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Global Navigation Satellite System (GNSS) Manual

Approved by the Secretary General
and published under his authority

Second Edition — 2013

International Civil Aviation Organization

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AMENDMENTS

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EXECUTIVE SUMMARY

The growth of aviation and the urgent need to reduce fuel consumption, emissions and delays, requires increased airspace and airport capacity as well as a focus on providing a preferred trajectory (route and altitude) to each airspace user. This, in turn, dictates improvements to communications, navigation and surveillance (CNS) services. Aircraft operators also seek gains in efficiency via approaches that offer the lowest possible minima and the significant safety benefits of straight-in approaches and vertical guidance.

The draft fourth edition of the *Global Air Navigation Plan* (Doc 9750, GANP) presents a high level summary of ICAO's aviation system block upgrade (ASBUs) methodology. The ASBUs define operational objectives that address four specific and interrelated aviation performance areas: greener airports; globally interoperable systems and data; optimum capacity; and flexible flights and efficient flight paths. The draft GANP and ASBUs recognize the Global Navigation Satellite System (GNSS) as a technical enabler supporting improved services that meet these objectives. Roadmaps in the draft GANP outline timeframes for the availability of GNSS elements, the implementation of related services and the rationalization of conventional infrastructure.

GNSS supports positioning, navigation and timing (PNT) applications. GNSS is already the foundation of performance-based navigation (PBN), automatic dependent surveillance – broadcast (ADS-B) and automatic dependent surveillance – contract (ADS-C), as described below. GNSS also provides a common time reference used to synchronize systems, avionics, communication networks and operations, and supports a wide range of non-aviation applications.

The ICAO *Charter on the Rights and Obligations of States Relating to GNSS Services* highlights the principles that shall apply in the implementation and operation of GNSS, including: the primacy of safety; non-discriminatory access to GNSS services; State sovereignty; the obligation of provider States to ensure reliability of services; and cooperation and mutual assistance in global planning.

This manual provides information about GNSS technology and operational applications to assist State regulators and air navigation service (ANS) providers to complete the safety and business case analyses needed to support implementation decisions and planning.

GNSS implementation

The introduction of GNSS-based services was made possible by the operational implementation of two core satellite constellations, the Global Positioning System (GPS) and the Global Navigation Satellite System (GLONASS), provided, respectively, by the United States of America and the Russian Federation. GPS and GLONASS signals are defined in Annex 10 – *Aeronautical Telecommunications*, Standards and Recommended Practices (SARPs).

In 1994, the United States offered GPS to support the needs of international civil aviation, and reaffirmed the offer in 2007; the ICAO Council accepted both offers. In 1996, the Russian Federation offered GLONASS to support the needs of international civil aviation; the ICAO Council accepted this offer. Both States are upgrading their constellations and have committed to ICAO to take all necessary measures to maintain service reliability. Europe and China are developing systems (respectively, Galileo and BeiDou) that will be interoperable with upgraded GPS and GLONASS. The availability of multiple constellations addresses certain technical and institutional issues.

GPS was declared fully operational in 1993, and several States approved the use of GPS guidance for instrument flight rules (IFR) en-route, terminal and non-precision approach (NPA) operations that same year. In 2001, ICAO adopted SARPs supporting GNSS operations based on augmenting core satellite constellation signals to meet safety and reliability requirements.

There are three augmentation systems defined in Annex 10: the aircraft-based augmentation system (ABAS); the satellite-based augmentation system (SBAS); and the ground-based augmentation system (GBAS).

ABAS is an avionics implementation that processes GPS and/or GLONASS signals to deliver the accuracy and integrity required to support en-route, terminal and non-precision approach (NPA) operations.

