APPENDIX

GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)

MANUAL

Note.— The manual is to be processed for publication under the authority of the Secretary General.

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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 Communication, Navigation, Surveillance and Air Traffic Management (CNS/ATM) systems and a foundation upon which States can deliver improved aeronautical navigation services.

Standards and Recommended Practices (SARPs) for the Global Navigation Satellite System (GNSS) were developed by the Global Navigation Satellite System Panel and introduced in ICAO Annex 10, Volume I in 2001 as a part of Amendment 76 to Annex 10. Guidance material in Attachment D to Volume I provides extensive guidance on technical aspects and application of GNSS SARPs that provided, at the publication date, for satellite-based en-route through Category I precision approach operations.

The primary purpose of this manual is to provide information on GNSS implementation aspects, which could assist States in the introduction of GNSS operations. The document 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. The manual also 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 document 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

1.1.1 The document describes concepts of operation using the core satellite constellations (GPS and GLONASS) and augmentation systems. It includes a basic explanation of satellite navigation technology including satellite systems, augmentations and avionics. It discusses providing service with GNSS, and describes implementation considerations to assist States to plan for the orderly introduction of service based on GNSS guidance. Finally, it describes future prospects for the evolution of GNSS.

1.2 GNSS ELEMENTS

1.2.1 The two core satellite constellations are the Global Positioning System (GPS) and the GLObal NAvigation Satellite System (GLONASS), provided by the United States of America and the Russian Federation respectively, in accordance with the SARPs. These systems provide independent capabilities and can be used in combination with future core constellations and augmentation systems. States authorising GNSS operations remain responsible for determining if GNSS meets Annex 10 performance requirements in their airspace and notifying users when performance does not meet these requirements.

1.2.2 Satellites in the core 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, then to calculate a three-dimensional position and precise time.

1.2.3 The GNSS receiver consists of an antenna and 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 Existing core satellite constellations alone do not meet aviation's strict requirements. To meet the operational requirements for various phases of flight, core 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 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 satellite, while GBAS uses a VHF data broadcast from a ground station.

1.3 OPERATIONAL ADVANTAGES OF GNSS

1.3.1 GNSS is global in scope, and is fundamentally different from traditional NAVAIDs. It has the potential to support all phases of flight providing a 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. These 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, too costly or impossible to provide reliable and accurate traditional NAVAID guidance. Many States exploit 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 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 navigation aid at the airport. GNSS may support approach 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 additionally exploited through the use of 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 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 navigation aids. 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 document.

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 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 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 service 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 navigation service providers to dedicate resources, move quickly and retain flexibility in order to meet the demands of its customers for GNSS services.

1.4.3 A challenge for GNSS is achieving a high availability of service. The first GNSS approvals relied on traditional NAVAIDs as a backup 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 likelyhood 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 Section 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 aerodrome physical characteristics 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 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 and the capabilities of GNSS, and operational approvals.

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

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.

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

a) ensuring regional and inter-regional coordination;

b) providing a forum for the exchange of expertise and information among States and international organisations, and

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

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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 staged implementation of GNSS service may be affected by various factors, including:

a) the existing navigation services;

b) availability of GNSS procedures design criteria;

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. Based on traffic volume and airspace structure, States can choose their level of involvement in the development and implementation of SBAS and/or GBAS. These implementation efforts require a high level of cooperation among States 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 GPS receivers. Operators used these early receivers as an aid to VFR and IFR navigation. They quickly saw the benefits of having a 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 that reason, GNSS avionics used in IFR operations should augment the GNSS signal to ensure, among other things, its integrity. The aircraft-based augmentation system (ABAS) augments and/or integrates GNSS information with information available onboard the aircraft to enhance the performance of the core satellite systems.

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 any expenditure on infrastructure. The exploitation of GPS/ABAS is a worthwhile first stage in a phased transition to GNSS guidance for all phases of flight.

2.2.5 Initial approvals 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 VOR, VOR/DME, NDB and NDB/DME non-precision approach 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 NAVAIDs, and comply with the visibility and minimum descent altitude associated with the traditional approach. Some VOR and NDB-based procedures are 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 procedure was not intended to be flown using an RNAV system.

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

2.2.8 Certain operational restrictions were deemed necessary for the implementation of GPS-based NPA procedures. The reasons for and nature of these restrictions varied by State including: the effects of GPS outages in large regions; the availability of traditional NAVAIDs as a backup; 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 (RAIM), but 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 integration of GNSS with the inertial data. The combination of GNSS 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 requires a 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 systems 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. SBAS, in certain configurations can support approaches with vertical guidance (APV). There are two levels of APV: APV I and APV II. Both use the same lateral obstacle surfaces as localizer, however APV II may have lower minima due to better vertical performance. There will 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 75 m (250 ft) DH 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 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 authorising 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 to the service area of the host SBAS.

2.3.7 In either case, the State, which 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 Section 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 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 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 may 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 2D 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 MHz - 117 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 broadcast and to 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 result in more runway-ends having qualified electronic precision approach guidance, resulting in significant safety and efficiency benefits. Such runways, however, should meet standards for physical characteristics and infrastructure.

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Chapter 3.

GNSS SYSTEM DESCRIPTION

3.1 GENERAL

3.1.1 GPS and 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 does not meet requirements for precision approach. Augmentation systems can be used to meet the four basic GNSS navigation operational performance requirements that are stated in GNSS SARPs in Annex 10, Volume I, Chapter 3, Table 3.7.2.4-1 and discussed in Section 4. Integrity, availability and continuity can be provided using on-board, ground- or satellite-based augmentation techniques. Accuracy can be enhanced using differential techniques. The total system, including core satellite constellations GPS and GLONASS, and all augmentation systems, is referred to as GNSS. Efforts to bring the full benefits of satellite navigation to users focus on developing these augmentations and certifying them for operational use.

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. World Geodetic System 1984 (WGS-84). GPS utilizes WGS-84 as the reference datum, however, GLONASS utilizes PZ-90. GNSS SARPs provide a transformation algorithm to convert PZ-90 into WGS-84 coordinates (see Section 5.6.3).

3.2 EXISTING SATELLITE-BASED NAVIGATION SYSTEMS

3.2.1 Global positioning system (GPS)

3.2.1.1 The global positioning system (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 comprises 24 satellites in six orbital planes. The satellites operate in near-circular 20 000 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 each satellite's navigation message. 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 civil 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 discontinuance 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 the nature of the navigation system integration. Most TSO C129 avionics do not see improvements in RAIM availability because they assume SA is present. The RAIM/FDE functionally in SBAS avionics takes advantage of SA being discontinued.

