability, and provide the performance needed for APV.

3.3.3.4 SBAS uses two-frequency range measurements to estimate the ranging delay introduced by the Earth's ionosphere, and broadcasts the corrections applicable at predetermined ionospheric grid points. The SBAS receiver interpolates between grid points to calculate the ionospheric correction along its line-of-sight to each satellite.

3.3.3.5 In addition to the clock, ephemeris and ionospheric corrections, SBAS assesses and broadcasts parameters that bound the uncertainty in the corrections. The User Differential Range Error (UDRE) for each ranging source describes the uncertainty in the clock and ephemeris corrections for that ranging source. The Grid Ionospheric Vertical Error (GIVE) for each ionospheric grid point describes the uncertainty in the ionospheric corrections around that grid point.

3.3.3.6 The SBAS receiver combines these error estimates (i.e. UDRE and GIVE) with estimates of the uncertainties in its own pseudorange measurement accuracy and in its tropospheric delay model in order to compute an error model of the navigation solution.

Levels of SBAS service

3.3.3.7 The GNSS SARPs allow for three levels of SBAS capability. Table 3-1 shows the different types of SBAS service, the corrections that would be provided, and the highest level of service that would be supported.

3.3.3.8 The type of service chosen would be a trade-off between the capability required and the cost. A system providing GNSS satellite status requires a few reference stations and simple master stations that provide integrity only. Providing basic differential corrections requires more reference stations and a more complex master station to generate clock and ephemeris corrections. Providing precise differential corrections requires more reference stations in order to characterize the ionosphere and provide ionospheric corrections. The four SBASs under development (i.e. European Geostationary Navigation Overlay Service (EGNOS), GPS and GEO Augmented Navigation (GAGAN) System, MTSAT Satellite-based Augmentation System (MSAS), and Wide Area Augmentation System (WAAS)) all provide precise differential corrections.

3.3.3.9 Ranging, satellite status and basic differential correction functions are usable throughout the entire GEO coverage area, and are technically adequate to support non-precision approaches by providing monitoring and integrity data for GPS, GLONASS and SBAS satellites. The only potential for integrity to be compromised is if there is a satellite orbit error that cannot be observed by the SBAS ground network and that creates an unacceptable error outside of the SBAS service area. This is however very unlikely for en-route, terminal and non-precision approach operations.

3.3.3.10 For a service area located relatively far from an SBAS ground network, the number of visible satellites for which that SBAS provides status and basic corrections will be reduced. Since SBAS receivers are able to use data from two SBASs simultaneously, and to use autonomous fault detection and exclusion when necessary, availability may still be sufficient to support approval of some operations (see 3.4.2).

SBAS coverage and service areas

3.3.3.11 It is important to distinguish between SBAS coverage areas and service areas. An SBAS coverage area is defined by GEO satellite signal footprints. Service areas for a particular SBAS are established by a State within an SBAS coverage area. The State is responsible for designating the types of operations that can be supported within a specified service area.

Table 3-1. Types of SBAS service

Type of SBAS service	*Corrections*	*Highest level of service supported*
GNSS satellite status and GEO ranging	No corrections	Through non-precision approach
Basic differential corrections	Clock and ephemeris	Through non-precision approach
Precise differential corrections	Clock, ephemeris and ionosphere	Through APV II

3.3.3.12 A State may obtain SBAS service by either cooperating with another State (the SBAS service provider) that has developed and deployed an SBAS or by developing its own SBAS. A State might choose the former if its airspace is within the SBAS service provider's coverage area. It would then have to negotiate an agreement with the SBAS service provider covering such aspects as the type of service and compensation arrangements. A State adjacent to the SBAS service area could possibly extend the SBAS service area into its airspace without hosting any SBAS infrastructure, or it could field reference stations linked to the master stations of the SBAS service provider. In both cases, the SBAS service provider's GEO satellites would broadcast data that would cover the SBAS service areas of both States. In any case, it is a State's responsibility to monitor the performance of the SBAS within its airspace and to provide a status monitoring and Notice to Airmen (NOTAM) service.

3.3.4 Ground-based Augmentation System (GBAS)

3.3.4.1 As defined in the SARPs, GBAS will support Category I operations and the provision of GBAS positioning service in the terminal area. It has the potential to support precision approach operations down to Categories II and III and some surface movement operations.

3.3.4.2 The GBAS ground facility monitors GPS and/or GLONASS signals at an aerodrome and broadcasts locally relevant integrity messages, pseudorange corrections and approach data via a VHF data broadcast (VDB) to aircraft within the nominal range of 37 km (20 NM) in the approach area (when supporting Category I operations) and within the range depending upon intended operations (when providing positioning service). When an SBAS service is available, GBAS can also provide corrections for the SBAS GEO ranging signal.

3.3.4.3 A single GBAS ground installation may provide guidance for up to 49 precision approaches within its VDB coverage, serving several runways and possibly more than one aerodrome. Allocation methodology may be found in Annex 10, Volume I, Attachment D, Section 7, and in RTCA/DO-245 (European Organisation for Civil Aviation Equipment (EUROCAE) ED-95), *Minimum Aviation System Performance Standards (MASPS) for Local Area Augmentation System (LAAS)*.

3.3.4.4 The GBAS VDB transmits with either horizontal or elliptical polarization (GBAS/H (standard) or GBAS/E (recommendation)). This allows service providers to tailor the broadcast to their user community. The majority of aircraft will be equipped with a horizontally polarized VDB receiving antenna, which can receive both GBAS/H and GBAS/E signals. Other aircraft, notably certain State aircraft, will be equipped with a vertically polarized antenna. These aircraft operations will be limited to using GBAS/E equipment. GBAS service providers should therefore indicate the type of VDB antenna polarization at each of their facilities in the Aeronautical Information Publication (AIP).

3.3.4.5 The broadcast final approach segment (FAS) data block defines the path in space for the final approach segment of each supported approach. It also defines "instrument landing system (ILS) lookalike" deviation guidance. For compatibility with stand-alone aircraft installations, the FAS data block is associated with a GBAS channel number in the range of 20 000 to 39 999.

3.3.4.6 The GBAS positioning service will support terminal area operations. The ground station broadcast indicates the range within which the differential corrections can be used, and its coverage area is dependent upon the ground system configuration and performance.

Levels of GBAS service

3.3.4.7 GBAS ground sub-systems provide two services: the precision approach service and the GBAS positioning service. The precision approach service provides deviation guidance for final approach segments, while the GBAS positioning service provides horizontal position information to support two-dimensional area navigation (2D RNAV) operations in terminal areas.

3.3.4.8 A primary distinguishing feature for GBAS ground sub-system configurations is whether additional ephemeris error position bound parameters are broadcast. This feature is required for the positioning service, but is only recommended for Category I precision approach service. If these parameters are not broadcast, the ground sub-system is responsible for ensuring the integrity of ranging source ephemeris without relying on the aircraft calculating and applying the ephemeris error position bound parameters. Providing the additional parameters allows increased flexibility in the siting and architecture of the ground sub-system.

3.3.4.9 There are therefore three possible configurations of GBAS ground sub-systems conforming to the GNSS SARPs:

a) a configuration that supports Category I precision approach only;

b) a configuration that supports Category I precision approach and also broadcasts the additional ephemeris error position bound parameters; and

c) a configuration that supports both Category I precision approach and the GBAS positioning service, while also broadcasting the ephemeris error position bound parameters referred to in item b).

3.3.4.10 The SARPs for GBAS to support other applications such as Categories II and III precision approaches and airport surface navigation are under development.

3.4 GNSS AVIONICS

3.4.1 ABAS Avionics

3.4.1.1 ABAS requires the use of one of the following techniques to enhance the performance (accuracy, integrity, continuity, and/or availability) of unaugmented GNSS and/or of the aircraft navigation system:

a) RAIM, a technique which uses redundant GNSS information to provide GPS data integrity;

b) aircraft autonomous integrity monitoring (AAIM), which uses information from additional on-board sensors to provide GPS data integrity; and

c) integration of GNSS with other sensors to provide improved aircraft navigation system performance.

GNSS receivers

3.4.1.2 An essential element of ABAS is a Basic GNSS receiver which provides, as a minimum, a RAIM fault detection function (see 3.4.1). Depending on its classification, the Basic GNSS receiver can support one or more of the following phases of flight: en-route, terminal and non-precision approach. To enhance the overall performance of the aircraft navigation system, it may be incorporated as a sensor into an integrated navigation system.

3.4.1.3 The term “Basic GNSS receiver” designates the GNSS avionics that at least meet the requirements for a GPS receiver as outlined in Annex 10, Volume I and the specifications of RTCA/DO-208 or EUROCAE ED-72A, as amended by United States Federal Aviation Administration (FAA) TSO-C129A or Joint

Aviation Authorities (JAA) TGL-3 (or equivalent). These documents specify the minimum performance standards that GNSS receivers should meet in order to comply with en-route, terminal area and non-precision approach procedures developed specifically for GNSS. The main requirement for the Basic GNSS receiver is to have the following capabilities incorporated:

a) integrity monitoring routines (e.g. RAIM fault detection);

b) turn anticipation; and

c) capability for approach procedure retrieved from the read-only electronic navigation database.

RAIM and FDE

3.4.1.4 There are two distinct events that can cause a RAIM alert. The first event occurs when there are not enough satellites with adequate geometry in view. The position estimate may still be accurate, but the integrity function of the receiver, i.e. the ability to detect a failed satellite, is lost. The second event occurs when the receiver detects a satellite fault. This type of alert results in the loss of GNSS navigation capability. If either alert is experienced while on approach, the pilot shall not rely on GNSS for final approach.

AAIM

3.4.1.5 AAIM uses the redundancy of position estimates from multiple sensors, including GNSS, to provide integrity performance that is at least equivalent to RAIM. These airborne augmentations may be certified in accordance with United States FAA TSO-C115A. An example is the use of an inertial navigation system or other navigation sensors as an integrity check on GPS data when RAIM is unavailable but GPS positioning information continues to be valid.

Integration of on-board information

3.4.1.6 Non-GNSS information can be combined with GNSS information to enhance the performance of the integrated navigation system. Examples include:

a) using an inertial navigation system or other navigation sensors as the positioning device to coast through short periods of poor satellite geometry or when the aircraft structure shadows the GNSS antennas while manoeuvring; and

b) using GNSS sensor data as an input to a multi-sensor navigation solution calculated by a flight management system. This augmentation improves the availability of the aircraft's navigation function.

3.4.2 SBAS Avionics

Characteristics of SBAS avionics

3.4.2.1 The term "SBAS receiver" designates the GNSS avionics that at least meet the requirements for a SBAS receiver as outlined in Annex 10, Volume I and the specifications of RTCA/DO-229C, as amended by United States FAA TSO-C145A/TSO-C146A (or equivalent).

3.4.2.2 An SBAS receiver produces differentially corrected three-dimensional positions and, depending on the receiver class (as defined in RTCA/DO-229C), horizontal and vertical deviations when an approach is selected. SBAS avionics provide several additional operational capabilities over the Basic GNSS receiver, including:

a) sensor design that takes advantage of the fact that SA is discontinued;

b) performance that includes FDE functionality;

c) ability to use geostationary satellite ranging;

d) ability to function as an improved sensor, even when the geostationary satellite downlink is not available; and

e) ability to provide vertical guidance.

3.4.2.3 The SBAS (Wide Area Augmentation System or WAAS) avionics certification requirements are contained in the following United States FAA TSOs:

a) TSO-C145A — *Airborne Navigation Sensors Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS).* This TSO applies to a sensor that provides information to an external on-board navigation function; and

b) TSO-C146A — *Stand-alone Airborne Navigation Equipment Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS).* This equipment includes its own navigation function and provides navigation guidance information directly to the cockpit displays.

Performance improvements with SBAS

3.4.2.4 SBAS avionics, at a minimum, will support FDE. This represents an integrity enhancement when compared with the Basic GNSS receiver. Depending on the level of service available, SBAS will support a wide range of operations including:

a) en-route and terminal area RNAV;

b) non-precision approach (NPA); and

c) approach procedures with vertical guidance (APV I and APV II).

Operational use of more than one SBAS

3.4.2.5 SBAS avionics should function within the coverage area of any SBAS. States or regions should coordinate through ICAO to ensure that SBAS provides seamless global coverage and that aircraft do not suffer operational restrictions. If a State does not approve the use of some or all SBAS signals for en-route through terminal operations, pilots would have to deselect GNSS altogether, since receiver standards do not permit deselection of a particular SBAS for these operations.

3.4.2.6 Receiver standards dictate that SBAS APV approaches cannot be flown using data from more than one SBAS, but deselection is possible for these approaches. States can specify, via the airborne database, the SBAS to be used to fly a procedure. States can also approve the use of more than one SBAS for APV (e.g. for back-up purposes). In this case the receiver would switch from one SBAS to another if required.