SBAS uses a network of ground reference stations and provides signals from geostationary Earth orbit (GEO) satellites to support operations from en-route through to approaches with vertical guidance over a large geographic area. SBAS approach operations do not require augmentation stations at the airports served. The Wide Area Augmentation System (WAAS), an SBAS developed by the United States, has been operational since 2003. It also provides service in Canada and Mexico. The Japanese Multi-functional Transport Satellite (MTSAT) Satellite-based Augmentation System (MSAS) became operational in 2007. The European Geostationary Navigation Overlay Service (EGNOS) became operational in early 2011. The Indian GPS and GEO Augmented Navigation System (GAGAN) is expected to be operational in 2013. The Russian System of Differential Correction and Monitoring (SDCM) is under development and is expected to be operational in 2015. These systems have the potential to support seamless guidance where their service areas overlap. As of 2012, almost 3 000 SBAS vertically guided approach procedures were implemented, mostly in North America, some of which support Category I (CAT I) minima, currently provided by the instrument landing system (ILS). Over 1 100 of these serve airports without ILS. For technical reasons described in this manual, the current SBAS architecture cannot reliably support approaches with vertical guidance in equatorial areas.

GBAS uses monitoring stations at airports to process signals from core constellations and broadcast corrections and approach path data to support precision approach operations. As of 2012, approximately 40 GBAS stations around the world were supporting testing and CAT I operations with special approvals. GBAS has the potential to support CAT II/III and some surface movement operations, as well as terminal area navigation.

Performance-based navigation (PBN)

One key to increased airspace capacity is a transition to a total area navigation environment in which aircraft maintain flight paths within defined corridors. GNSS-based PBN provides seamless, harmonized and cost-effective guidance from departure to vertically guided final approach that provides safety, efficiency and capacity benefits. The *Performance-based Navigation (PBN) Manual* (Doc 9613 – hereafter referred to as the PBN Manual) describes implementation processes, and for each navigation application, air navigation services (ANS) provider considerations and a navigation specification describing performance, functionality and associated operations. Navigation specifications include approval processes and requirements for aircraft, aircrew knowledge and training. The PBN concept represents a shift from technology-based to performance-based navigation, but for all except the least demanding applications, GNSS is required. GNSS enables States to develop a PBN implementation plan in accordance with ICAO Resolution A37-11 – Performance-based navigation global goals.

Automatic dependent surveillance – broadcast (ADS-B)

Improved surveillance performance is the key to reduced separation standards, increased airspace capacity and the ability to support user-preferred trajectories. ADS-B is based on aircraft broadcasting GNSS position, velocity and other on-board data. ADS-B ground stations, which are much less costly than radars, receive and process aircraft ADS-B data for use on controller situation displays. Other suitably equipped aircraft can also process and display these data to enhance aircrew situational awareness. Several States have implemented ADS-B in areas where there is no radar coverage. This has allowed for a reduction in separation from as much as eighty to five nautical miles, thus increasing airspace capacity and supporting reductions in fuel consumption and emissions.

Automatic dependent surveillance – contract (ADS-C)

In oceanic and remote areas where it is not possible to install either radar or ADS-B ground stations, ADS-C position reports are relayed via communications satellites to air traffic control (ATC). In this implementation, ATC specifies when to provide position reports in a contract. A significant number of aircraft already use ADS-C in designated oceanic and non-radar continental airspace, and this technology has also led to reduced separation standards.

Safety risk management

GNSS SARPs and avionics standards were developed to meet recognized safety targets, so, in most cases, no further analysis of technical risk is required. Procedure design standards in the *Procedures for Air Navigation Services – Aircraft Operations* (PANS-OPS) (Doc 8168) have a similar safety foundation. Many States have introduced GNSS-based services since GPS was declared fully operational in 1993. The regulations and operational procedures developed by these States reflect a safety assessment that can be used as a basis by other States when they are developing regulations, training programmes, procedures and implementation plans for their operational environment.

GNSS signals are vulnerable to intentional and unintentional interference and to certain natural phenomena. States can manage this by controlling the use of spectrum and by having procedures in place and retaining some conventional infrastructure to mitigate the impact on operations in the event of a temporary loss of service. This manual discusses related issues and describes strategies for rationalizing networks of conventional aids.