3.2.1.5 Elimination of the SA error component does not eliminate other errors. Therefore, no changes are expected for either SBAS or GBAS augmentations.

3.2.1.6 The GPS SPS Performance Standard defines the level of performance that the US Government commits to provide to all civil users. ICD GPS 200C details the technical characteristics of the SPS L-band carrier and the C/A code and the technical definition of requirements between the GPS constellation and SPS receivers. Additional information concerning GPS can be found on the US Coast Guard's NAVCEN web site, 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 RF signals transmitted by GLONASS satellites. The system operated by the Russian Federation Ministry of Defence. 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 this offer.

3.2.2.2 The nominal GLONASS space segment consists of twenty-four operational satellites and several spares. GLONASS satellites orbit at an altitude of 19 100 km 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 are required to determine a two-dimensional position and time if altitude is knownThe user's receiver may track these satellites either simultaneously or sequentially. Satellites broadcast in two L-band portions of the RF spectrum and have two binary codes, the C/A code and the P code, and the data message. GLONASS is based upon a frequency division multiple access (FDMA) concept. GLONASS satellites transmit carrier signals at different frequencies. A GLONASS receiver separates the total incoming signal from all visible satellites by assigning different frequencies to its tracking channels. The use of FDMA permits each GLONASS satellite to transmit identical P and C/A codes.

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 UTC.

3.2.2.5 Ephemeris information includes each satellite's three-dimensional Earth-Centred Earth-fixed position, velocity and acceleration for every half-hour epoch. For a measurement time somewhere between the half-hour epochs, a user interpolates the satellite's coordinates using position, velocity and acceleration from the half-hour marks before and after the measurement time.

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 master control, 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 synchronisation of satellite clocks with GLONASS system time. To accomplish the necessary synchronisation, the master control station provides 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, Russian Federation, Ministry of Defence, Moscow and on the Centre's web site: www.rssi.ru/SFCSIC/SFCSIC_main.html.

3.3 AUGMENTATION SYSTEMS

3.3.1 Three augmentations, ABAS, SBAS and 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 Section 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 onboard 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 to detect the presence of an unacceptably large position error for a given mode of flight. Fault detection and exclusion (FDE) uses a minimum of six satellites to, not only detect a faulty satellite, but exclude it from the navigation solution so 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 centered at the true aircraft position that is assured to contain the indicated horizontal position within the specified integrity requirement.

3.3.2.5 For receivers that cannot take advantage of SA being discontinued, average RAIM availability is 99.99 per cent for en-route and 99.7 per cent for non-precision approach operations for 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. Receivers that can take advantage of SA having been discontinued (e.g. SBAS receivers), have increased the availability of RAIM to 100 per cent for en-route and 99.998 per cent for non precision approach; FDE availability ranges from 99.92 per cent for en-route to 99.1 per cent for non precision approach.

3.3.2.6 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 SBAS, as defined in the SARPs, has the potential to support en-route through Category I precision approach operations. Initial SBAS architectures will typically support operations down to 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 each satellite's broadcast ephemeris and clock. For each monitored GPS or GLONASS satellite, SBAS estimates the errors in the broadcast ephemeris parameters and satellite clock, and broadcasts 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 (GEO) satellites in fixed orbital slots over the equator. The SBAS satellites also provide ranging signals similar to GPS; however, these ranging signals cannot be received by Basic GNSS receivers. SBAS messages ensure integrity, improve availability, and provide the performance needed for APV and Category I precision approach operations.

3.3.3.4 SBAS uses two-frequency range measurements to estimate the ranging delay introduced by the Earth's ionosphere, and broadcasts 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 with estimates of the uncertainties in its own pseudorange measurement accuracy and in its tropospheric delay model, 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. The table below shows the type of SBAS service, the correction that would be provided, and the highest level of service that would be supported by type of SBAS.

Table 3-1: Type 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, ionosphere	Through APV II

3.3.3.8 The type of service chosen would be a trade-off between the capability required and 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 (EGNOS, GAGAN, MSAS, 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.

3.3.3.12 A State may obtain SBAS service by either: cooperating with another State (called 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 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 SBAS service provider's master stations. 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 provide a status monitoring and NOTAM service.

3.3.4 Ground-based augmentation (GBAS)

3.3.4.1 GBAS, as defined in SARPs, supports 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 RTCA/DO-245 (EUROCAE ED 95), *Minimum Aviation System Performance Standards for GPS/LAAS*.

3.3.4.4 The GBAS VDB transmits with either horizontal or elliptical polarisation (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 indicate the type of VDB antenna polarisation at each of their facilities in the 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 "ILS look-alike" 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 supports 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 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 assuring the integrity of ranging source ephemeris without reliance on the aircraft calculating and applying the ephemeris bound. Providing the additional parameters allows the ground sub-system increased flexibility in its siting or architecture.

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 b).

3.3.4.10 SARPs for GBAS to support other applications such as Category 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 (either accuracy, integrity, continuity, and/or availability) of unaugmented GNSS and/or the aircraft navigation system:

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

b) aircraft autonomous integrity monitoring (AAIM) which uses information from additional onboard 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, at a minimum, a RAIM fault detection function (Section 3.4.1). These support one or more of the following phases of flight depending on the classification of the receiver: en-route, terminal and non-precision approach. They may be incorporated into an integrated navigation system which provides integrity performance equivalent to RAIM, or to enhance the overall performance of the aircraft navigation system.

3.4.1.3 The term “Basic GNSS receiver” designates GNSS avionics that at least meet requirements for a GPS receiver in Annex 10, Volume I, and specifications of RTCA DO-208 or EUROCAE ED-72A, as amended by FAA TSO-C129A or JAA TSO C129 (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, for example, RAIM fault detection;

b) turn anticipation; and

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

Receiver autonomous integrity monitoring (RAIM) and fault detection and exclusion (FDE)

3.4.1.4 There are two distinct events that can cause a RAIM alert. The first 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, that is, 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.

Aircraft autonomous integrity monitoring (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 FAA TSO C-115A. An example is using 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 onboard 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 maneuvering; 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 GNSS avionics that at least meet requirements for a SBAS receiver in Annex 10, Volume I, and specifications of RTCA DO-229C, as amended by FAA TSO-C145A/146A (or equivalent).