3.4.3 GBAS Avionics

3.4.3.1 The term “GBAS receiver” designates the GNSS avionics that at least meet the requirements for a GBAS receiver as outlined in Annex 10, Volume I and the specifications of RTCA/DO-253A, as amended by the relevant United States FAA TSO (or equivalent).

Precision approach

3.4.3.2 Like ILS and microwave landing system (MLS), GBAS will provide lateral and vertical guidance relative to the defined final approach course and glide path. The GBAS receiver will employ a channelling scheme that selects the VDB frequency. Approach procedure data are uplinked via the VDB. Each separate procedure requires a different channel assignment.

3.4.3.3 GBAS avionics standards have been developed to mimic the ILS, in terms of aircraft system integration, in order to minimize the impact of installing GBAS on the existing avionics. For example, display scaling and deviation outputs will be equivalent to the ILS. All avionics will provide final approach course and glide path guidance to all configurations of ground stations.

Positioning service

3.4.3.4 The GBAS positioning service will provide position, velocity and time data that can be used as an input to an on-board navigator.

3.4.3.5 When not applying differential corrections from a GBAS ground station, the receiver functions in accordance with RTCA/DO-229C (if SBAS is available) or with United States FAA TSO-C129A, Class B1 or C1.

Multi-mode receiver (MMR)

3.4.3.6 In line with ICAO SARPs and the strategy for the introduction and application of non-visual aids to approach and landing, which permit a mix of systems providing precision approach service, industry has developed the multi-mode receiver. This receiver may support precision approach operations based on ILS, MLS and GNSS (GBAS and possibly SBAS).

3.4.4 SBAS and GBAS integrity

For SBAS and GBAS, integrity monitoring is accomplished by the avionics continually comparing Horizontal/Lateral and Vertical Protection Levels (HPL/LPL and VPL), derived from the augmentation signal and satellite pseudorange measurements, against the alert limit for the current phase of flight. When either the vertical or the horizontal limit is exceeded, an alert is given to the pilot. In addition, the SBAS ground system monitors individual satellites and can send a “DO NOT USE” message if the satellite has an integrity problem or a “NOT MONITORED” message if the satellite is not visible to the ground system. A satellite with a “DO NOT USE” message cannot be used under any circumstances, while a satellite with a “NOT MONITORED” message can be used in an ABAS RAIM integrity check. For a precision approach, the aircraft GBAS receiver only uses satellites for which corrections are available.

3.4.5 Summary of GNSS Avionics Standards

Table 3-2 gives the avionics standards for the various augmentation systems.

Table 3-2. GNSS avionics standards for augmentation

Augmentation systems	*United States FAA Technical Standard Order (TSO)*	*RTCA (EUROCAE) Minimum Operational Performance Standards/Minimum Aviation System Performance Standards (MOPS/MASPS)*
ABAS	TSO-C129A Level 2 (en-route/terminal) TSO-C129A Levels 1 or 3 (non-precision approach)	RTCA/DO-208 EUROCAE ED-72A
SBAS*	TSO-C145A TSO-C146A	RTCA/DO-229C EUROCAE equivalent under development
GBAS	Under development	RTCA/DO-245 RTCA/DO-246B RTCA/DO-253A EUROCAE ED-95

* SBAS avionics meet all ABAS requirements.

Chapter 4

PROVIDING SERVICES WITH GNSS

4.1 GENERAL

4.1.1 Before introducing new navigation services, a State should evaluate navigation systems against four essential criteria:

a) accuracy;

b) integrity (including time-to-alert);

c) continuity of service; and

d) availability of service.

4.1.2 Availability is the cornerstone of these specifications in that it denotes the availability of accuracy with integrity and continuity. The level of service and operational restrictions that could be imposed depend on the level of availability of that service.

4.1.3 In the development of GNSS SARPs, the total system requirements were used as a starting point for deriving specific signal-in-space performance requirements. In the case of GNSS, degraded performance which would simultaneously affect multiple aircraft was considered. This resulted in more stringent requirements for certain signal-in-space performance.

4.1.4 Detailed design system performance requirements are outlined in Annex 10 — *Aeronautical Telecommunications*, Volume I (*Radio Navigation Aids*), Chapter 3, Table 3.7.2.4-1. This chapter describes these criteria and their relationship to the levels of service that can be offered by a State within its airspace.

4.1.5 In addition to the technical aspects, safety and operational issues have to be considered too (see Chapter 5).

4.2 PERFORMANCE CHARACTERISTICS

4.2.1 Accuracy

4.2.1.1 GNSS position accuracy is the difference between the estimated and actual aircraft position.

4.2.1.2 Ground-based systems such as VHF omnidirectional radio range (VOR) and instrument landing system (ILS) have relatively repeatable error characteristics. Therefore their performance can be measured for a short period of time (e.g. during flight inspection) and it is assumed that the system accuracy does not change after the measurement. GNSS errors however can change over a period of hours due to satellite geometry changes, the effects of the ionosphere and augmentation system design.

4.2.1.3 While errors can change quickly for a core satellite constellation, satellite-based augmentation system (SBAS) and ground-based augmentation system (GBAS) errors would vary slowly over time.

4.2.2 Integrity and Time-to-Alert

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

4.2.2.2 The type of operation and the phase of flight dictate the maximum allowable horizontal/lateral and vertical errors and the maximum time to alert the pilot. These are shown in Table 4-1.

4.2.2.3 Following an alert, the crew should either resume navigating using traditional navigation aids (NAVAIDs) or comply with procedures linked to a GNSS-based level of service with less stringent requirements. For example, if alert limits are exceeded for Category I precision approach, before the aircraft crosses the final approach fix, the crew could restrict descent to a decision altitude associated with an APV operation.

4.2.3 Continuity

4.2.3.1 Continuity is the capability of the system to perform its function without unscheduled interruptions during the intended operation. This is expressed as a probability. For example, there should be a high probability that the service remains available throughout a full instrument approach procedure.

4.2.3.2 Continuity requirements vary from a lower value for low traffic density en-route airspace to a higher value for areas with high traffic density and airspace complexity, where a failure could affect a large number of aircraft.

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

Table 4-1. GNSS integrity alert limits by airspace

Operation	*Oceanic en-route*	*Continental en-route*	*Terminal*	*Non-precision approach*	*Approach procedure with vertical guidance (APV)*		*Category I*
					APV-I	*APV-II*	
Horizontal/ Lateral alert limit	7.4 km (4 NM)	7.4 to 3.7 km (4 to 2 NM)	1.85 km (1 NM)	556 m (0.3 NM)	40 m (130 ft)	40 m (130 ft)	40 m (130 ft)
Vertical alert limit	N/A	N/A	N/A	N/A	50 m (164 ft)	20 m (66 ft)	10 to 15 m (33 to 50 ft)
Maximum time-to-alert	5 min	5 min	15 s	10 s	6 s	6 s	6 s

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

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

4.2.4 Availability

4.2.4.1 The availability of a service is the portion of time during which the system is simultaneously delivering the required accuracy, integrity and continuity. The availability of GNSS is complicated by the movement of satellites relative to a coverage area and by the potentially long time it takes to restore a satellite in the event of a failure. The level of availability for a certain airspace at a certain time should be determined through design, analysis and modelling, rather than through measurement. Guidance material pertaining to reliability and availability is contained in Annex 10, Volume I, Attachment F.

4.2.4.2 The availability specifications in Annex 10, Volume I, Chapter 3, Table 3.7.2.4-1, present a range of values valid for all phases of flight. When establishing the availability requirements for GNSS, the desired level of service to be supported should be considered. Availability should be directly proportional to the reliance on a GNSS element used in support of a particular phase of flight.

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

4.2.4.4 An availability prediction tool can determine the periods when GNSS will not support an intended operation. If this tool is used in flight planning, then from an operational perspective, there remains only a continuity risk associated with the failure of necessary system components between the time the prediction is made and the time the operation is conducted.

4.3 OPERATIONAL POTENTIAL OF GNSS AUGMENTATION SYSTEMS

4.3.1 The core satellite constellations alone cannot meet the stringent aviation requirements of accuracy, integrity, continuity and availability discussed in this chapter. Table 4-2 shows the potential of aircraft-based augmentation system (ABAS), SBAS or GBAS to meet the navigation requirements for a particular phase of flight. It remains up to States however to approve a specific augmentation system or a combination of augmentation systems for specific operations within their airspace.

4.3.2 Under risk management principles, some operational limitations may be applied to compensate for availability or continuity performance that is lower than the specified levels.

Table 4-2. Level of service from GNSS augmentation elements

Augmentation element/ operation	*Oceanic en-route*	*Continental en-route*	*Terminal*	*Instrument approach and landing**
Core satellite constellation with ABAS	Suitable for navigation when fault detection and exclusion (FDE) is available. Pre-flight FDE prediction might be required.	Suitable for navigation when receiver autonomous integrity monitoring (RAIM) or another navigation source is usable.	Suitable for navigation when RAIM or another navigation source is usable.	Suitable for non-precision approach (NPA) when RAIM is available and another navigation source is usable at the alternate aerodrome.
Core satellite constellation with SBAS	Suitable for navigation.	Suitable for navigation.	Suitable for navigation.	Suitable for NPA and APV, depending on SBAS performance.
Core satellite constellation with GBAS	N/A	GBAS positioning service output may be used as an input source for approved navigation systems.	GBAS positioning service output may be used as an input source for approved navigation systems.	Suitable for NPA and precision approach (PA) Category I (potentially Category II and Category III).

* Specific aerodrome infrastructure elements and physical characteristics are required to support the visual segment of the instrument approach. These are defined in Annex 14 — *Aerodromes* and *Aerodrome Design Manual* (Doc 9157).

Chapter 5

GNSS IMPLEMENTATION

5.1 GENERAL

The implementation of GNSS operations requires that States consider a number of elements. This chapter describes the following elements:

a) planning and organization;

b) procedure development;

c) air traffic management (airspace and air traffic control (ATC) considerations);

d) aeronautical information services;

e) system safety analysis;

f) certification and operational approvals;

g) anomaly/interference reporting; and

h) transition planning.

5.2 PLANNING AND ORGANIZATION

5.2.1 Implementation Planning

5.2.1.1 Considering the complexity and diversity of the global airspace system, planning can best be achieved if organized regionally and/or in wide areas of common requirements and interest, taking into account traffic density and level(s) of service required.

5.2.1.2 Planning and implementation is the responsibility of a State within the flight information regions (FIRs) where it provides air traffic services, unless States have agreed to jointly plan services in an area covering more than one State. Owing to the global nature of GNSS signals, it is important to coordinate the planning and implementation of GNSS services to the greatest extent possible. While this objective is normally pursued through ICAO and its regional bodies, it should be supplemented by bilateral and multilateral coordination where necessary. The coordination should address detailed aspects not covered within the ICAO framework.

5.2.2 Establishing a GNSS Implementation Team

5.2.2.1 Experience has shown that the decision to implement GNSS within States should be made at the highest level and coordinated regionally within the ICAO planning and implementation regional groups (PIRGs).

5.2.2.2 Successful implementation programmes usually involve cooperative efforts that include all entities and/or individuals who are affected by the possible outcomes and who will have the authority for committing resources to ensure completion of the programme.

5.2.2.3 It is necessary that users, including air carriers, general aviation and the military, be included in the GNSS implementation team so that they can communicate their specific requirements. Users will then be able to assist State authorities in developing an effective and efficient GNSS implementation strategy.

5.2.2.4 A technical committee could be formed and given the responsibility of defining requirements and executing the implementation plan. Team composition may vary from State to State, but the core group responsible for the GNSS programme should include members with operational expertise in aviation, and could include:

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*. Persons responsible for developing instrument approach procedures and obstacle clearance criteria, etc.;

d) *aeronautical information service*. Persons who are involved in Notice to Airmen (NOTAM), procedure design, databases, etc.;

e) *air traffic services*. Persons responsible for developing ATC procedures and controller training;

f) *aerodrome operator*. Persons responsible for developing aerodrome infrastructure to support approach operations;

g) *engineering*. Engineers responsible for the design of systems and equipment;

h) *airline representatives*. Personnel from flight operations and flight crew training;

i) *other user groups*. Representatives of general, business and commercial aviation; unions; other modes of transport that may use GNSS; surveyors; GNSS receiver manufacturing representatives; etc.;

j) *military representatives*; and

k) *other foreign civil aviation or ICAO officials*.

5.2.2.5 An example of a Terms of Reference (TOR) for a GNSS implementation team as well as a GNSS implementation checklist are contained in Appendix C and Attachment A to Appendix C.