Business case

The business case supporting an implementation decision considers the costs and benefits of the operational implementation of a GNSS-based service. Several States have completed such analyses for the implementation of ABAS, SBAS, GBAS, ADS-B and ADS-C operations. This manual describes the factors that are normally considered. The implementation of en-route, terminal and NPA operations relying on core constellations has significant benefits in terms of reduced flying time and improved airport access. Without the requirement to install ground aids and because approach procedure flight checks are not required periodically and do not require aircraft with complex equipment, ANS provider-costs are low.

ANS providers need to include aircraft operators in the development of business cases to ensure that all benefit and cost elements are validated and that investments are coordinated. The analysis needs to consider all GNSS-based services to ensure that operators acquire avionics that meet their expectations. Experience has shown that operators will invest in avionics if there are significant incremental benefits.

Implementation of GNSS-based services

GPS has provided safety and efficiency benefits to civil aviation since 1993, leading to widespread acceptance of GNSS-based services by aircraft operators, State regulators and ANS providers. Many States have started reorganizing airspace for increased efficiency based on PBN, ADS-B and ADS-C, and have designed approaches that enhance safety and improve airport accessibility. The availability of multiple constellations broadcasting on multiple frequencies will make GNSS more robust and will allow service expansion with increased benefits after 2020 when systems and avionics are available. In the meantime, ANS providers can work with aircraft operators to expand GNSS-based services and benefits while planning next generation services.

When planning to implement GNSS-based operations, States are encouraged to refer to the GANP and relevant ASBUs, to comply with ICAO provisions and to take advantage of the expertise and information available at the ICAO planning and implementation regional groups (PIRGs).

FOREWORD

The draft fourth edition of the *Global Air Navigation Plan* (Doc 9750, GANP) presents a high level summary of ICAO's aviation system block upgrade (ASBU) methodology. ASBUs define operational objectives that address goals of: greener airports; globally interoperable systems and data; optimum capacity; and flexible flights and efficient flight paths. The Global Navigation Satellite System (GNSS) is recognized within the ASBU system as a key element of the air navigation system that will deliver improved services and meet these objectives.

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

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

This manual is to be used in conjunction with the relevant provisions in Annex 10, Volume I, and with the *Performance-based Navigation (PBN) Manual* (Doc 9613).

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

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GLOSSARY

AAIM	Aircraft autonomous integrity monitoring
ABAS	Aircraft-based augmentation system
ACARS	Aircraft communications addressing and reporting system
ACAS	Airborne collision avoidance system
ADF	Automatic direction finder
ADS-B	Automatic dependent surveillance – broadcast
ADS-C	Automatic dependent surveillance – contract
AIC	Aeronautical information circular
AIP	Aeronautical information publication
AIRAC	Aeronautical information regulation and control
AIS	Aeronautical information service
AM(R)S	Aeronautical mobile (R) services
ANS	Air navigation services
APC	Approach
APNT	Alternative position, navigation and timing
APV	Approach procedure with vertical guidance
ARAIM	Advanced RAIM
ARNS	Aeronautical radio navigation service
ASBU	Aviation system block upgrade
ATC	Air traffic control
ATM	Air traffic management
ATS	Air traffic services
Baro VNAV	Barometric vertical navigation
BDT	BeiDou time
BeiDou	BeiDou navigation satellite system
C/A	Coarse/acquisition
CAT I	Category I
CAT II	Category II
CAT III	Category III
CDMA	Code-division-multiple-access
CFIT	Controlled flight into terrain
CGS2000	China Geodetic System 2000
C/N ₀	Carrier-to-noise density
CNS	Communications, navigation and surveillance
CONOPS	Concept of operations
COSPAS-SARSAT	Space system for search of vessels in distress – global search and rescue satellite-aided system
CPDLC	Controller-pilot data link communications
CSA	Code of standard accuracy
DA	Decision altitude
DH	Decision height
DME	Distance measuring equipment
EASA	European Aviation Safety Agency
EC	European Commission
EDCN	EGNOS data collection network
EGNOS	European Geostationary Navigation Overlay Service
ELT	Emergency locator transmitter