3.4.2.2 An SBAS receiver outputs differentially corrected 3D positions and depending on the receiver class (as defined in RTCA DO-229), 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 (WAAS) avionics certification requirements are contained in the following FAA Technical Standard Orders:

a) TSO C-145, Airborne Navigation Sensors Using the Global Positioning System Augmented by the Wide Area Augmentation System (WAAS). This TSO applies to a sensor that provides information to an external onboard navigation function; and

b) TSO C-146, Stand-alone Airborne Navigation Equipment Using the Global Positioning System 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 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 de-selection 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 de-selection is possible for these operations. 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 GNSS avionics that at least met requirements for a GBAS receiver in Annex 10, Volume I, and specifications of RTCA DO-253A, as amended by respective FAA TSO (or equivalent).

Precision approach

3.4.3.2 Similar to ILS and MLS, GBAS provides lateral and vertical guidance relative to the defined final approach course and glide path. The GBAS receiver employs a channelling scheme that selects the VDB frequency. Approach procedure data are up-linked 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, to minimize impact of installing GBAS on the existing avionics. Display scaling and deviation outputs, for example, will be equivalent to 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 provides 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 DO-229 (if SBAS is available) or FAA TSO-C129A Class B1 or C1.

Multi-mode receiver (MMR)

3.4.3.6 ICAO SARPs and the strategy for 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

3.4.4.1 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

3.4.5.1 Table 3.2 gives avionics standards for the various augmentation systems.

Table 3.2. GNSS avionics Standards for augmentation

Augmentation	FAA Technical Standard Order (TSO)	RTCA (EUROCAE) MOPS/MASPS
ABAS	TSO-C129A Level 2 (En-route/Terminal) TSO-C129A Levels 1 or 3 (NPA)	RTCA DO-208 EUROCAE ED-72A

Augmentation	FAA Technical Standard Order (TSO)	RTCA (EUROCAE) MOPS/MASPS
SBAS	TSO-C145 TSO-C146	RTCA DO-229C EUROCAE Equivalent under development
GBAS	Under Development	RTCA DO-245 RTCA DO-246 RTCA DO-253 EUROCAE ED-95

* SBAS avionics meet all ABAS requirements.

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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 to derive specific signal-in-space performance requirements. In the case of GNSS, degraded performance which would simultaneously affect multiple aircraft was considered. This resulted in certain signal-in-space performance requirements being more stringent.

4.1.4 Detailed design system performance requirements are depicted in Annex 10, Volume I, Chapter 3, Table 3.7.2.4-1. This chapter describes these criteria and their relationship to levels of service that can be offered by a State within its airspace.

4.1.5 In addition to these technical aspects, safety and operational issues have to be considered (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 VOR and ILS have relatively repeatable error characteristics, so that 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 test. 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 system, SBAS and 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 the following table:

Table 4-1. GNSS integrity alert limits by airspace

Operation:	Oceanic en-route	Continental en-route	Terminal	NPA	APV-I	APV-II	Cat I
Horizontal/lateral alert limit	7.4 km (4 NM)	7.4-3.7 km (2-4 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 - 15 m (33-50 ft)
Maximum Time-to-alert	5 min	5 min	15s	10s	6s	6s	6s

4.2.2.3 Following an alert, the crew should either resume navigating using traditional 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 more stringent 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 through the use of alternative navigation means, or the use of ATC surveillance and intervention to ensure that separation is maintained.

4.2.3.4 For approach and landing operations, each aircraft can be considered independently. 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, this 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. It 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 would not be necessary to NOTAM a service outage if continuity fell 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 the potentially long time 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 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 that element.

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 for States in 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 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 operation is conducted.

4.3 OPERATIONAL POTENTIAL OF GNSS AUGMENTATION SYSTEMS

4.3.1 The core satellite constellations alone cannot meet stringent aviation requirements of accuracy, integrity, continuity and availability discussed above. Table 4-2 shows the potential of 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 counterbalance less than specified availability or continuity performance.

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 FDE is available. Pre-flight FDE prediction might be required.	Suitable for navigation when RAIM or another navigation source is usable.	Suitable for navigation when RAIM or another navigation source is usable.	Suitable for 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 PA Cat I (potentially Cat II and 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 and Doc 9157, *Aerodrome Design Manual.*

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Chapter 5.

GNSS IMPLEMENTATION

5.1 GENERAL

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

a) planning and organisation;

b) procedure development;

c) air traffic management (airspace and 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 a State's responsibility within 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 latter 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 Regional Implementation Planning Groups (PIRGs).

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

5.2.2.3 There is a need for users, including air carriers, general aviation, and the military, to be included in the GNSS implementation team to allow them to communicate their specific requirements. Users will then be able to assist State authorities to develop an effective and efficient GNSS implementation strategy.

5.2.2.4 A technical committee could be formed and given the responsibility for defining requirements and executing the implementation plan. Team composition may vary by 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 developing obstacle clearance criteria, etc.

d) *Aeronautical information service*. Persons who are involved in 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, commercial aviation, unions, as well as other modes of transport that may use GNSS; surveyors, GNSS receiver manufacturing representatives etc.

j) *Military representatives*.

k) *Other foreign civil aviation or ICAO officials.* For educational purposes.

5.2.2.5 A sample of a Terms of Reference (TOR) for a GNSS Implementation Team as well as a GNSS Implementation Checklist are contained in 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 various requirements for each approval stage and steps needed for implementation, and should consider regional and global planning for CNS/ATM systems.

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 service providers and airspace users. Business case development at the State level is essential in determining the effect of GNSS and also to choose the most cost-effective implementation strategy. Circular 257, *Economics of Satellite-based Air Navigation Services*, *Report on the Financial and Related Organizational and Managerial Aspects of Global Navigation Satellite System (GNSS) Provision and Operation* (Doc 9660) and the *Manual on Air Navigation Services Economics* (Doc 9161/3) will be of use in developing a GNSS plan, particularly where the implementation of SBAS and/or GBAS is envisaged.

5.2.4 Training

5.2.4.1 The transition to GNSS represents a significant change for aviation, so it requires new approaches to regulating, providing service and operating aircraft. A successful transition to GNSS requires a comprehensive orientation and training programme aimed at all involved parties. This programme should keep pace as GNSS evolves.

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

5.2.4.3 Staffs in regulatory and service provider organisations require foundation training to be able to appreciate how GNSS could affect their area of responsibility. This should include: the basic theory of GNSS operations; GNSS capabilities and limitations; avionics performance and integration; current regulations; and concepts of operation. This should be followed by job-specific training to prepare staff to plan, manage, operate and maintain the system.