5.2.3 Developing a GNSS Plan

5.2.3.1 The plan should identify capabilities that should be in place in order to meet the various requirements at each approval stage and perform the steps needed for implementation. Regional and global planning for communications, navigation, and surveillance/air traffic management (CNS/ATM) systems should also be considered.

5.2.3.2 The GNSS plan should include the development of a business case. The adoption of CNS/ATM systems has major economic and financial implications for both service providers and airspace users. The development of a business case at the State level is essential in determining the effect of GNSS and also in choosing the most cost-effective implementation strategy. Some useful references for developing a GNSS plan, particularly where the implementation of SBAS and/or GBAS is envisaged, include:

- *Economics of Satellite-based Air Navigation Services* (Cir 257),
- *Report on Financial and Related Organizational and Managerial Aspects of Global Navigation Satellite System (GNSS) Provision and Operation* (Doc 9660); and
- *Manual on Air Navigation Services Economics* (Doc 9161).

5.2.4 Training

5.2.4.1 The transition to GNSS represents a significant change for aviation, so it requires new approaches to regulation, provision of services and operation of aircraft. A successful transition to GNSS requires a comprehensive orientation and training programme aimed at all involved parties. This programme should keep pace with the evolution of GNSS.

5.2.4.2 It is most important that the decision makers in aviation organizations have a broad appreciation of the capabilities and potential of GNSS to deliver services. The GNSS transition path and timetable depend on a variety of factors, so the information provided to decision makers should evolve accordingly.

5.2.4.3 Staff in regulatory and service provider organizations require fundamental training to be able to appreciate how GNSS could affect their areas of responsibility. Training should include:

— the basic theory of GNSS operations;

— GNSS capabilities and limitations;

— avionics performance and integration;

— current regulations; and

— concepts of operation.

It should be followed by job-specific training to prepare the staff to plan, manage, operate and maintain the system.

5.2.4.4 For many pilots, GNSS represents the first exposure to avionics that requires programming instead of simply the selection of a frequency. The wide variety of pilot interfaces dictates a new approach to training and certification of pilots. Aircraft operators should develop manuals and other documents aimed at assisting pilots use GNSS properly and safely.

5.2.4.5 ATC training should include the application of GNSS to area navigation (RNAV) in order to ensure maximum use of GNSS-based RNAV.

5.3 PROCEDURES DEVELOPMENT

5.3.1 En-route Procedures

5.3.1.1 Significant benefit has been observed where a GNSS-based RNAV route structure has been developed in areas with sparse or no terrestrial navigation aids (NAVAIDs). As the use of GNSS increases, additional benefits may be derived from reduced route spacing in non-radar areas.

5.3.1.2 Pilot procedures, contained in aircraft operating manuals, should also be developed to address the characteristics of GNSS and to minimize pilot and ATC workload. General pilot procedures for the use of GNSS are included in the *Procedures for Air Navigation Services — Aircraft Operations*, Volume I — *Flight Procedures* (PANS-OPS, Doc 8168).

5.3.2 Terminal Procedures

5.3.2.1 PANS-OPS, Volumes I and II criteria for GNSS terminal, non-precision approach and departure operations have been developed in line with avionics performance obtained with a Basic GNSS receiver. Standard instrument departure/standard instrument arrival (SID/STAR) criteria have also been published.

5.3.2.2 An important requirement is that approach and departure procedures should be stored in and retrieved from the airborne database. For these operations, manual pilot entry of waypoints is not permitted.

5.3.3 Design Criteria for Satellite-based Augmentation System (SBAS) and Ground-based Augmentation System (GBAS) Procedures

SBAS and GBAS obstacle clearance and design criteria are being developed by ICAO to cover all SBAS and GBAS operations.

5.3.4 Ground and Flight Inspection

5.3.4.1 The *Manual on Testing of Radio Navigation Aids* (Doc 8071), Volume II — *Testing of Satellite-based Radio Navigation Systems* provides guidance on the testing of GNSS. Specific ground/flight inspection topics discussed include:

a) ground testing and inspection procedures;

b) flight testing and inspection procedures;

c) identification of operational status;

d) electromagnetic interference; and

e) database validation.

5.3.4.2 The manual stresses that the core satellite constellation signals are the responsibility of the States providing the signals. They are therefore not tested as part of ground or flight testing procedures for GNSS. As opposed to the testing of terrestrial NAVAIDs, GNSS testing focuses on an assessment of procedures for data accuracy and operational suitability rather than for signal-in-space characteristics. Various types of ground and flight testing procedures are identified. Possible electromagnetic interfering sources and mitigation/elimination techniques are also described. In addition, procedures for the validation of the database are also discussed.

5.3.5 Ground Recording/Monitoring

5.3.5.1 Unlike terrestrial NAVAIDs, GNSS encompasses a number of different elements that may be controlled by foreign entities. Recording systems should fulfil the purpose of recording sufficient information to allow incident investigators to ascertain that any GNSS service was operating in compliance with Annex 10 — *Aeronautical Telecommunications* at any point in time and throughout the area in which GNSS-based operations have been permitted. This means not only monitoring the broadcast data but also establishing some measure of estimated user performance.

5.3.5.2 Whilst the monitoring activity has to take place, there is no explicit requirement for the monitoring to be independent of the GNSS service being recorded and this task may be delegated to other States or entities. For example, a GBAS station could record and archive data on its own performance.

5.3.5.3 It will not be possible to establish precisely the levels of performance at the user level everywhere within the area of responsibility of an air traffic services (ATS) provider for the following reasons:

a) user and monitor receivers may track different sets of satellites;

b) variations in the tracked satellite signals that are caused by airframe shape and antenna installations cannot be estimated by a monitor;

c) aircraft dynamics can affect satellite signal reception;

d) terrain masking can affect the user or monitor;

e) error sources such as multipath, receiver noise and the ionosphere may not be correlated between the monitor and the user's receiver; and

f) user receivers may apply their own specific augmentation techniques such as receiver autonomous integrity monitoring/fault detection and exclusion (RAIM/FDE) or baro-aiding.

5.3.5.4 The prime objective of the monitoring system should be to record pertinent GNSS parameters in order to aid in a post-incident investigation of potential GNSS performance, rather than fulfil the safety-related system monitoring requirements that are imposed by the SARPs. However, it is possible to develop a reasonably representative model of potential user level performance across a wide area for a variety of user equipment from a data set recorded in a limited number of physical locations. The recorded data used for post-incident/accident investigations may also be used to support periodic confirmation of GNSS performance in the service area.

5.3.5.5 Further guidance concerning the GNSS parameters to be recorded for post-incident investigations are contained in Annex 10 — *Aeronautical Telecommunications*, Volume I (*Radio Navigation Aids*), Attachment D.

5.3.6 Helicopter Instrument Approach Operations to Heliports

GNSS creates an opportunity to provide instrument approach guidance to heliports independent of traditional NAVAIDs. Appropriate helicopter procedure design and obstacle clearance criteria that account for unique helicopter flight characteristics are being developed by ICAO for non-precision, approach procedure with vertical guidance (APV) and precision approaches and departures. No modification or additional augmentation to the GNSS signal-in-space, beyond that identified in the Annex 10, Volume I, Chapter 3, should be required to support heliport instrument approach operations.

5.4 AIRSPACE CONSIDERATIONS

5.4.1 General

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

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

5.4.1.3 Generic airspace designations used in the *Global Air Navigation Plan for CNS/ATM Systems* (Doc 9750) are:

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

b) oceanic airspace with high density traffic;

c) continental airspace with high density traffic;

d) terminal area with low density traffic; and

e) terminal area with high density traffic.

5.4.2 Oceanic En-route Airspace

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

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

5.4.3 Continental En-route and Terminal Airspace

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

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

5.4.4 Terminal, Approach/Departure Airspace

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

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

5.4.4.3 In planning GNSS approach and departure procedures, the impact on existing traffic flows should be considered. In particular close attention should be paid to holding patterns, missed approach procedures, and the determination of initial, intermediate and final approach fixes.

5.5 ATC CONSIDERATIONS

5.5.1 General

Transitioning from the current fixed, ground-based airway and route infrastructure to a GNSS-based system requires a major shift in current procedures. ATC planners will have to consider revising aircraft separation standards, re-examining airspace management and design, and redesigning route/track definition and structure.

5.5.2 Lateral Separation in Non-radar Airspace

The revision to the current airway structure is generally a two-step approach, rather than an overlay of current airways. The first step is the development and implementation of “advanced navigation routes” based upon a modification of current “off-airway” routes. The second step involves the development of routings that provide increased flexibility for air traffic management tied directly to reduced aircraft separation. However, current use of RNAV tracks normally requires independent surveillance (radar) coverage, with some exception in the oceanic areas and other remote airspace. Without independent surveillance, separation standards on these newly developed routes are usually far greater than on those in airspace where radar is available. Similar considerations apply to the implementation of parallel routes. Currently, in airspace where radar monitoring is not available to control lateral deviations, the size of protected airspace cannot be reduced and the spacing of route centrelines cannot be closer than 25 km (13 NM) for unidirectional and 33 km (18 NM) for bi-directional routes. This does not allow for the realization of the full benefit of RNAV capabilities in a non-radar environment. Service providers have to move towards narrower RNAV routes and reduced spacing between parallel routes in non-radar airspace in order to encourage users to equip with GNSS avionics. Unless lateral separation standards for GNSS/Advanced RNAV routes equal to at least those on today's traditional NAVAID routes are established, benefits from GNSS implementation cannot be fully realized.

5.5.3 Longitudinal Separation

GNSS position reports may be accepted for the application of longitudinal separation. In cases where position reports are to be used between a mix of aircraft using GNSS and distance measuring equipment (DME), the effect of DME slant range should be considered. In order to compensate for the DME slant range, it has been determined that, if the aircraft providing DME-based reports is within 18.5 km (10 NM) from the DME facility and above 3 000 m (10 000 ft), then its position report cannot be used for the application of longitudinal separation from an aircraft providing GNSS-based reports. This distinction should be considered in establishing separation minima.

5.5.4 Minimum En-route Altitude

Terrestrial NAVAID coverage limitations affect minimum obstacle clearance altitude (MOCA). General aviation and rotorcraft aircraft are at times forced to fly at undesirable operating altitudes in order to meet minimum altitudes along airways. In wintertime, icing conditions often require smaller aircraft to operate at even lower altitudes, where ATC has to protect additional lateral airspace in case aircraft lose terrestrial NAVAID reception. As GNSS provides coverage to the ground, MOCA can be based on considerations of terrain, obstructions and communications coverage.

5.6 AERONAUTICAL INFORMATION SERVICES

5.6.1 General

A State Aeronautical Information Publication (AIP) covering the implementation and uses of GNSS should include the following aspects:

a) description of GNSS services;

b) information about the approval of GNSS-based operations;

c) the World Geodetic System — 1984 (WGS-84) coordinate system;

d) airborne navigation database; and

e) status monitoring and NOTAM.

5.6.2 Information about the Approval of GNSS-based Operations

5.6.2.1 Once a State decides to approve the use of GNSS for flight operations, users should be informed of the applicable State regulations, procedures and training requirements.

5.6.2.2 Due to the pace of development of GNSS technology and operations, aircraft operators require information which can assist them in planning for the acquisition of avionics. Continuous update of this information is required.

5.6.2.3 Information updates may be carried out by the issuance of an Aeronautical Information Circular (AIC), State AIP or in some cases, advisory circulars. Experience has shown that aircraft operators require detailed information to ensure compliance with regulations as well as ensure the most effective and efficient use of GNSS.

5.6.3 WGS-84 Coordinate System

5.6.3.1 With GNSS, navigation guidance depends on the accurate position of a series of waypoints. This means that waypoint coordinates, particularly those used for approach and landing, should be based on the same geodetic reference system. In support of GNSS, ICAO has adopted the coordinate system known as the World Geodetic System — 1984 (WGS-84) as the common geodetic reference datum for civil aviation.

5.6.3.2 The use of WGS-84 coordinates for GNSS operations is required by Annex 10. Additional information on the use of WGS-84 may be found in Annex 4 — *Aeronautical Charts*, Annex 11 — *Air Traffic Services*, Annex 14 — *Aerodromes*, and Annex 15 — *Aeronautical Information Services*, as well as the *World Geodetic System — 1984 (WGS-84) Manual* (Doc 9674). The manual contains guidance material regarding, among other related topics, the transformation of existing coordinates and reference data to WGS-84. It should be noted that this transformation is a mathematical process, which does not take into consideration the quality and accuracy of the original coordinates.

5.6.3.3 Many States have elected to resurvey to WGS-84 standards due to the lack of integrity of their existing surveys, and the resurvey is considered to be a preferred option in the transition to WGS-84.