ETSO	European Technical Standard Order
EU	European Union
EUROCAE	European Organization for Civil Aviation Equipment
FAA	Federal Aviation Administration
FAS	Final approach segment
FD	Fault detection
FDE	Fault detection and exclusion
FDMA	Frequency division multiple access
FMS	Flight management system
ft	Feet
GAGAN	GPS Aided GEO Augmented Navigation System
GANP	Global Air Navigation Plan
GAST	GBAS approach service type
GBAS	Ground-based augmentation system
GBAS/E	GBAS VDB elliptical polarization
GBAS/H	GBAS VDB horizontal polarization
GEO	Geostationary Earth Orbit (satellite)
GIVE	Grid ionospheric vertical error
GLONASS	GLOBAL NAVIGATION Satellite System
GLS	GBAS landing system
GNSS	Global navigation satellite system
GPS	Global Positioning System
GPWS	Ground proximity warning system
GRAS	Ground-based regional augmentation system
HAL	Horizontal alert limit
HEO	Highly Elliptical Orbit
HMI	Hazardously misleading information
HPL	Horizontal protection level
Hz	Hertz
ICAO	International Civil Aviation Organization
ICD	Interface control document
IFR	Instrument flight rules
IGSO	Inclined geosynchronous orbit
ILS	Instrument landing system
IRS	Inertial reference system
ITRF	International terrestrial reference frame
ITU	International Telecommunication Union
LAL	Lateral alert limit
LEO	Lower Earth orbit
LNAV/VNAV	Lateral navigation/vertical navigation
LP	Localizer performance
LPL	Lateral protection level
LPV	Localizer performance with vertical guidance
m	Metres
MASPS	Minimum aviation system performance standard
MEA	Minimum en-route altitude
MEO	Medium Earth orbit
MLS	Microwave landing system
MMR	Multi-mode receiver
MOPS	Minimum operational performance standards
MSAS	MTSAT Satellite-based Augmentation System
MTSAT	Multifunctional Transport Satellite
NAGU	Notice Advisory to GLONASS Users

NANU	Notice Advisory to NAVSTAR Users
NDB	Non-directional radio beacon
NOTAM	Notice to Airmen
NPA	Non-precision approach
NSP	Navigation Systems Panel
P-code	Precise code
PAN	Performance analysis Network
PANS-ATM	Procedures for Air Navigation Services — Air Traffic Management (Doc 4444)
PANS-OPS	Procedures for Air Navigation Services — Aircraft Operations (Doc 8168)
PBN	Performance-based navigation
PIRG	Planning and Implementation Regional Group
PNT	Positioning, navigation and timing
PPS	Precise positioning service
PRN	Pseudo-random noise
PZ-90	Parameters of the Earth 1990 coordinate system used in GLONASS
RAIM	Receiver autonomous integrity monitoring
RF	Radio frequency
RNAV	Area navigation
RNP	Required navigation performance
RNSS	Radionavigation-satellite service
RSOO	Regional safety oversight organization
RTCA	RTCA, Inc.
SA	Selective availability
SAR	Search and rescue
SARPs	Standards and Recommended Practices
SBAS	Satellite-based augmentation system
SDCM	System of differential correction and monitoring
SID	Standard instrument departure
SIS	Signal-in-space
SPS	Standard positioning service
STAR	Standard instrument arrival
TACAN	UHF tactical air navigation aid
TAWS	Terrain awareness and warning system
TSO	Technical standard order
UDRE	User differential range error
UTC	Coordinated Universal Time
VAL	Vertical alert limit
VDB	VHF data broadcast
VFR	Visual flight rules
VHF	Very high frequency
VMC	Visual meteorological conditions
VNAV	Vertical navigation
VOR	VHF omnidirectional radio range
VPL	Vertical protection level
WAAS	Wide Area Augmentation System
WGS-84	World Geodetic System — 1984

Chapter 1

INTRODUCTION

1.1 GENERAL

1.1.1 The global navigation satellite system (GNSS) is defined in Annex 10 as a worldwide position and time determination system that includes one or more satellite constellations, aircraft receivers and system integrity monitoring, augmented as necessary to support the required navigation performance for the intended operation.