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

5.2.4.5 ATC training should include the application of GNSS to RNAV to ensure maximum use of this technology.

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 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 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* (Doc 8168, *PANS-OPS*).

5.3.2 Terminal procedures

5.3.2.1 PANS-OPS, Volume I and II criteria for GNSS terminal, non-precision approach and departure operations have been developed, consistent with avionics performance obtained with a Basic GNSS receiver SID/STAR criteria, have 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 SBAS and GBAS procedure design criteria

5.3.3.1 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) data base validation.

5.3.4.2 The manual stresses that the core satellite constellation signals are the responsibility of States providing the signals. This element is therefore not tested as part of ground or flight testing procedures for GNSS. As opposed to testing of terrestrial NAVAIDs, GNSS testing focuses on an assessment of procedures for data accuracy and operational suitability rather than 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 described.

5.3.5 Ground recording

5.3.5.1 Unlike terrestrial NAVAIDs, GNSS encompasses a number of different elements that may be controlled by foreign entities. Recording systems should fulfill the purpose of recording sufficient information to allow incident investigators to ascertain that any GNSS service was operating in compliance with Annex 10 at any point in time, 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 needs to take place, there is no explicit requirement for the monitoring to be independent of the GNSS service being recorded and 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 precisely establish levels of performance at the user level everywhere within an ATS provider's area of responsibility for the following reasons:

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

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 affecting 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 RAIM/FDE or baro-aiding.

5.3.5.4 The prime objective of the monitoring system should be to record pertinent GNSS parameters to aid in a post incident investigation of potential GNSS performance. Rather than provide monitoring to 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 with a limited number of physical locations. The recorded data used for post incident/accident investigations may then also support periodic confirmation of GNSS performance in the service area.

5.3.5.5 Further guidance concerning the GNSS parameters to be recorded for incident investigations are contained in Annex 10, Volume I, Chapter 3, Attachment D.

5.3.6 Helicopter instrument approach operations to heliports

5.3.6.1 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, 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 traffic density suggests 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

5.4.2.1 The efficient use of this airspace is currently limited by the absence of traditional NAVAIDs, lack of surveillance and poor communication 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 assist in the provision of 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 using advances in surveillance based on ADS.

5.4.3 Continental en-route and terminal

5.4.3.1 Where continental en-route airspace is served by radar, independent surveillance and the availability of traditional NAVAIDs already allows 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. Availability of alternate aerodromes will also be increased by the introduction of GNSS.

5.4.4 Terminal, approach/departure

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. GNSS, as an RNAV system, allows the design of procedures 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 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

5.5.2.1 The revision to the current airway structure is generally a two-step approach, rather than an overlay of current airways. First is the development and implementation of “advanced navigation routes” based upon a modification of current “off-airway” routes. The second 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 implementation of parallel routes. Currently, in airspace where lateral deviations cannot be controlled with the aid of radar monitoring, the size of protected airspace cannot be reduced and the spacing of route centrelines cannot be closer than 25 km (16.5 NM) for unidirectional and 33 km (18 NM) for bi-directional routes. This does not allow for 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. Without establishing lateral separation standards for GNSS/Advanced RNAV routes equal to at least those on today's traditional NAVAID routes, benefits from GNSS implementation can not be fully realized.

5.5.3 Longitudinal separation

5.5.3.1 GNSS position reports may be accepted for the application of longitudinal separation. Where position reports are going to be used between a mix of aircraft using GNSS and 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 can not 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

5.5.4.1 Terrestrial NAVAID coverage limitations affect minimum obstacle clearance altitude (MECA). 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. GNSS provides coverage to the ground, so MECA can be based on terrain, obstructions and communications coverage considerations.

5.6 AERONAUTICAL INFORMATION SERVICES

5.6.1 General

5.6.1.1 The following aspects are expected to be included in a State AIP to cover the implementation and use of GNSS:

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

b) the WGS-84 coordinate system;

c) airborne navigation database; and

d) 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 to plan for the acquisition of avionics; continuous update of this information is required.

5.6.2.3 This may be carried out by the issuance of an Aeronautical Information Circular (AIC), State Aeronautical Information Publication (AIP) or in some cases advisory circulars. Experience has shown that aircraft operators require detailed information to ensure compliance with regulations and 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 Annexes 4, 11, 14 and 15, and ICAO *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 therefore elected to re-survey to WGS-84 standards due to the lack of integrity of their existing surveys, and the re-survey is considered to be a preferred option in 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 Section 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 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, the avionics is 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. This requires an appreciation of data coding standards and their proper use.

5.6.4.4 Two harmonized EUROCAE/RTCA documents are available to assist in the production and handling of aeronautical data: *Requirements for the Aeronautical Data Process* (RTCA DO-200A/EUROCAE ED-76) and *Industry Requirements 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 (Annex 15; PANS-ATM, Doc 4444).

5.6.5.2 Requirements for monitoring terrestrial NAVAIDS are contained in Annex 10, Volume I. With these NAVAIDs, service is directly related to equipment status. For example, if an 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 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 the 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 it complicates status monitoring and the provision of a NOTAM service for GNSS.

5.6.5.5 Status monitoring and NOTAM considerations related to ABAS, SBAS and GBAS are described below, 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 whether to develop a status monitoring and NOTAM system for ABAS operations should be made taking account of the nature of ABAS approvals. In many cases ABAS operations are predicated on having a full complement of traditional NAVAIDs available for backup 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 as well as 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 programmes 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 GEO satellite signals. These footprints virtually cover a hemisphere (except high latitudes), but the service area is restricted to a specified smaller region (ECAC States for EGNOS, India for GAGAN, Japanese FIR for MSAS and the USA for 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 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 model can identify airspace and airports, where service outages were expected, and be used to create NOTAMs. The system element status data (current and forecast) required for the model could be obtained via a bilateral arrangement with the SBAS operator, or via a real time broadcast of the data, if the SBAS operator chose to provide data in this way.

5.6.5.13 The situation becomes more complex when an SBAS service area established by a State lies within the coverage areas of more than one SBAS, and the signals from both SBAS are needed to meet performance requirements. In this case, the State would have to obtain SBAS system element status from two SBAS operators, and a more complex model would be required.