5.6.4 Airborne Navigation Database

5.6.4.1 The safety of GNSS navigation and approach guidance depends on the integrity of the data in the airborne navigation database used by the avionics. Aeronautical information originates with States that are required to ensure that the quality (accuracy, integrity and resolution) of position data is retained from the time of survey to the submission of information to database suppliers who, with avionics manufacturers, create the airborne navigation database. This process should also ensure consistency with the data used in ATS flight data and radar systems.

5.6.4.2 All waypoint coordinates and essential leg type designators, particularly those used in instrument approach and departure procedures, should be verified and validated by the appropriate State authority (see 5.8.3). For safety reasons, manual entry or updating of instrument procedure information in the airborne navigation database is not permitted. GNSS avionics cannot operate in the approach mode unless approach waypoints are retrieved from the database. This does not however prevent the storage of “user defined data” within the equipment for en-route navigation or other purposes, as long as effective verification procedures are employed.

5.6.4.3 Maps and charts used by pilots are required to be completely consistent with airborne navigation databases. In addition, avionics are required to provide guidance along the flight path prescribed by the procedure designer. This imposes a new requirement on State authorities to understand how avionics data are used and to have an appreciation of data coding standards and their proper use.

5.6.4.4 Two harmonized EUROCAE (European Organisation for Civil Aviation Equipment)/RTCA documents are available to assist in the production and handling of aeronautical data: *Standards for*

Processing Aeronautical Data (RTCA/DO-200A/EUROCAE ED-76) and *Standards for Aeronautical Information* (RTCA/DO-201A/EUROCAE ED-77). These documents provide a framework for developing valid waypoint coordinates and for ensuring that only correct coordinates reside in airborne navigation databases.

5.6.5 Status monitoring and NOTAM

General

5.6.5.1 State air navigation services (ANS) providers have the responsibility to monitor and to report the status of navigation services. To support this requirement, navigation service providers should provide status information to ATS. If the status of a navigation service changes, pilots should be advised via direct communications and/or via a NOTAM system (see Annex 15 — *Aeronautical Information Services* and *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, Doc 4444)).

5.6.5.2 The requirements for monitoring terrestrial NAVAIDs are found in Annex 10, Volume I. With these NAVAIDs, service is directly related to equipment status. For example, if an instrument landing system (ILS) fails, the associated precision approach will not be available. Accordingly, a NOTAM stating that the ILS has failed indicates to the pilot what service will be unavailable.

5.6.5.3 In the case of GNSS, when a system element (e.g. a Global Positioning System (GPS) satellite or an SBAS reference station) fails, neither ATS nor the pilot can relate the failure to a loss of service. GNSS service providers should therefore determine the effects of such failures and provide information on service outages. This information should be presented to ATS operational staff in such a way that it supports the requirement to advise pilots of service interruptions. The information should also be used to generate a NOTAM.

5.6.5.4 GNSS avionics play a much larger role than traditional avionics in meeting accuracy, integrity, continuity and availability standards. While GNSS avionics meet specific standards, avionics manufacturers can use different techniques to meet these same standards. In addition, GNSS avionics can be integrated with inertial and other systems to enhance performance. This introduces a variable that does not exist with terrestrial NAVAIDs, and which complicates status monitoring and the provision of a NOTAM service for GNSS.

5.6.5.5 Status monitoring and NOTAM considerations related to aircraft-based augmentation system (ABAS), SBAS and GBAS are described in the following paragraphs, along with a description of status reporting alternatives.

ABAS

5.6.5.6 In the case of ABAS, service availability depends on the number of satellites in view and their geometry, the receiver mask angle, and integration with other avionics, notably inertial systems.

5.6.5.7 A decision on whether or not to develop a status monitoring and NOTAM system for ABAS operations should be made by taking into account the nature of ABAS approvals. In many cases ABAS operations are predicated on having a full complement of traditional NAVAIDs available for back-up when ABAS cannot support service.

5.6.5.8 Some States have implemented RAIM prediction services that can be used for generating NOTAMs. RAIM prediction requires knowledge of the current status of and planned outages for the core satellite constellations. This information is available from the operators of these satellite constellations.

5.6.5.9 Some States found that the computer models used to generate RAIM outage advisories produced a very high volume of NOTAM data, exceeding existing processing capacity. Various alternatives need to be considered, including the possible need to update the NOTAM system or provide alternative reporting systems. An option is to have aircraft operators perform predictions using avionics-specific prediction programs on a local computer.

SBAS

5.6.5.10 In the case of an SBAS, the coverage area is defined by the footprints of the geostationary earth orbit (GEO) satellite signals. These footprints virtually cover a hemisphere (except high latitudes), but the service area is restricted to a specified smaller region (European Civil Aviation Conference (ECAC) States for European Geostationary Navigation Overlay Service (EGNOS), India for GPS and GEO Augmented Navigation (GAGAN), Japanese FIR for MTSAT Satellite-based Augmentation System (MSAS) and the United States for Wide Area Augmentation System (WAAS)). The entity providing the SBAS signals-in-space is the SBAS operator.

5.6.5.11 Before approving operations based on SBAS signals, a State is expected to provide a status monitoring and NOTAM system. To determine the effect of a system element failure on service, a software (service volume) model should be put in place. The complexity of such a model and the need to ensure that the model accurately reflects the service being provided suggest that the State should arrange to use the same model used by the SBAS operator.

5.6.5.12 Using the current and forecast status of the basic system elements and the locations where the State has approved operations, the software model can identify airspace and airports, where service outages are expected, and it can be used to create NOTAMs. The system element status data (current and forecast) required for the model could be obtained through a bilateral arrangement with the SBAS operator or through a real time broadcast of the data, if the SBAS operator chooses to provide data in this way.

5.6.5.13 When an SBAS service area established by a State lies within the coverage areas of more than one SBAS, the State can use the same models for each SBAS provider. There is no need to develop a new, integrated model, since for approach procedures with vertical guidance, the aircraft can use only one SBAS at a time, and the availability of en-route through non-precision approach is sufficient to obviate the requirement to model the combination of SBAS data.

GBAS

5.6.5.14 In the case of GBAS, service is usually provided to one aerodrome. Precision approach and surface movement services that can be supported by GBAS depend on the number of satellites in the view of reference and aircraft receivers, the satellite geometry and the status of GBAS system elements. Thus status monitoring and NOTAM services also require computer-modelling techniques although the processes would be simpler than those for SBAS.

5.6.5.15 It may be possible for a GBAS element failure to result in downgraded service rather than a complete service interruption.

5.7 CERTIFICATION AND OPERATIONAL APPROVALS

5.7.1 System Safety

5.7.1.1 Regulators, service providers and aircraft operators should all ascertain that a GNSS operation is safe before it is introduced. This requires a systematic use of engineering and management tools to identify, analyse and mitigate hazards during all phases of the system's life cycle. The process is defined as a given task to be performed by a combination of people, procedures, technologies (hardware and software) and data within a given environment. This approach can be referred to as Safety Risk Management.

5.7.1.2 Annex 11 — *Air Traffic Services* calls for a safety assessment before making significant safety-related changes to the ATC system. Some States have developed a GNSS safety plan, which is integrated with an overall project plan for the system. The safety plan details the system safety activities to be carried out during the life of the system. For example, the plan may include Hazard List, Hazard Analysis, Operational Safety Reviews, and Fault Tree Analysis. By documenting the results of those activities, the level of safety achieved can be demonstrated at any point in time.

5.7.1.3 This Safety Risk Management approach has two advantages. First, it considers the complete system and all of its elements. Second, "building" safety into a system from the beginning and throughout the system's life usually results in the most efficient use of resources.

5.7.2 Operational Approvals

5.7.2.1 It is a State's responsibility to authorize GNSS operations in its airspace. This is achieved by issuing a document approving the use of GNSS for oceanic, domestic en-route, terminal, approach and departure operations for aircraft with certified equipment and an approved flight manual. The approval should specify any limitations on proposed operations.

5.7.2.2 The use of GNSS may be authorized for visual flight rules (VFR) or instrument flight rules (IFR). This authorization may apply to the use of GNSS alone or to use with other aircraft systems. It may also be used to define landing minima.

5.7.2.3 In some States, there is a requirement to endorse a pilot's instrument rating for the types of radio navigation aids that are qualified for use, including en-route navigation, position fixing or instrument approach. Individual types of radio navigation aids may be endorsed (e.g. VHF omnidirectional radio range (VOR), automatic direction finder (ADF), and ILS). In some States however there are no requirements for individual navigation aids endorsement. Bearing in mind the fundamental differences between traditional NAVAIDs and GNSS, and considering the limitations of the application of GNSS, there is a distinct need for GNSS-specific training.

5.7.2.4 When commercial operators receive specific authorization to use GNSS, the conditions include provisions for specific training, pilot certification requirements and the handling of airborne databases.

5.7.2.5 States may require aircraft flying through their airspace to be equipped with certain minimum levels of GNSS avionics.

5.7.3 Avionics

IFR avionics

5.7.3.1 As with any other item of avionics equipment, a GNSS receiver is required to be of an approved type and to be installed in accordance with specific criteria. Any installation should be validated by a series of tests, measurements and inspections. Certification and check procedures are based on the performance standards contained in RTCA and EUROCAE documentation and in State documents.

5.7.3.2 Several States have developed airworthiness requirements governing the installation of the approved GNSS equipment. GNSS avionics installations can be approved as part of the original aircraft type design (type certificate) or as a modification to the original aircraft type design (supplemental type certificate). The Technical Standard Order (TSO) process addresses only the qualification of equipment to a minimum standard. Certified equipment should be evaluated for compatibility with every type of aircraft in which it is to be installed.

5.7.3.3 Supplements to aircraft flight manuals are part of the certification process. Most aircraft manufacturers have made additions to their aircraft flight manuals to include GNSS. The appropriate State authority should approve these manuals, which contain operating procedures and limitations necessary to ensure the proper operation of the avionics.

5.7.3.4 Since many States apply United States Federal Aviation Administration (FAA) or Joint Aviation Authorities (JAA) standards, harmonization of these standards is essential.

Use of non-IFR GNSS receivers for VFR navigation

5.7.3.5 There are a number of GPS receivers available that do not meet the standards for IFR operations. Many pilots use such receivers to supplement VFR navigation, particularly in areas where there are few landmarks and where traditional NAVAIDs are not available or are unreliable.

5.7.3.6 Non-IFR receivers provide accurate guidance most of the time, but they do not necessarily provide a warning if a satellite is broadcasting erroneous signals. As a result, the receivers may provide hazardous and misleading information. Other problems result from poor antenna location with portable receivers, the inability to update receiver databases in some cases, and the use of map data other than WGS-84.

5.7.3.7 Non-IFR GPS receivers may be used to supplement VFR navigation. Standard VFR navigation procedures, pilotage or dead reckoning, should continue to be applied to ensure safety. Any difference between the GNSS position and the navigation data available from other sources should 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 be followed. There have been accidents related to excessive reliance on GPS, where pilots have continued in deteriorating weather conditions without visual references. Some States have published safety material on this subject.

5.7.3.8 Some States have adopted the use of VFR reporting points. GNSS assists in navigating to these VFR reporting points in visual meteorological conditions.

5.7.4 GNSS for approach operations

Non-precision approach (NPA) and approach procedure with vertical guidance (APV)

5.7.4.1 The *Procedures for Air Navigation Services — Aircraft Operations* (PANS-OPS, Doc 8168), contain information and procedure design criteria for GNSS terminal and NPA operations. It is well recognized that an APV operation provides for a vertically stabilized approach, thereby helping to reduce the probability of controlled flight into terrain (CFIT). Annex 10, Volume I, Chapter 3, Table 3.7.2.4-1, defines two different levels of APV operations, and GNSS avionics standards support APV-I and APV-II operations. Volumes I and II of PANS-OPS (Doc 8168) are being updated to include information and procedure design criteria for these operations.

5.7.4.2 Before publishing APV approach procedures for an aerodrome, States should ensure that the aerodrome meets the appropriate requirements relating to APV operations, including:

a) width and length of runway strip;

b) obstacles within the approach obstacle limitation surface;

c) availability of appropriate meteorological information;

d) adequacy of runway edge lighting and marking; and

e) taxiway configuration.

5.7.4.3 To support the introduction of APV, some modifications of the existing aerodrome Standards and requirements can be expected in the medium term in order to accommodate the advantages of this type of approach without incurring the expense necessary to meet precision approach requirements.

Precision approach

5.7.4.4 States that publish precision approach procedures for aerodromes should ensure that the procedures comply with the PANS-OPS (Doc 8168) or other approved design criteria. As with traditional NAVAIDs, Category I, II and III precision approach operations require special pilot and operator certification.