1.1.2 The draft fourth edition of the *Global Air Navigation Plan* (Doc 9750, GANP) recognizes GNSS as a key element of the air navigation system that will deliver improved services and meet environmental, efficiency and safety objectives.

1.1.3 The ICAO “Charter on the Rights and Obligations of States Relating to GNSS Services” addresses institutional issues. The Charter highlights the principles that shall apply in the implementation and operation of GNSS, including: the primacy of safety; non-discriminatory access to GNSS services; State sovereignty; the obligation of provider States to ensure reliability of services; and cooperation and mutual assistance in global planning.

1.1.4 States are ultimately responsible for ensuring that new air navigation services meet established safety Standards. In some cases, States pool resources to establish a regional safety oversight organization (RSOO) to ensure a common approach to safety regulation, oversight and enforcement. References to States in this manual also apply to RSOOs.

1.1.5 The content of this manual is aligned with several Assembly Resolutions as well as with the *Performance-based Navigation (PBN) Manual* (Doc 9613), *Safety Oversight Manual* (Doc 9734) and *Safety Management Manual (SMM)* (Doc 9859). Readers should be familiar with these and other relevant ICAO documents.

1.1.6 The navigation and PBN roadmaps in the GANP are reproduced in Appendices D and E. These roadmaps, which will be updated with each GANP revision, outline the time frames for the availability of GNSS elements, the implementation of related services and the rationalization of conventional infrastructure. These roadmaps provide States with planning outlines that are consistent with the ASBUs.

1.1.7 This manual provides information about GNSS technology and operations that will assist States to oversee the safety of GNSS operations and complete the business case analyses needed to support implementation decisions and planning.

1.2 GNSS ELEMENTS

1.2.1 The introduction of GNSS-based services was made possible by the operational implementation of two core satellite constellations, GPS and GLONASS, provided, respectively, by the United States and the Russian Federation. Both States are upgrading their constellations and have committed to ICAO to maintain service levels. Europe and China are developing systems (Galileo and BeiDou) that will be interoperable with upgraded GPS and GLONASS. All systems that are offered to support international civil aviation will be included in Annex 10. The frequencies used by existing and emerging core constellations are depicted in Appendix C.

1.2.2 The existing core satellite constellations were not designed to meet civil aviation performance requirements. Their signals require augmentation in the form of ABAS, GBAS or SBAS as prescribed in Annex 10. There are also SARPs for the ground-based regional augmentation system (GRAS), but no States plan to implement GRAS.

1.2.3 Annex 10 prescribes a six-year advance notice of any change in the SARPs that will require the replacement or modification of GNSS equipment. A six-year notice is also required of a core constellation or augmentation system provider who plans to terminate service.

1.3 IMPLEMENTATION OF GNSS-BASED SERVICES

1.3.1 Implementation of a GNSS-based service requires a State to complete, approve or accept safety assessments that support the implementation of training, airspace, instrument and ATC procedures, and the fielding of related systems, in compliance with applicable regulations.

1.3.2 ANS providers and aircraft operators will also normally complete business case analyses to support implementation of a GNSS-based service. Several States have completed such analyses for the implementation of ADS-B, ADS-C, Basic GNSS, GBAS and SBAS operations.

1.3.3 The transition to GNSS-based services represents a significant change for aviation, so it requires new approaches to regulation, provision of services, airspace, instrument and ATC procedures, and operation of aircraft.

1.3.4 A successful transition requires a comprehensive orientation and training programme aimed at all involved parties, including decision-makers in aviation organizations. Staff in regulatory and ANS provider organizations require training to better appreciate how they can contribute to the operational implementation of GNSS-based services. Training should include: the basic theory of GNSS operations; GNSS capabilities and limitations; avionics performance and integration; applicable regulations; and concepts of operation. This manual addresses most of these requirements.