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 view of reference and aircraft receivers, satellite geometry and on the status of GBAS system elements. Thus status monitoring and NOTAM services also require computer-modelling techniques although the processes would be simpler than 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 system life cycle phases. The process is defined as a combination of people, procedures, technologies (hardware-software) and data within a given environment to perform a given task. This approach can be referred to as Safety Risk Management.

5.7.1.2 Annex 11 calls for a safety assessment prior to 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 plan details the system safety activities to be carried out during the system's life (e.g. 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 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 a 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 VFR or IFR. This authorisation may be for the use of GNSS alone, or for use with other aircraft systems, and 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 qualified for use, including en-route navigation, position fixing or instrument approach. Individual types of radio navigation aids may be endorsed (e.g. VOR, ADF, ILS). In some States, however, there are no requirements for individual navigation aid 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 Where commercial operators receive specific authorisation to use GNSS, 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 be installed in accordance with specific criteria. A series of tests, measurements and inspections should validate any installation. 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 type design (supplemental type certificate). The Technical Standard Order (TSO) process addresses only the qualification of equipment to a minimum standard. Equipment certified should be evaluated for compatibility with every type of aircraft in which it is 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 use FAA or Joint Airworthiness 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 visual flight rules (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 receiver 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 used 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 over-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 in visual meteorological conditions to these VFR reporting points.

5.7.4 GNSS for approach operations

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

5.7.4.1 *Procedures for Air Navigation Services — Aircraft Operations* (Doc 8168, PANS-OPS), 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, helping to reduce the probability of Controlled Flight Into Terrain (CFIT). Annex 10, Volume I, Chapter 3, 3.7.2.4 defines two different levels of APV operations, and GNSS avionics standards support APV-I and APV-II operations. PANS-OPS Volume I and II 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 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 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 the procedures comply with the PANS-OPS or other approved design criteria. As with traditional NAVAIDs, Category I, II and III precision approaches operations require special pilot and operator certification.

5.7.5 Anomaly/interference reporting

5.7.5.1 GNSS signals need to be protected, and means should be in place to report GNSS anomalies in order to assist in determining the cause and 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 practical, 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 practical, including a description of the event (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 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 this 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 appropriate advisories and NOTAMs are issued 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 closure.

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 to track reports of anomalies and is helpful to this coordination. States may require more detailed information to allow 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 within the State's AIP and enacted by Aeronautical Information Circular (AIC).

5.8 INTERFERENCE

5.8.1 General

5.8.1.1 The potential for interference 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 A characteristic of current satellite navigation systems is relatively weak received signal power, meaning that an interference signal could cause loss of service at a relatively lower received power level than with current terrestrial systems. Due to the nature of the signal source, interference may not only be limited to areas near terrestrial GNSS augmentation installations, but may exist wherever the GNSS signal is authorized for operational use.

5.8.1.3 GPS and GLONASS have filings with the International Telecommunication Union (ITU) to operate using spectrum allocated to the radionavigation satellite service (RNSS) in the band 1 559 to 1 610 MHz. The RNSS allocation in this band is shared on a co-primary basis with the aeronautical radionavigation service (ARNS). SBAS also has a filing under the RNSS allocation in this band.

5.8.1.4 States wishing to approve GNSS-based operations should ensure that existing frequency assignments in the 1 559 - 1 610 MHz band with the potential to interfere with the GNSS operations be moved to other frequency assignments or bands where feasible.

5.8.1.5 At the World Radio Conference in 2000 (WRC-2000), co-primary allocations with the ARNS between 1 164 - 1 215 MHz were also made for RNSS. Planned GPS enhancements (L5), GLONASS-K (L3) and future Galileo applications are to file under the RNSS allocation, sharing this spectrum with the existing ARNS systems such as DME (and TACAN). In this band the ARNS will be afforded full protection from the RNSS, these new RNSS applications should ensure compatibility with existing frequency assignments in the band.

5.8.2 Sources of interference

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 used by a number of States. The use of these links, as stated in footnotes S5.355A and S5.359A to the radio regulations of the ITU, is due to be phased out by not later than 2015.

5.8.2.2 Potential sources of interference from services operating in bands outside of the 1 559 - 1 610 MHz band include harmonics and spurious emissions of mobile satellite services UHF TV broadcast stations and other high power sources. Out-of-band noise, discrete spurious products and inter-modulation products from radio services operating near the 1 559 - 1 610 MHz band can also cause interference problems. Potential sources of interference for future GNSS applications in the band 1 164 - 1 215 MHz include in-band effects from DME/TACAN transponders and out-of-band effects from SSR transponders, DME interrogators and radars (above 1 215 MHz). ILS, VOR, COM and VDL transmissions in the same VHF 108 - 137 MHz band may cause interference to GBAS VHF data broadcast (VDB) receivers. Further, commercial VHF FM broadcasting stations operating in the 88 - 108 MHz band may interfere with GBAS VDB receivers. There is therefore a need for mitigation measures including frequency coordination to prevent operational impacts to aviation GNSS users operating in any State.

5.8.2.3 There is also potential for harmful interference to GNSS from sources located on the aircraft, which has to be accounted for in designing new avionics and aircraft system integration.

5.8.3 Interference detection, flight inspection and ground monitoring

5.8.3.1 Increasing reliance on GNSS will require States to re-examine their respective capabilities to detect, localize and identify interference sources, in order to minimize potential service disruptions in their airspace. This examination may result in a requirement for airborne and ground equipment for detecting and localising potential sources of RFI to the GNSS signals.

5.8.3.2 Interference is of primary concern in the approach and landing environment. Interference during these phases of flight has the potential for the most significant consequences. GNSS receivers are required to achieve a minimum level of performance in the presence of both continuous wave and pulsed interference. GNSS SARPs in Annex 10 define thresholds for interference around the GPS, GLONASS and SBAS frequencies. If interference exceeds these pre-determined thresholds, then receiver performance will degrade. Therefore, in order to quickly identify and mitigate GNSS interference in the landing environment, a combination of interference detection systems may be required. For example, evaluation of RFI direction finding and localisation technologies in one State have resulted in initial development processes in four main platforms of interest - flight testing aircraft, land fixed (located at airport), land mobile (surface vehicle) and handheld. Such a range of systems, would provide the capability to locate and initiate measures to terminate sources of interference.

5.8.3.3 The extent of interference mitigation development a particular State may desire to implement should be predicated on the extent of services provided by GNSS and the required availability for those services.