5.7.5 Anomaly/Interference Reporting

5.7.5.1 GNSS signals should be protected, and measures should be in place to report GNSS anomalies in order to assist in determining the cause and to introduce, if necessary, appropriate mitigation measures. The term “anomaly” is used to report GNSS service outages. The term “interference” should not be used for either intentional or unintentional interference, until the actual cause is determined. For example, some anomalies can be attributed to aircraft installation and/or avionics malfunctions or to reduced visibility of satellites due to airframe or terrain masking. The following guidance is intended to assist in anomaly/interference reporting by pilots and controllers.

5.7.5.2 Pilot action(s) may include:

a) reporting the situation to ATC as soon as practicable and requesting special handling as required;

b) forwarding the aircraft call sign, location, altitude and time of occurrence to ATC; and

c) forwarding information to the designated authority as soon as practicable, including a description of the event (e.g. how the avionics failed/reacted during the anomaly).

5.7.5.3 Controller action(s) may include:

a) recording minimum information, including aircraft call sign, location, altitude and time of occurrence;

b) attempting to identify other GNSS-equipped aircraft that are experiencing the anomaly;

c) broadcasting the anomaly report to other aircraft, as necessary;

d) forwarding information to the designated authority; and

e) requesting the pilot to file a complete report in accordance with State procedures.

5.7.5.4 Pilots should be advised via direct communications and/or via a NOTAM if interference to GNSS is predicted or detected.

5.7.5.5 It is highly desirable to establish a national focal point unit to collect anomaly-related information and to determine the course of action required to resolve reported anomalies. This unit should analyse and distribute information to the appropriate agencies within the State and/or other international agencies. Some actions that the focal point unit may take are:

a) evaluate the anomaly reports;

b) advise ATS and provide situational updates;

c) notify agency responsible for frequency management;

d) ensure the issuance of appropriate advisories and NOTAMs as necessary;

e) coordinate with State/Agency that provides core satellite constellation(s) or other element(s) of GNSS;

f) attempt to locate/determine the source of the anomaly;

g) implement national policy to mitigate the anomaly; and

h) track and report all activities relating to the anomaly until conclusion of issue.

5.7.5.6 National and international coordination of actions to prevent and mitigate GNSS interference is essential. To facilitate the reporting process, the use of a standard form allows for the tracking of reports of anomalies and is helpful to the coordination efforts. States may require more detailed information for an analysis of GNSS anomalies. Data collection and the subsequent evaluation of these data are fundamental in providing decision makers with the requisite support for implementation actions. Any form adopted by a State should be included in the State's AIP and enacted by AIC.

5.8 GNSS VULNERABILITY

5.8.1 General

5.8.1.1 The most notable GNSS vulnerability lies in the potential for interference, which exists in all radionavigation bands. As with any navigation system, the users of GNSS navigation signals should be protected from harmful interference resulting in the degradation of navigation performance.

5.8.1.2 The GNSS SARPs require a specified level of performance in the presence of levels of interference as defined by the receiver interference mask. These interference levels are generally consistent with the International Telecommunication Union (ITU) regulations. Interference at levels above the mask may cause degradation or even loss of service, but such interference is not allowed to result in hazardously misleading information (HMI).

5.8.1.3 GPS and Global Navigation Satellite System (GLONASS) have filings with the ITU to operate, using spectrum allocated to the Radionavigation Satellite Service (RNSS) in the 1 559 – 1 610 MHz and 1 164 – 1 215 MHz bands. The RNSS allocation in these bands is shared with the Aeronautical Radionavigation Service (ARNS). SBAS also has a filing under the RNSS allocation in the former band. GBAS is operated in the 108 – 117.975 MHz band, shared with ILS and VOR (ARNS).

5.8.2 Sources of Vulnerability

5.8.2.1 There are a number of sources of potential interference to GNSS from both in-band and out-of-band sources. Of particular concern is the use of the 1 559 – 1 610 MHz band by point-to-point microwave links that are allowed by a number of States. The use of these links, as stated in footnotes 5.362B and 5.362C in the Radio Regulations of the ITU, is due to be phased out starting in 2005 and completed by no later than 2015. In addition, no new links should be permitted.

5.8.2.2 *Unintentional interference*. The likelihood and operational effect of interference vary with the environment. Unintentional interference is not considered a significant threat provided that States exercise proper control and protection over the electromagnetic spectrum for both existing and new frequency allocations. Furthermore, the introduction of GNSS signals on new frequencies will ensure that unintentional interference does not cause the complete loss of GNSS service (outage) although enhanced services depending upon the availability of both frequencies might be degraded by such interference.

5.8.2.3 *Intentional interference*. The risk of intentional interference depends upon specific issues that must be addressed by States. For States that determine that the risk is unacceptable in specific areas, operational safety and efficiency can be maintained by adopting an effective mitigation strategy through a combination of on-board mitigation techniques (e.g. use of inertial navigation system (INS)), procedural methods and terrestrial navigation aids.

5.8.2.4 *Ionosphere*. Scintillation can cause loss of GNSS satellite signals in the equatorial and auroral regions, but is unlikely to cause complete loss of GNSS service and will be mitigated with the addition of new GNSS signals and satellites. Ionospheric changes may limit the SBAS and GBAS services that can be provided in the equatorial region using a single GNSS frequency. These changes must be considered when designing operations based on the augmentation systems.

5.8.2.5 *Other vulnerabilities*. System failure, operational errors and discontinuation of service could be significantly mitigated by independently managed constellations, funding and robust system design. Spoofing, the intentional corruption of signals to cause an aircraft to deviate and follow a false flight path, is mitigated through normal procedures and independent ground and collision avoidance systems.

5.8.2.6 States should assess the GNSS vulnerability in their airspace and select appropriate mitigations depending on the airspace in question and the operations that must be supported. These mitigations can ensure safe operations and enable States to avoid the provision of new terrestrial navigation aids, reduce existing terrestrial navigation aids, and discontinue them in certain areas. Fault detection features such as RAIM are built into GNSS receivers, which eliminate the risk of position errors posing threat to navigation availability. To date, no vulnerabilities have been identified that compromise the ultimate goal of a transition to GNSS as a global system for all phases of flight. The assessment of GNSS vulnerability aspects and mitigation alternatives should continue.

5.8.3 Evaluating GNSS vulnerabilities

5.8.3.1 There are three principal aspects to be considered in the evaluation of GNSS vulnerabilities.

a) Interference and atmospheric (ionosphere) effects are of primary concern. Operational experience is the best way to assess the likelihood of unintentional interference. Each State must consider the motivation to intentionally interfere with GNSS based on the potential safety and economic impacts on aviation and non-aviation applications. Atmospheric effects are unlikely to cause a total loss (outage) of GNSS but may impact some services (e.g. approaches with vertical guidance in equatorial regions). The likelihood of specific effects can be categorized as negligible, unlikely or probable.

b) All operations and services dependent on GNSS should be identified and considered together, since GNSS interference can potentially disrupt all GNSS receivers at the same time over a certain area. GNSS is used for navigation services as well as other services such as precision timing with communications and radar systems, and may also be used for ADS services. In these cases, GNSS represents a potential common point of failure.

c) The impact of a GNSS outage on an operation or service should be assessed by considering the types of operations, traffic density, availability of independent surveillance and communications and other factors. The impact can be categorized as none, moderate or severe.

5.8.3.2 By considering these aspects as a function of airspace characteristics, air navigation service providers can determine whether mitigation is required and, if so, at what level. Appendix D provides examples of assessments. Mitigation is most likely to be required for vulnerabilities with major impacts that have a moderate to high likelihood of occurrence.

5.8.4 Reducing the Likelihood of Unintentional Interference

5.8.4.1 On-aircraft interference can be prevented by proper installation of GNSS equipment, its integration with other aircraft systems (e.g. shielding, antenna separation and out-of-band filtering) and restrictions on the use of portable electronic devices on board aircraft.

5.8.4.2 *Spectrum management*. Effective spectrum management is the primary means of mitigating unintentional interference from man-made transmitters. Operational experience has indicated that the threat of unintentional interference can be virtually eliminated by applying effective spectrum management. There are three aspects of effective spectrum management, namely:

a) creation of regulations/laws that control the use of spectrum;

b) enforcement of those regulations/laws; and

c) vigilance in evaluating new radio frequency (RF) sources (new systems) to ensure that they do not interfere with GNSS.

5.8.5 Mitigating the Effects of GNSS Outages

5.8.5.1 There are three principal methods currently available for mitigating the effects of GNSS outages on aircraft operations when GNSS supports navigation services. They are:

a) by taking advantage of existing on-board equipment such as inertial navigation systems and implementing advanced GNSS capabilities and GNSS receiver technologies (e.g. application of multiple constellations and frequencies, adaptive antennas, etc.);

b) by employing procedural (pilot or air traffic control) methods, taking due consideration of the workload and technical implications of the application of such mitigations in the relevant airspace. Particular issues that need to be considered include:

— the impact that the loss of navigation will have on other functions such as surveillance in an ADS environment; and

— the potential for providing the necessary increase in aircraft route spacing and/or separation in the airspace under consideration; and

c) by taking advantage of terrestrial radio navigation aids used as a back-up to GNSS or integrated with GNSS. In identifying an appropriate terrestrial infrastructure, due account should be taken of the following factors.

— Increased reliance is being placed upon the use of RNAV operations. DME provides the most appropriate terrestrial navigation infrastructure for such operations, as it provides an input to multi-sensor navigation systems which allow continued RNAV operation in both en-route and terminal airspace. This same capability can be used for RNAV approach operations if the DME coverage is sufficient.

— If it is determined that an alternate precision approach service is needed, instrument landing system (ILS) or microwave landing system (MLS) may be used. This would likely entail retaining a minimum number of such systems at an airport or within an area under consideration.

5.8.5.2 States wishing to approve GNSS-based operations should ensure that existing frequency assignments in the 1 559 – 1 610 MHz band and the 1 164 – 1 215 MHz band that have the potential to interfere with those GNSS operations be moved to other frequency assignments or bands, where feasible.

5.8.5.3 According to compatibility studies conducted to assess the effects of RF interference on the additional GNSS signals to be introduced in the frequency bands that are used by ground-based aeronautical navigation systems, it has been concluded that based on the present distance measuring equipment/UHF Tactical Air Navigation Aid (DME/TACAN) infrastructure and assuming worst case power levels and interrogation rates, the impact of RF interference on the processing of GNSS signals is tolerable. Nevertheless, it is recommended that States minimize or avoid — if practicable — new assignments of DME and TACAN facilities at or near GNSS frequencies to keep the impact on GNSS as low as possible. The compatibility studies also concluded that an increase in the number of DME/TACAN facilities in areas with a high density of such facilities operating on the same or near the frequency band used by GNSS could result in interference beyond the levels tolerable by GNSS receivers that are capable of using new GNSS elements and signals. Therefore it is recommended that States with such high density areas should assess whether such an increase of the DME/TACAN infrastructure is tolerable, before new DME/TACAN facilities are planned in these areas.

5.8.5.4 For GBAS, frequency coordination is necessary to ensure that other transmitters in the 108 – 117.975 MHz or adjacent bands (e.g. ILS, VOR, VHF Digital Link 4 (VDL-4) and FM stations) do not cause harmful interference.

5.8.5.5 Timing vulnerabilities need to be addressed through system design. The current practice of time transfer makes use of GNSS but it also uses alternative methods as back-ups. Suitable system design can result in the ability to meet required timing accuracies for many days and sometimes indefinitely in the absence of GNSS.

5.8.5.6 By adopting an effective strategy using one or more methods identified in this section, a service provider will not only ensure safe aircraft operations in case of GNSS outages but will also discourage the attempts of intentional interference by reducing the potential effects of these attempts.

5.8.6 Summary

In their planning and introduction of GNSS services, States should:

a) assess the sources of vulnerability in their airspace and utilize, as necessary, the mitigation methods as outlined in 5.8.5;

b) provide effective spectrum management and protection of GNSS frequencies to reduce the possibility of unintentional interference;

c) take full advantage of on-board mitigation techniques, particularly inertial navigation systems;

d) where it is determined that terrestrial navigation aids need to be retained as part of an evolutionary transition to GNSS, give priority to the retention of DME in support of INS/DME or DME/DME RNAV for en-route and terminal operations, and to the retention of ILS or MLS in support of precision approach operations at selected runways; and

e) take full advantage of the future contribution of new GNSS signals and constellations in the reduction of GNSS vulnerabilities.