5.8.3.4 It may be appropriate for flight inspection of GNSS-based procedures to include a survey of the surrounding interference environment. This provides the opportunity for the flight inspection to identify any unintentional interference that has the potential to disrupt approach operations. Further guidance on GNSS testing is provided in ICAO Doc 8071, *Manual on Testing of Radio Navigation Aids*, Volume II —*Testing of satellite-based radio navigation systems*.

5.8.3.5 Other sources of interference may be intermittent or mobile transmitters. Hence, at busy airfields with a significant amount of GNSS-based approaches it may be appropriate for the air traffic service provider to implement an interference ground monitoring system to provide timely notification to ATC of the possibility of interference.

5.8.4 Mitigation methods

5.8.4.1 There are a variety of different mitigation methods that can be applied to provide truly robust interference mitigation. A long-term mitigation methods is to deal with interference at its source. Until the discontinuation of microwave point-to-point links operation in the 1 159 - 1 610 MHz frequency band, the need for frequency reassignments for these links may arise in some regions to protect GNSS-based operations. Regulatory authorities can mandate appropriate performance standards, which limit unwanted emissions from interference sources such as TV and commercial VHF transmitters. Robust GNSS receiver designs will mitigate against harmful interference, both in the short and long term.

5.8.4.2 Coordination between VHF FM broadcasting services and the aviation community should be conducted using methods similar to ITU-R SM 1009-1. This ITU recommendation for ILS and VOR will ensure the protection of GBAS VDB signals.

5.8.4.3 Selection of the aircraft GNSS antenna location should take into account the possibility of on-board interference. On large aircraft, sufficient isolation between a transmitting antenna and a GNSS receiving antenna can usually be obtained to mitigate an interference problem. The possible generation of inter-modulation products on the aircraft from one transmitter (with multiple carriers) or multiple transmitters is controlled by a combination of transmitter filtering. It is recommended that airframe manufacturers, airline operators and State regulatory authorities take action to control such occurrences. The combination of appropriately shielded GPS and GLONASS antenna cabling, separation of antennas and cables and transmitter filters can solve most interference problems on board small aircraft.

5.8.4.4 The combined use of GPS and GLONASS signals in the same receiver can provide a more robust design against certain interference than either GPS or GLONASS alone due to its use of multiple frequencies. In the case of future GNSS applications such as GPS L5 and Galileo E5, other techniques may be required to mitigate against the possibility of interference from on-board equipment such as DME interrogator.

5.8.4.5 Protection can also be obtained from the effects of interference through the coupling of GNSS receivers with inertialnavigation systems (INS), as the functions of both systems are complementary.

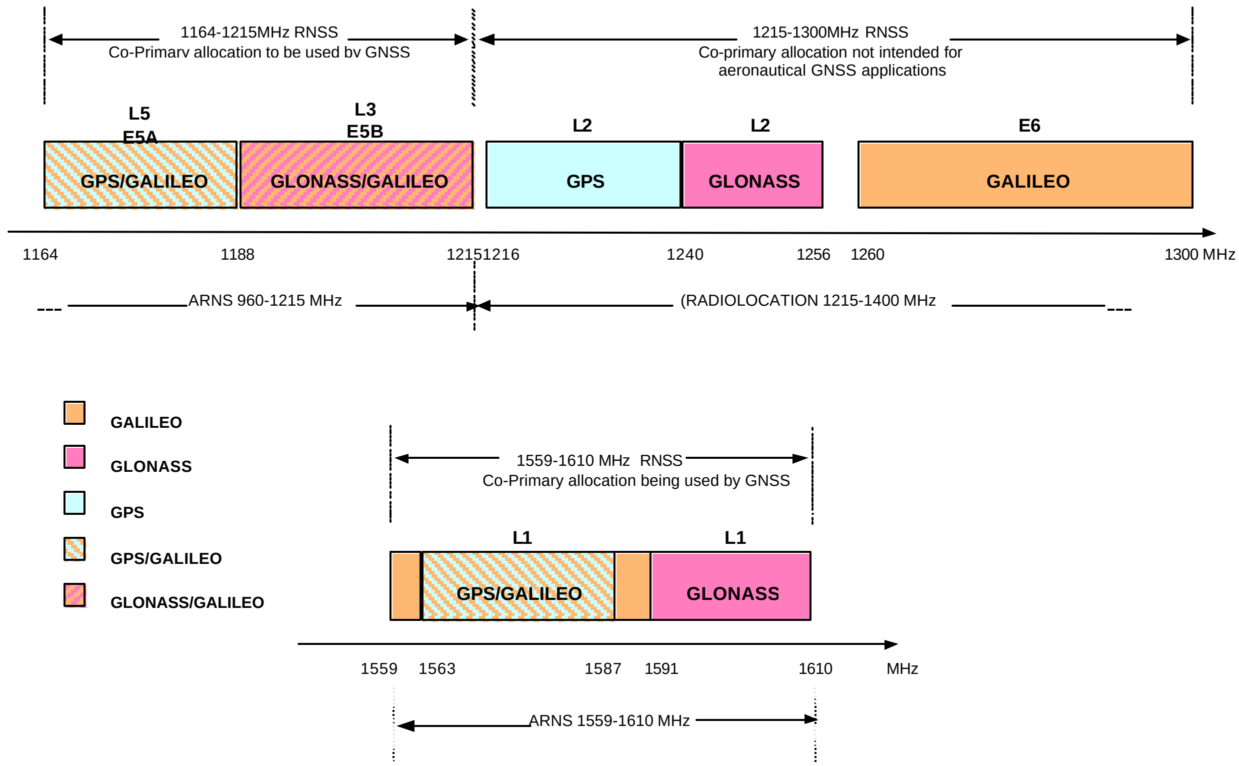
The radiation pattern of the antenna and the antenna's position on the aircraft are important in rejecting ground-based interference. Additionally, both adaptive antenna and adaptive notch filter technologies have been applied to GNSS to help overcome the problems of interference. Whilst the technologies were originally developed to protect military users from hostile jammers of the GNSS signals, they have more recently found civil applications.

5.8.5 GNSS spectrum protection

5.8.5.1 The GNSS elements — GPS, GLONASS, SBAS, GBAS and their associated radio frequency are defined in the SARPs. The operations of the present GNSS elements are entirely based on the availability of aeronautical radionavigation services (ARNS) protection afforded to the 1 559 to 1 610 MHz band. It is extremely important that this core frequency band of GNSS is protected and that ICAO and all interested parties continue to maintain the status of the band.

5.8.5.2 In the longer term, the present GNSS elements will evolve as described in Chapter 6. GNSS signals in the 1559 to 1 610 MHz band will continue to be needed and protected. GNSS evolution will develop within this band as planned for GPS and GLONASS, with their projected enhanced signal structure and additional signal power.

5.8.5.3 GNSS evolution will also make use of new frequency bands. The ITU WRC 2000 allocated additional spectrum for RNSS applications, and a number of States have filed applications with the ITU. These include applications to use the bands 1 164 - 1 215 MHz, 1 260 - 1 300 MHz and 5 000 - 5 150 MHz. Those bands in which RNSS services are currently available or planned for use by GNSS are illustrated in Figure 5.1 together with information regarding the nature of their allocations in the ITU radio regulations.



5.8.5.4 GNSS needs to be protected internationally and at the national level by State radio administration policy which should account for the needs of aeronautical safety-of-life applications. This is essential if potential interference problems similar to that already existing for GPS and GLONASS are to be avoided. Fully protected GNSS frequency bands can only be achieved globally by State Radio Administrations agreeing collectively to protect these bands and, where necessary, include appropriate provisions in the ITU Radio Regulations. It is also necessary for State Civil Aviation Authorities to ensure compatibility between future GNSS signals in the 960 - 1 215 MHz band and existing ARNS protection of DME (and TACAN) to preserve the capability of existing infrastructure.

5.8.6 Summary

5.8.6.1 Interference from unintentional or intentional sources can present a risk to the safe use of GNSS, particularly for approach and landing operations. Therefore, the protection of the frequency spectrum used by aeronautical safety services is of paramount importance. International regulations state that the radionavigation service is afforded special protection. The ITU Radio Regulation S4.10 states that:

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

5.8.6.2 Each State planning to implement GNSS-based operations should ensure that regulations are in place to protect the use of the spectrum for radionavigation-satellite service (RNSS) and aeronautical radionavigation services (ARNS). Application of suitable electromagnetic compatibility standards using ITU-R recommendations and other available criteria should ensure adequate protection of GNSS.

5.8.6.3 The key issue for States is to access the likelihood and effects of interference to GNSS services in their airspace and utilize, as necessary, the mitigation methods appropriate to the operations being undertaken.

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 current navigation infrustructure.

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 committed to equip with GNSS avionics before decommissioning dates 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 supporting 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 in consideration of 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 2010 to 2015 period, 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 also allow receivers to eliminate ionospheric errors, 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 high levels. Moreover, 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 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 prove this promise; thus a decision will not be possible in the near term. In the mean time, 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 where 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 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 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 staged approach to a transition, by the advent of new features (e.g. dual frequency satellites) and by the addition of new GNSS elements (augmentations 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 perspective.

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. This decision, as noted above, requires close coordination with users.

5.9.4 Need for a back-up

5.9.4.1 Although it is a considerable engineering challenge, GNSS elements can be designed to meet the high levels of availability required to support a full transition to GNSS guidance for specific phases of flight. The key issue is not related to system design, however, but to the possibility of interference with GNSS signals, as described in Section 5.8. The interference possibility would require a backup to GNSS service. In some instances this backup can be procedural, while in others, the backup can be provided by terrestrial NAVAIDs, or by inertial systems in aircraft.

5.9.4.2 From a transition planning perspective, States should analyse GNSS outage risks taking into account the likelihood of interference, the possible duration and areas affected, traffic levels and, most importantly, the effects on operations. This analysis should consider each phase of flight separately, and should account for the fact that, in many States, traffic levels are not homogeneous. It may be possible, for example, to decommission all terrestrial NAVAIDs in sparsely-settled areas where the likelihood of interference is very low, while in busier areas, terrestrial NAVAIDs may be needed as a backup. The analysis should assess the effectiveness of procedural mitigation strategies as well as the use of terrestrial NAVAIDs.

5.9.4.3 Decisions to retain terrestrial NAVAIDs should be based on meeting the requirement in the most efficient and effective way from the perspective of users and service providers. These decisions should also consider regional and global factors to ensure that users do not have to retain different sets of avionics for different areas.

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Chapter 6.

EVOLUTION OF THE GNSS

6.1 GENERAL

6.1.1 GNSS will evolve, possibly by adding functions for existing elements, improvements of existing elements, creation of new elements, and decommissioning of others. The GNSS SARPs will have to evolve to take into account these changes.

6.1.2 The general position of ICAO as defined as early as 1990, at the Tenth Air Navigation Conference is to foresee 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, Volume I, Chapter 3, 3.7.2.4 do not include all types of operations, and should 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 The GNSS can be used in conjunction with applications such as automatic dependent surveillance (ADS) by 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. This may be used for data time stamping, surveillance and communication systems synchronisation and system management. The external systems that rely on this information may also impose additional requirements on GNSS.

6.2.4 As 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 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 foresee a possibility of GNSS service interruption or degradation during a national emergency situation as quoted in Article 89 of the Convention on International Civil Aviation. 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 Annex 10, Volume I provides SARPs for GPS, GLONASS, ABAS, SBAS and GBAS. These systems and related SARPs will evolve to supply an improved service by 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 modernisation

6.4.2.1 GPS is evolving to meet civil user needs. 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 civil use; the addition of a third civil signal (L5); protection and availability of one of the two new signals for safety-of-life services (ARNS allocation) by 2005; enhanced signal structure and additional signal power. The United States Government discontinued the use of SA effective 2 May 2000.

6.4.2.2 Although L2 is currently not part of the GPS Standard Positioning Service (SPS), many civil 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 C/A coded signals is essential for many critical GPS uses. The signals are planned to enhance the ability of GPS to support civil users' needs. A second, non-safety-of-life coded signal will be added at the GPS L2 frequency (1 227.60 MHz) on satellites scheduled for launch beginning in 2003. A third civil 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 2005. The L5 signal is a more robust signal with a power level of -154 dB. Until the second coded civil 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 the GPS system will meet civil and military requirements envisioned for the next 30 years. GPS III is being developed 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, be available for launch in 2007 and the full transition to GPS III (operational implementation) is expected to begin in 2009. Challenges that are being addressed include:

a) representing both civil 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 requirement 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 launch of the first GLONASS-M satellite is scheduled for 2003; the active lifetime will be increased up to 7 years (in comparison with current figure of 3 years) and technical specifications will be improved.

6.4.2.6 The following additional functions are foreseen for GLONASS-M satellites:

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

b) the introduction of radio links between GLONASS-M satellites to perform on-line 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 10 years that will transmit the standard accuracy signal for civilian users on three frequencies: L1, L2, L3.