5.9 TRANSITION PLANNING

5.9.1 General

5.9.1.1 The ICAO vision for GNSS implementation strategy is intended to:

a) retain the goal of evolutionary transition to a GNSS which would eliminate the requirement for existing NAVAIDs;

b) preserve the need to retain some or all existing NAVAIDs during the transition; and

c) emphasize that the need to retain traditional NAVAIDs during the transition does not imply a requirement to add ground NAVAIDs when introducing GNSS-based operations in the areas with less developed existing navigation infrastructure.

5.9.1.2 State decisions on GNSS implementation should take into account the following major considerations:

a) that GNSS meets all requirements, in particular a requisite level of availability of service for given operations or phases of flight, considering system design and interference issues; and

b) that users are equipped or are committed to equip with GNSS avionics before the decommissioning deadlines for existing terrestrial NAVAIDs.

5.9.1.3 There may always be a need to retain some terrestrial NAVAIDs, for example, if the risk of interference is high and ground-based navigation back-up is a preferred mitigation. In any case, GNSS will bring operational benefits to users, and it will quite likely be possible to decommission terrestrial NAVAIDs that support specific operations in specific areas.

5.9.1.4 To be most effective, GNSS transition planning should be done on a national, regional and global basis in concert with complementary improvements in communications, surveillance and air traffic management. It should also be done in close coordination with users to ensure that they are equipped to take advantage of new services as these services become available.

5.9.2 Transition Stages

5.9.2.1 The core satellite constellations can support improved en-route, terminal and non-precision approach operations. However terrestrial NAVAIDs should be retained if ABAS cannot deliver the requisite availability of service. In some instances, States may be able to decommission or avoid having to replace infrequently used or redundant NAVAIDs.

5.9.2.2 With the advent of SBAS, GNSS will support high availability RNAV operations and approaches with vertical guidance to most runways. This could allow the decommissioning of many traditional NAVAIDs, although interference will remain the key issue when considering mitigation alternatives.

5.9.2.3 GBAS will support high availability precision approach and could allow decommissioning of some ILS or MLS, particularly at airfields equipped with multiple ILS installations.

5.9.2.4 The next generation core constellations, which should be available in the period from 2010 to 2015, will have features that will make GNSS more capable and more robust. Multiple frequencies will make it likely that some level of service will continue in the event of unintentional interference. The use of multiple frequencies will also allow receivers to eliminate ionospheric errors, thus increasing the availability of ABAS for en-route through non-precision approach operations and making it possible for SBAS to deliver high levels of availability of APV and Category I precision approach service.

5.9.2.5 With the increased number of satellites, their improved capabilities, and with more satellite signals being broadcast, availability will reach higher levels. Moreover, with the use of two or more independent constellations, a key institutional concern over the reliance on a single system, will be resolved. The next generation satellites will still require an independent integrity augmentation, but the complementary augmentation systems should be less costly and less complex.

5.9.2.6 GNSS does have the potential to replace all terrestrial NAVAIDs, but a considerable amount of work is necessary to resolve related issues and fulfil this promise. Thus a decision will not be possible in the near term. In the meantime, this issue should be addressed on a case-by-case basis.

5.9.3 Avionics Equipage

5.9.3.1 At all stages of a GNSS transition, States should work closely with users and develop approach, terminal and en-route procedures that will deliver the maximum safety and efficiency benefits. For example, GNSS approaches should be designed in such a way that they will result in lower minima, and they should be introduced with user airport networks in mind to encourage users to equip with GNSS avionics.

5.9.3.2 Equipping a fleet of aircraft with GNSS avionics requires a considerable amount of time and resources. Many operators have equipped with GNSS avionics while performing major maintenance, and even then have found that adding GNSS avionics results in extra down time for the aircraft. In all cases, operators will decide to equip only if the payback period is relatively short. Because of the considerable investment involved, operators avoid multiple modernizations, and as upgrades are required (e.g. from GPS to SBAS), they strongly prefer simple card or software upgrades.

5.9.3.3 The avionics equipage is complicated by the stage-by-stage approach to a transition, by the advent of new features (e.g. dual frequency satellites), and by the addition of new GNSS elements (i.e. augmentation systems and new constellations). States need therefore to work closely with operators to develop a coordinated transition strategy and plan that is practical and achievable from the service provider's and aircraft operator's perspectives.

5.9.3.4 In some States, and at some point in the future, it may be necessary to mandate equipage to ensure the efficient use of airspace. As have already been noted, this decision requires close coordination with users.

Chapter 6

EVOLUTION OF THE GNSS

6.1 GENERAL

6.1.1 GNSS will evolve, possibly by adding functions to existing elements, improving existing elements, creating new elements and signals (see Figure 6-1), and decommissioning other elements. The GNSS SARPs will have to evolve to take into account these changes.

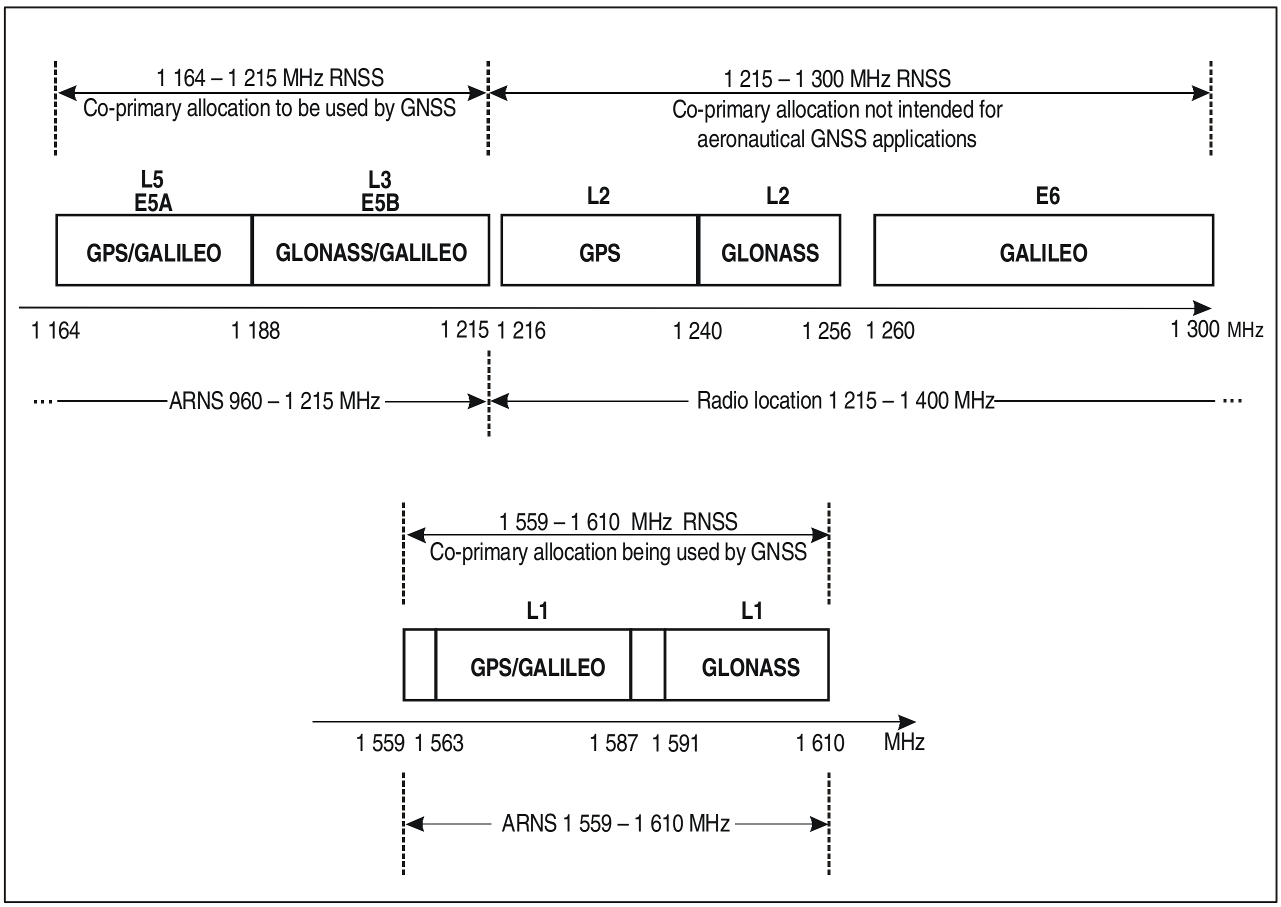

Figure 6-1. GNSS spectrum

6.1.2 The general position of ICAO, as defined in 1990 at the Tenth Air Navigation Conference, envisages that in the long run GNSS will be able to guide all phases of flight and aircraft operations. This evolution will require a number of years since each development needs to be designed, tested and validated to maintain or to increase civil aviation safety. The current performance requirements in Annex 10 — *Aeronautical Telecommunications*, Volume I (*Radio Navigation Aids*), Chapter 3, 3.7.2.4, do not include all types of operations, and should therefore be expanded to include Category II and Category III precision approach and airport surface movement guidance.

6.2 GNSS REQUIREMENTS TO SUPPORT OTHER APPLICATIONS

6.2.1 GNSS can be used in conjunction with applications such as automatic dependent surveillance (ADS) through integration with digital communication technology. Such new applications may impose additional requirements on GNSS.

6.2.2 The main changes to performance requirements are expected in the areas of surface navigation to support "gate-to-gate" operations and "free flight" or "free route" operational concepts.

6.2.3 GNSS also provides a source of precise time which may be used for data time stamping, surveillance and communication systems synchronization and system management. The external systems that rely on this information may also impose additional requirements on GNSS.

6.2.4 Since a future GNSS would be a multi-modal system (i.e. used by modes of transportation other than aviation), cooperation and coordination between the various user communities may be necessary.

6.3 SECURITY ASPECTS

6.3.1 The security of terrestrial navigation aids (NAVAIDs) that support aeronautical navigation is the responsibility of local authorities. GNSS coverage extends over the territory of many States, so security should be addressed at a regional or global level. It is important that the GNSS elements used by civil aviation are protected against terrorism or hostile acts.

6.3.2 It is also necessary to anticipate the possibility of GNSS service interruption or degradation during a national emergency situation (Article 89 of the *Convention on International Civil Aviation* refers). GNSS security aspects are being addressed at national and international levels and may result in new procedures to protect the safety and efficiency of aeronautical navigation.

6.4 GNSS EVOLUTION

6.4.1 General

Annex 10, Volume I, provides the SARPs for Global Positioning System (GPS), Global Navigation Satellite System (GLONASS), aircraft-based augmentation system (ABAS), satellite-based augmentation system (SBAS) and ground-based augmentation system (GBAS). These systems and the related SARPs will evolve to supply improved service through further development of existing elements as well as the addition of new elements. In the process of this evolution, care should be taken to ensure that backward compatibility is preserved and that aircraft operators will not be subject to excessive costs and economic losses.

6.4.2 Evolution of Existing GNSS Elements

GPS modernization

6.4.2.1 GPS is evolving to meet the needs of civilian users. The objective is to make the system more robust, increase system availability and reduce the complexity of GPS augmentations. Some planned enhancements include: the addition of a new signal on L2 for civilian use; the addition of a third civilian signal (L5); protection and availability of one of the two new signals for safety-of-life services (aeronautical radionavigation service allocation) by 2005; and enhanced signal structure and additional signal power. The United States Government discontinued the use of selective availability (SA) effective 2 May 2000.

6.4.2.2 Although L2 is currently not part of the GPS standard positioning service (SPS), many civilian users employ codeless or semi-codeless dual frequency receivers to support their requirements. Consequently, the United States Government has determined that the availability of two additional coarse acquisition (C/A) coded signals is essential for many critical GPS uses. The signals are planned to enhance the ability of GPS to support the needs of civilian users. A second, non-safety-of-life coded signal is added at the GPS L2 frequency (1 227.60 MHz) on satellites scheduled for launch beginning in 2005. A third civilian signal (L5) that can meet the needs of critical safety-of-life applications such as civil aviation will be added at the 1 176.45 MHz frequency. The third signal will be implemented on satellites scheduled for launch beginning in 2006. The L5 signal is a more robust signal with a power level of –154 dB. Until the second coded civilian GPS signal is operational, the United States will not intentionally reduce the current received minimum radio frequency signal strength of the P(Y) code on the L2 link, nor will the United States intentionally alter the modulation codes.

6.4.2.3 The GPS III programme will include satellites with navigation payloads to support increased M Code power, enhanced L1 and L2, and the L5 signal. Programme objectives under GPS III ensure that the GPS system will meet civilian and military requirements envisioned for the next 30 years. GPS III is being developed by using a three-phase approach that is flexible, allows for future changes, and reduces risk. The development of GPS III satellites will begin in 2005, and the first satellite will be available for launch in 2012, with the objective of a full transition to GPS III in 2017. Challenges that are being addressed include:

a) representing both civilian and military GPS user requirements;

b) bounding GPS III requirements within operational objectives;

c) providing a flexibility that would allow for future changes to meet user requirements through 2030; and

d) providing robustness for the increasing dependency on precise positioning and timing as an international utility.

GLONASS

6.4.2.4 The long-term Russian Federation programme for GLONASS development and modernization (up to 2010) envisages an upgrade of both space and control segments as well as the design of user equipment for mass and special customers.

6.4.2.5 The first GLONASS-M satellite with a lifetime of seven years and improved technical characteristics was launched in 2003.

6.4.2.6 The following additional functions are implemented in GLONASS-M satellites:

a) a new civilian signal in the L2 band, enhancing navigation accuracy and reliability and increasing receiver interference immunity for civilian use; and

b) radio links between GLONASS-M satellites in order to perform online control of system integrity and to increase the duration of satellite constellation autonomous operation without the loss of navigation accuracy.

6.4.2.7 The next upgrade envisages the development of GLONASS-K satellite with better accuracy and a lifetime of more than ten years that will transmit the standard accuracy signals for civilian users in the bands L1, L2 and L3.

6.4.2.8 The GLONASS-K L3 signal will have frequency division of channels and will occupy a bandwidth of 26 MHz band in the 1 189 – 1 215 MHz band (L3). The use of this signal, together with other navigation signals, will increase the stability and reliability of the navigation solution. The next upgrade of GLONASS-K will introduce the capability to receive and retransmit distress signals.

SBAS evolution

6.4.2.9 A key to providing approach procedures with vertical guidance (APV) approaches with SBAS is correcting for the signal delay caused by the ionosphere. This requires a relatively dense network of reference stations and complex calculations to ensure the integrity of these corrections. Future navigation satellites would broadcast coded signals on two or more frequencies, allowing receivers to calculate the delay directly and remove the associated error. New generations of navigation satellites will have this feature, so that SBAS will be capable of supporting APV and probably Category I approaches in all service areas with fewer reference stations. States should take this into account when planning for SBAS.

6.4.3 Addition of New GNSS Elements

6.4.3.1 Several States are considering the development of new GNSS elements to be added to existing elements in the framework of a future GNSS. This would require the development of new sections of GNSS SARPs.

European activities

6.4.3.2 In June 1999, the Council of Ministers of Transport of the European Community made the decision to start the definition phase of a European satellite navigation system called Galileo. It was proposed that Galileo be the European contribution to the long-term GNSS, aimed at providing Europe with the capability to distribute worldwide satellite-based navigation services.

6.4.3.3 The definition phase has confirmed that Galileo should provide global signals that can be further augmented by regional and local services. Galileo will use a constellation of 30 medium earth orbit (MEO) satellites in three orbital planes. Galileo’s global signals will support open, safety-of-life, commercial and publicly regulated services. Galileo will also provide a Search and Rescue service compatible with COSPAS/SARSAT (space system for search of vessels in distress/search and rescue satellite-aided tracking). It may also provide other navigation-related communication services.

6.4.3.4 Although clearly independent, Galileo will be compatible and interoperable with GPS. Several of its signals, which will be transmitted in the 1 559 – 1 610 and 1 164 – 1 215 MHz frequency bands, are being designed for easy use by combined GPS and Galileo receivers. The start of the operational service of Galileo is planned for 2008.

Ground-based regional augmentation system (GRAS)

6.4.3.5 GRAS is a blending of SBAS/GBAS concepts intended to enhance GPS/GNSS capabilities for supporting civilian navigation needs. This approach is SBAS-like in its use of a distributed network of reference stations for monitoring GPS and of a central processing facility for computing GPS integrity and differential correction information. But instead of transmitting this information to users via dedicated geostationary earth orbit (GEO) satellites, GRAS delivers SBAS message data to a network of terrestrial stations for a local check as well as for reformatting and rebroadcasting in the GBAS format in the 108 – 117.975 MHz band. Each terrestrial station emits a GBAS-like VHF data broadcast (VDB) signal in a managed time slot. Users can employ a GPS/GRAS-capable receiver to obtain GPS augmentation data for both en-route as well as terminal area approach/departure operations, depending on the VHF network coverage. The GRAS approach could be beneficial where a GEO satellite is either not available or too costly to broadcast SBAS data. GRAS also allows for national control of the system while providing unified corrections and integrity for en-route capability.

6.5 PROTECTION DATES

6.5.1 In order to protect investments in radionavigation equipment, a concept of protection dates has been introduced in Annex 10, Volume I, which precludes changes to SARPs that would otherwise necessitate early replacement of equipment in use. This is achieved by means of the ICAO commitment stated in Chapter 2 of Annex 10, Volume I, that no change in, or addition to, the Standards will require equipment replacement before a predetermined date (e.g. 1 January 2010 for instrument landing system (ILS) or 31 December 2015 for microwave landing system (MLS)). In addition, continuity in the provision of specific aeronautical radionavigation services is ensured through a requirement to introduce alternative services on the basis of regional air navigation agreements that involve both service providers and users. It is further recommended that such agreements should provide at least a five-year advance notice of forthcoming changes (e.g. replacement of ILS with MLS or GBAS).

6.5.2 In general, this concept of protection dates is also applied in GNSS SARPs although it was modified to allow for evolution of the system through its gradual enhancements. To enable such an evolution, incremental amendments to GNSS SARPs will be required, and some of them may affect backward compatibility of GNSS elements. In accordance with the Standard in 2.4.1 in Chapter 2 of Annex 10, Volume I, such amendments will be introduced and published in the Annex at least six years prior to the date when they are realized in the system and put into operation. Furthermore, a case of discontinuation of GNSS services provided by its various elements is covered in 2.4.2 in Chapter 2 of Annex 10, Volume I, which permits the termination of a GNSS service on the basis of at least a six-year advance notice made by a service provider. This would thus allow users and other affected parties sufficient lead time to adapt to such changes.

Appendix A

ACRONYMS

AAIM	Aircraft autonomous integrity monitoring
ABAS	Aircraft-based augmentation system
ADF	Automatic direction finder
ADS	Automatic dependent surveillance
AI	Accuracy and integrity service
AIC	Aeronautical Information Circular
AIP	Aeronautical Information Publication
ANS	Air navigation services
ANSEP	Air Navigation Services Economics Panel
APV	Approach procedure with vertical guidance
ARNS	Aeronautical Radionavigation Service
ATC	Air traffic control
ATS	Air traffic services
C/A	Coarse acquisition
CFIT	Controlled flight into terrain
CNS/ATM	Communications, navigation, and surveillance/Air traffic management
COSPAS	Space system for search of vessels in distress
CPDLC	Controller-pilot data link communications
CSA	Channel of standard accuracy
DH	Decision height
DME	Distance measuring equipment
ECAC	European Civil Aviation Conference
EGNOS	European Geostationary Navigation Overlay Service
EUROCAE	European Organisation for Civil Aviation Equipment
FAA	Federal Aviation Administration (of the United States)
FAS	Final approach segment
FD	Fault detection
FDE	Fault detection and exclusion
FDMA	Frequency division multiple access
FIR	Flight information region
FMS	Flight management system
GAGAN	GPS and GEO Augmented Navigation (System)
GBAS	Ground-based augmentation system
GBAS/E	GBAS VDB elliptical polarization
GBAS/H	GBAS VDB horizontal polarization
GEO	Geostationary earth orbit
GIVE	Grid ionospheric vertical error
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation satellite system
GPS	Global Positioning System
GRAS	Ground-based regional augmentation system
HPL	Horizontal protection level

ICAO	International Civil Aviation Organization
ICD	Interface Control Document
IFR	Instrument flight rules
ILS	Instrument landing system
INS	Inertial navigation system
ITU	International Telecommunication Union
JAA	Joint Aviation Authorities
JTSO	JAA Technical Standing Order
LAAS	Local area augmentation system
LNAV/VNAV	Lateral navigation/vertical navigation
LPL	Lateral protection level
MASPS	Minimum Aviation System Performance Standards
MEO	Medium earth orbit
MLS	Microwave landing system
MMR	Multi-mode receiver
MOCA	Minimum obstacle clearance altitude
MOPS	Minimum Operational Performance Standards
MSAS	MTSAT Satellite-based augmentation system
MTSAT	Multi-functional transport satellite
NAVAID	Navigation aid
NDB	Non-directional beacon
NOTAM	Notice to Airmen
NPA	Non-precision approach
P-code	Precise code
PA	Precision approach
PANS-ATM	Procedures for Air Navigation Services — Air Traffic Management
PANS-OPS	Procedures for Air Navigation Services — Aircraft Operations
PIRG	Planning and implementation regional group
PPS	Precise positioning service
PVT	Position, velocity and time
PZ-90	Parameters of the Earth 1990 coordinate system
RAIM	Receiver autonomous integrity monitoring
RF	Radio frequency
RFI	Radio frequency interference
RNAV	Area navigation
RNP	Required navigation performance
RNSS	Radionavigation Satellite Service
RT	Ranging and timing service
SA	Selective availability
SARPs	Standards and Recommended Practices
SARSAT	Search and rescue satellite-aided tracking
SBAS	Satellite-based augmentation system
SID	Standard instrument departure
SIS	Signal-in-space
SPS	Standard positioning service
SSR	Secondary surveillance radar
STAR	Standard instrument arrival
TACAN	UHF Tactical air navigation aid
TOR	Terms of Reference
TSO	Technical Standard Order (United States FAA)
UDRE	User differential range error
UTC	Coordinated Universal Time
VDB	VHF data broadcast

VFR	Visual flight rules
VHF	Very high frequency
VOR	VHF omnidirectional radio range
VPL	Vertical protection level
WAAS	Wide area augmentation system
WGS-84	World Geodetic System — 1984
WRC	World Radiocommunication Conference

Appendix B

REFERENCES

1. RELEVANT ICAO PUBLICATIONS

The following are ICAO publications related to GNSS implementation. Document summaries can be found in the *Catalogue of ICAO Publications and Audio-visual Training Aids*.

Assembly Resolutions

A32-19:	Charter on the Rights and Obligations of States Relating to GNSS Services
A32-20:	Development and elaboration of an appropriate long-term legal framework to govern the implementation of GNSS
A33-15:	Consolidated statement of continuing ICAO policies and practices related to communications, navigation, and surveillance/air traffic management (CNS/ATM) systems

Annexes to the Convention on International Civil Aviation

Annex 2	*Rules of the Air*
Annex 4	*Aeronautical Charts*
Annex 6	*Operation of Aircraft*
Annex 10	*Aeronautical Telecommunications,* Volume I *(Radio Navigation Aids)*
Annex 11	*Air Traffic Services*
Annex 14	*Aerodromes*
Annex 15	*Aeronautical Information Services*

Documents

Doc 4444	*Procedures for Air Navigation Services — Air Traffic Management*
Doc 7030	*Regional Supplementary Procedures*
Doc 7300	*Convention on International Civil Aviation*

Doc 8071 *Manual on Testing of Radio Navigation Aids*, Volume II — *Testing of Satellite-based Radio Navigation Systems*

Doc 8126 *Aeronautical Information Services Manual*

Doc 8168 *Procedures for Air Navigation Services — Aircraft Operations*
Volume I — *Flight Procedures*
Volume II — *Construction of Visual and Instrument Flight Procedures*

Doc 8400 *Procedures for Air Navigation Services — ICAO Abbreviations and Codes*

Doc 8697 *Aeronautical Chart Manual*

Doc 9161 *Manual on Air Navigation Services Economics*

Doc 9426 *Air Traffic Services Planning Manual*

Doc 9613 *Manual on Required Navigation Performance (RNP)*

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

Doc 9674 *World Geodetic System — 1984 (WGS-84) Manual*

Doc 9689 *Manual on Airspace Planning Methodology for the Determination of Separation Minima*

Doc 9750 *Global Air Navigation Plan for CNS/ATM Systems*

Circulars

Cir 257 *Economics of Satellite-based Air Navigation Services*

Cir 278 *National Plan for CNS/ATM Systems*

2. OTHER PUBLICATIONS

EUROCAE ED-72A *MOPS for Airborne GPS Receiving Equipment Used for Supplemental Means of Navigation*

EUROCAE ED-95 *MASPS for a Global Navigation Satellite System GBAS to Support Cat 1 Operation*

ITU-R SM 1009-1 *Compatibility Between the Sound-Broadcasting Service in the Band of About 87 – 108 MHz and the Aeronautical Services in the Band 108 – 137 MHz*

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

RTCA/DO-229C *Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment*

RTCA/DO-245 *Minimum Aviation System Performance Standards (MASPS) for Local Area Augmentation System (LAAS)*

RTCA/DO-246 *GNSS-Based Precision Approach Local Area Augmentation System (LAAS) — Signal-in-Space Interface Control Document (ICD)*

RTCA/DO-253A *Minimum Operational Performance Standards for GPS Local Area Augmentation System Airborne Equipment*

RTCA/DO-200A/EUROCAE ED-76 *Standards for Processing Aeronautical Data*

RTCA/DO-201A/EUROCAE ED-77 *Standards for Aeronautical Information*

U.S. FAA TSO-C115 *Airborne Area Navigation Equipment Using Multi-Sensor Inputs*

U.S. FAA TSO-C129A *Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS)*

U.S. FAA TSO-C145A *Airborne Navigation Sensors Using Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS)*

U.S. FAA TSO-C145A *Stand-Alone Airborne Navigation Equipment Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS)*

Appendix C

GNSS IMPLEMENTATION TEAM — EXAMPLE OF TERMS OF REFERENCE

1. INTRODUCTION

1.1 This document presents an example of the Terms of Reference for a Global Navigation Satellite System (GNSS) implementation team. The team includes members from the regulatory and service provider organizations as well as user representatives. The Terms of Reference also defines the roles of the team members with respect to the implementation of GNSS operations.