6.4.2.8 The GLONASS-K L3 signal will have frequency division of channels and will occupy a 22 MHz band in the 1 164 - 1 215 MHz band. The use of the L3 signal, together with other accuracy signals will increase the stability and reliability of navigation signals. The next upgrade of GLONASS-K will introduce the capability of receiving and re-transmitting distress signals.

SBAS evolution

6.4.2.9 A key to providing 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 this source of error. New generations of navigation satellites will have this feature, meaning 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 European Community Council of Ministers of Transport made the decision to start the definition phase of a European satellite navigation system, called Galileo. It is 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 public regulated services. Galileo will also provide a Search and Rescue service compatible with COSPAS/SARSAT and 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 to be easy to use by combined GPS and Galileo receivers. It is planned to start the operational service of Galileo in 2008.

Ground-based regional augmentation system (GRAS)

6.4.3.5 GRAS is a blending of satellite/ground-based augmentation systems (SBAS/GBAS) concepts to enhance GPS/GNSS capabilities for supporting civil navigation needs. This approach, is SBAS-like in using a distributed network of reference stations for monitoring GPS, and a central processing facility for computing GPS integrity and differential correction information. But instead of transmitting this information to users via dedicated geostationary satellites (GEOs), GRAS delivers SBAS message data to a network of terrestrial stations for a local check and reformatting and rebroadcasting in the GBAS format and in the 108 - 117.975 MHz band. Each site 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 sovereignty control while providing unified corrections and integrity for en-route capability.

6.5 PROTECTION DATES

6.5.1 In order to protect investments in radio navigation 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 Volume I that no change in, or addition to, the Standards will require the equipment replacement before a predetermined date (e.g. 1 January 2010 for ILS or 1 January 2015 for MLS). In addition, continuity in the provision of specific aeronautical radio navigation 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 notice of the forthcoming change (e.g. replacement ILS with MLS or GBAS).

6.5.2 In general, this concept is also applied in GNSS SARPs although it was modified to allow for evolution of the system through its gradual enhancements. To enable such 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, 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. Further, a case of discontinuation of GNSS services provided by its various elements is covered in Chapter 2, 2.4.2 which permits the termination of a GNSS service on the basis of at least six-year advance notice made by a service provider. This would allow users and other affected parties sufficient lead-time to adapt to such changes.

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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 with vertical guidance
ARNS	aeronautical radio navigation service
ATS	air traffic services
C/A	coarse acquisition
CNS/ATM	communications, navigation, and surveillance/air traffic management
CPDLC	controller-pilot data link communications
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
FD	fault detection
FDE	fault detection and exclusion
GAGAN	GPS and GEO Augmented Navigation System
GBAS	ground-based augmentation system
GBAS/E	GBAS VDB elliptical polarisation

GBAS/H	GBAS VDB horizontal polarisation
GEO	geostationary earth orbit
GLONASS	GLObal NAvigation Satellite System
GPS	Global Positioning System
GRAS	ground-based regional augmentation system
ICAO	International Civil Aviation Organisation
IFR	instrument flight rules
ILS	instrument landing system
ITU	International Telecommunication Union
JAA	Joint Aviation Authorities
JTSO	JAA Technical Standing Order
LNAV/VNAV	lateral navigation/vertical navigation
MASPS	minimum aviation system performance standards
MEO	medium earth orbit
MLS	microwave landing system
MMR	multi-mode receiver
MSAS	multifunctional transport satellite-based augmentation system
NPA	non-precision approach
PANS-ATM	Procedures for Air Navigation Services — Air Traffic Management
PANS-OPS	Procedures for Air Navigation Services — Aircraft Operations
PPS	precise positioning service
PVT	position, velocity and time
RAIM	receiver autonomous integrity monitoring
RFI	radio frequency interference
RNAV	area navigation
RNP	required navigation performance
RNSS	radio navigation satellite services

RT	ranging and timing service
SA	selective availability
SARPs	Standards and Recommended Practices
SBAS	satellite-based augmentation system
SIS	signal-in-space
SPS	standard positioning service
TACAN	tactical air navigation
TSO	technical standard order (FAA)
VDB	VHF data broadcast
VFR	visual flight rules
VHF	very high frequency
VOR	VHF omnidirectional radio range
WAAS	wide area augmentation system
WGS-84	World Geodetic System - 1984

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APPENDIX B

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

A31-6: Consolidated statement of continuing ICAO policies and practices related to communications, navigation and surveillance/air traffic management (CNS/ATM) systems

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

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

ICAO 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 the 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

ICAO Circulars

Circ 257	Economics of Satellite-based Air Navigation Services
Circ 278	National Plan for CNS/ATM Systems

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APPENDIX C

GNSS IMPLEMENTATION TEAM —
EXAMPLE TERMS OF REFERENCE

1. INTRODUCTION

1.1 This document sets out example Terms of Reference for a Global Navigation Satellite System (GNSS) Implementation Team. The team includes members from regulatory and service provider organisations, and user representatives and defines the roles of participants 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 developing the standards, systems, procedures and the terms and conditions of 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 organisations 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 branches and divisions in the two organisations are described in Section 2.

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 Attachment to this document provides a GNSS Implementation Checklist, designed to assist States in introducing GNSS-based operations.

2. ROLES

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 its 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 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 to make 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 organization**

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 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 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**

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 **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 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 maximize harmonisation;

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 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 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 to Appendix C

GNSS implementation checklist

No.	Items to check	GNSS Manual reference
1.	Establish GNSS Implementation Team (GIT) Identify members from the regulator, air navigation service provider and the aviation community	Section 5.2.2
2.	Develop a GNSS Plan, defining State operational requirements and a schedule for the introduction of GNSS-based services. Identify required regulatory changes and business case elements to support expenditures on procedures development, related elements and augmentation systems.	Section 5.2.3
3.	Define procedures, airspace and ATS requirements Develop operational use policy, separation standards application and ATC procedures for GNSS operations.	Sections 5.3, 5.4, 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 AIP, AICs 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.	Sections 5.6, 5.7
5.	Plan for the introduction of GNSS operations in oceanic, continental and terminal areas, based on traffic density and airspace characteristics.	Section 5.4
6.	Develop and publish GNSS approach procedures, using approved design criteria and accounting for aerodrome standards.	Section 5.7.4
7.	Develop guidance material and approval processes covering the installation of GNSS avionics.	Sections 3.4, 5.7.3

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

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