1.2 A common goal of a regulator and a service provider is to ensure that aircraft operators receive the benefits of GNSS technology in a timely and effective fashion while maintaining high standards of safety. The GNSS implementation team supports this goal by fostering a cooperative approach to the development of the standards, systems, procedures as well as the terms and conditions for regulatory approvals that respond to the needs of the aviation community.

1.3 Regulating GNSS and providing GNSS-related services require that various branches in the regulatory and service provider organizations allocate resources to specific tasks. A key goal of a GNSS implementation team is to identify resource requirements to allow managers to plan effectively. The GNSS-related roles of the branches and divisions in the organizations are described in section 2 of this appendix.

1.4 Material developed by ICAO, including SARPs and guidance material, form the basis for the actions taken by the GNSS implementation team.

1.5 The attachment to this appendix provides a GNSS implementation checklist, designed to assist States in introducing GNSS-based operations.

2. ROLES AND RESPONSIBILITIES

2.1 Service Provider

2.1.1 *Satellite navigation programme office (SNPO)*

a) act as the focal point for the development of satellite navigation technology for aviation purposes;

b) develop State performance requirements for GNSS and specify augmentation system architecture to meet operational requirements;

c) complete trials and studies to prove GNSS concepts and their performance;

d) participate, as appropriate, in international activities to ensure harmonization of international standards and respective national requirements and to avoid duplication of efforts;

e) coordinate provision of GNSS-based service to aircraft operators;

f) maintain knowledge of aircraft, pilot and operator certification standards and work with certification staff to ensure that approvals are consistent with GNSS performance;

g) maintain knowledge of GNSS avionics standards and performance;

h) develop the business case for augmentation systems and establish appropriate strategies for fielding these systems, mitigating GNSS outages and decommissioning terrestrial NAVAIDs, as appropriate;

i) assist aircraft operators in making informed decisions on the use of satellite navigation technology;

j) coordinate the development of survey standards to meet the accuracy requirements of satellite navigation;

k) participate in the development of GNSS equipment specifications; and

l) develop and adhere to a Safety Management Plan to cover the introduction of GNSS-based operations.

2.1.2 *Flight inspection*

a) complete flight trials and system performance studies to support GNSS implementation;

b) monitor GNSS performance; and

c) carry out necessary flight inspections for GNSS-based procedures.

2.1.3 *Aeronautical information services*

a) publish instrument approach and other GNSS-based procedures;

b) coordinate airspace-related GNSS issues with air traffic services (ATS);

c) develop standards for and control input to databases containing GNSS procedure coordinates;

d) provide aeronautical information on GNSS procedures to database suppliers and chart producers; and

e) incorporate GNSS information in the Notice to Airmen (NOTAM) system.

2.1.4 *Engineering*

a) develop technical specifications for augmentation systems;

b) procure and field GNSS augmentations, including related communications links;

c) perform life cycle management of augmentation systems;

d) develop hardware and software to support GNSS flight inspections, trials and studies; and

e) provide spectrum management to protect GNSS frequencies.

2.1.5 *Air traffic services (ATS)*

a) develop procedures and train staff to support GNSS-based operations;

b) provide air traffic services to support GNSS-based operations; and

c) participate in the development of GNSS-based procedures and in the development of the strategy and plans for decommissioning terrestrial NAVAIDs, as appropriate.

2.2 Regulator

2.2.1 *Air navigation services (ANS) and airspace*

a) monitor the service provider's research and development of GNSS technology, and consider the service provider's recommendations for operational approvals based on this technology;

b) develop GNSS-based instrument procedure design standards;

c) oversee the certification of GNSS augmentation systems and related airspace procedures;

d) approve survey standards;

e) approve database integrity standards;

f) evaluate aeronautical studies completed by the service provider to assess the impact of decommissioning terrestrial navigation aids (NAVAIDs), as appropriate; and

g) conduct ongoing safety oversight of the service provider with respect to the introduction of GNSS-based operations.

2.2.2 *Aircraft certification*

a) develop national standards and guidance material for the certification of GNSS equipment and its installation and certification in nationally registered aircraft. Where necessary, the development of standards and guidance may be accomplished as a joint effort with other airworthiness authorities to avoid duplication of effort and to maximize harmonization;

b) certify or oversee the certification, as applicable, of GNSS avionics equipment designed and manufactured nationally as well as the installation of GNSS equipment in nationally registered aircraft; and

c) participate, as appropriate, in the development of GNSS avionics specifications, such as RTCA or European Organisation for Civil Aviation Equipment (EUROCAE) standards.

2.2.3 *Commercial and business aviation*

a) develop crew training and certification standards for the use of GNSS avionics by commercial and business aircraft operators; and

b) approve the operational use of GNSS by commercial and business aircraft operators.

2.2.4 *General aviation*

a) develop flight instructor guidelines and flight training standards for the use of GNSS avionics by general aviation operators; and

b) approve the operational use of GNSS by general aviation.

2.2.5 *Aerodrome*

a) adopt survey standards and carry out World Geodetic System — 1984 (WGS-84) surveys for GNSS-based operations.

2.3 Aircraft Operators

a) develop and implement plans for the introduction of GNSS-based operations; and

b) provide requisite training of pilots and technical personnel.

2.4 User Representation

a) a wide cross section of users can provide strategic guidance and detailed recommendations on GNSS implementation; and

b) specific user categories can participate in working groups assessing issues of significance to them.

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Attachment A to Appendix C

GNSS IMPLEMENTATION CHECKLIST

No.	Items to check	GNSS Manual reference
1	Establish GNSS implementation team. Identify members from the regulator, air navigation service provider and the aviation community.	5.2.2
2	Develop a GNSS Plan that defines State operational requirements and also a schedule for the introduction of GNSS-based services. Identify required regulatory changes and business case elements to support expenditures on development of procedures, related elements and augmentation systems.	5.2.3
3	Define procedures, airspace and ATS requirements. Develop an operational use policy, a separation standards application and ATC procedures for GNSS operations.	5.3, 5.4 and 5.5
4	Implement Aeronautical Information Services elements. Inform aircraft operators of the terms and conditions associated with the approval to use GNSS via the State Aeronautical Information Publication, Aeronautical Information Circulars and advisory circulars. Provide material to support training of pilots and ATS personnel. Implement the WGS-84 standard for surveys, publications and databases. Implement systems to support the requirement for database integrity. Develop status monitoring and NOTAM systems to support GNSS operations.	5.6 and 5.7
5	Plan for the introduction of GNSS operations in oceanic, continental and terminal areas, based on traffic density and airspace characteristics.	5.4
6	Develop and publish GNSS approach procedures, using approved design criteria and accounting for aerodrome standards.	5.7.4
7	Develop guidance material and approval processes covering the installation of GNSS avionics. Identify equipment and installation standards, including provisions in Aircraft Flight Manual Supplements.	3.4 and 5.7.3

No.	*Items to check*	*GNSS Manual reference*
8	Develop guidance material and processes covering the operational approval of GNSS. Establish requirements for specific operator approvals, pilot training and certification.	5.7.2
9	Establish flight inspection requirements and procedures and acquire the needed equipment.	5.3.4
10	Establish training and certification requirements for procedure designers and ATS personnel.	5.2.4
11	Develop a system of post-implementation reviews to ensure the effective and safe introduction of GNSS operations.	5.7

Appendix D

EXAMPLES OF GNSS VULNERABILITY ASSESSMENT FOR EXISTING OPERATIONS

The guidelines for evaluating the impact and likelihood of a GNSS outage are provided in 5.8. This appendix provides two examples of how this evaluation methodology can be applied to existing GNSS operations. These examples do not take into account future GNSS signals or constellations.

1. CONGESTED AIRSPACE OVER MID-LATITUDE REGION

The following example applies to existing GNSS operations in airspace with a high density of aircraft operations over a mid-latitude region with effective spectrum management.

1.1 *Unintentional interference*. Unintentional interference has been encountered in the United States and Europe. In the United States, there have been six confirmed cases of interference to GPS in the last years. Based on operational experience, unintentional interference is unlikely but cannot be neglected.

1.2 *Intentional interference*. For current operations, there is no significant motivation to deliberately interfere with GNSS. In addition, intentional interference has never been encountered. The likelihood of this interference is negligible for existing operations. The threat of intentional interference may however change over time as reliance on GNSS increases.

1.3 The impact of interference is to cause a GNSS outage within the line-of-sight of the interferer. The majority of air carrier operators in these regions are equipped with inertial navigation and/or a flight management system (FMS) with a distance measuring equipment/distance measuring equipment (DME/DME) area navigation (RNAV) capability. DME facilities are available in the majority of airspace. While some aircraft are not equipped with an independent RNAV capability, safety for these aircraft can nonetheless still be maintained and operations continued, perhaps with reduced efficiency. Therefore, unintentional and intentional interference have a moderate impact.

1.4 *Spoofing*. There is no significant likelihood of spoofing, and the impact would be moderate.

1.5 *Ionospheric effects*. For mid-latitude regions, ionospheric scintillation that causes loss of GNSS positioning has never been experienced, so the likelihood of occurrence is considered negligible. There would be no operational impact due to the expected short duration of the event, the available terrestrial navigation aids and the high level of equipage available to use those aids.

1.6 *Summary*. Table D-1 summarizes the likelihood and operational impact of the vulnerabilities that have been identified. The table maps the likelihood of occurrence against the operational impact. The State should mitigate any vulnerability that is remote and has a severe impact, or that is probable and has any impact. In addition, consideration should be given to vulnerabilities that are remote and have a moderate impact.

Table D-1. GNSS vulnerabilities in congested airspace — Mid-latitudes

		Operational impact		
		No impact	*Moderate impact*	*Severe impact*
Likelihood	Negligible	Ionospheric effects	Intentional interference; spoofing	
	Remote		Unintentional interference	
	Probable			

2. REMOTE AREAS OVER EQUATORIAL REGION

The following example applies to existing GNSS operations in remote airspace with a low density of aircraft operations over an equatorial region with effective spectrum management.

2.1 *Unintentional interference*. Most sources of unintentional interference are less likely to appear in remote regions. With effective spectrum management, the likelihood of interference in these areas may be negligible. The impact of outage may be moderate to severe due to unavailability of radar services.

2.2 *Intentional interference*. Intentional interference has not been encountered, and there is no significant motivation to deliberately interfere with GNSS, given the low density of operations and the remote areas. The likelihood of this interference is considered to be negligible for existing operations. The threat of intentional interference may however change over time as reliance on GNSS increases. The impact of intentional interference is the same as unintentional interference.

2.3 *Spoofing*. There is no significant threat due to spoofing, and even if there were, the impact would be moderate.

2.4 *Ionospheric effects*. For equatorial regions, ionospheric scintillation that impacts GNSS performance is likely to occur. The operational effect is moderate, since it is typically a degradation in performance and not a complete loss of navigation capability. In the event that a complete loss of positioning occurs, it does not persist for very long and the low density of operations ensures continued safety.

2.5 *Summary*. Table D-2 summarizes the likelihood and operational impact of the vulnerabilities that have been identified. The most significant issue is the potential for ionospheric scintillation. States should take action to reduce the impact of this effect. This can be accomplished through:

a) operational procedures that ensure continued operation during brief GNSS outages, and

b) continued research on the duration and likelihood of severe scintillation.

Table D-2. GNSS vulnerabilities in remote areas — Equatorial

		Operational impact		
		No impact	*Moderate impact*	*Severe impact*
Likelihood	Negligible		Unintentional and intentional interference; spoofing	
	Remote			
	Probable		Ionospheric effects	

— END —