1.4 OPERATIONAL APPLICATIONS OF GNSS

1.4.1 General

1.4.1.1 GNSS enables PBN and provides navigation guidance for all phases of flight, from en-route through to precision approach. By providing position information, GNSS enables ADS-B, ADS-C, moving map displays, terrain awareness and warning systems (TAWS) and synthetic vision systems. Emergency Locator Transmitters (ELTs) also use GNSS position data. GNSS also supports a wide variety of precision timing applications. Many States already employ GNSS to deliver improved service to aircraft operators where no conventional systems exist.

1.4.1.2 The first approvals to use GNSS came in 1993, supporting IFR en-route (domestic and oceanic), terminal and NPA operations. These approvals were based on the use of GPS signals and certified GPS avionics. The original approvals came with some operational restrictions but delivered significant benefits to aircraft operators. Since 1993, GPS has gained widespread acceptance by States and aircraft operators.

1.4.1.3 GNSS provides accurate guidance in remote, oceanic and mountainous areas where it is too costly or impossible to provide reliable and accurate conventional navigation aid guidance. GNSS can also provide service where it is not possible to install conventional aids (e.g. approaches to runways on islands).

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

1.4.1.5 The availability of GNSS-based services will allow the phased decommissioning of some conventional aids. This will result in savings for ANS providers and aircraft operators in the longer term. Even in the early stages of GNSS implementation, States may be able to avoid the cost of replacing some of these aids.

1.4.2 Performance-based navigation (PBN)

1.4.2.1 Meeting the goal of increased airspace capacity requires the transition to a total area navigation environment based on aircraft maintaining flight paths within defined corridors while en route, in the terminal area and on approach. The *Performance-based Navigation (PBN) Manual* (Doc 9613) explains the PBN concept and defines aircraft area navigation performance requirements in navigation specifications. These prescribe the accuracy, integrity, availability, continuity and functionality needed to support a particular airspace concept. The PBN concept represents a shift from technology-based to performance-based navigation, but, for all except the least demanding applications, GNSS is the key enabler.

1.4.2.2 ABAS and SBAS, as defined in Annex 10, support the application of GNSS signals-in-space within all the PBN specifications, ranging from oceanic en-route to approach with vertical guidance. The Standards for ABAS and SBAS avionics are identified within each individual PBN specification. ABAS supports the RNP approach navigation specification down to LNAV minima and when combined with barometric vertical navigation guidance (Baro VNAV), supports approaches with vertical guidance down to LNAV/VNAV minima. SBAS supports RNP approach with vertical guidance down to LPV minima, and localizer-like guidance down to LP minima, where vertical guidance is not feasible due to obstacles or terrain. RNP approach (APCH) requires GNSS.

1.4.2.3 In States without SBAS service and where few aircraft are equipped with Baro VNAV, GNSS can provide lateral guidance for straight-in approaches to the majority of runways now served by circling procedures, which are associated with a higher accident rate. The GBAS positioning service defined in Annex 10 may support some terminal area PBN in future, but GBAS is primarily designed to support CAT I/II/III operations and it will not likely be used for PBN to the same extent as ABAS and SBAS. GBAS approach is not considered a PBN operation.

1.4.2.4 GNSS enables compliance with ICAO Assembly Resolution A37-11, which requires States to "... complete a PBN implementation plan as a matter of urgency to achieve:

- 1) implementation of RNAV and RNP operations (where required) for en-route and terminal areas according to established timelines and intermediate milestones;
- 2) implementation of approach procedures with vertical guidance (APV) (Baro VNAV and/or augmented GNSS), including LNAV-only minima, for all instrument runway ends, either as the primary approach or as a back-up for precision approaches by 2016 with intermediate milestones as follows: 30 per cent by 2010, 70 per cent by 2014; and
- 3) implementation of straight-in LNAV-only procedures, as an exception to 2) above, for instrument runways at aerodromes where there is no local altimeter setting available and where there are no aircraft suitably equipped for APV operations with a maximum certificated take-off mass of 5 700 kg or more;".

1.4.2.5 The availability of "off-the-shelf" ABAS and SBAS avionics brings PBN within the economic reach of all aircraft operators. This allows States to design en-route and terminal airspace for maximum capacity and to support aircraft operators' requirements for preferred trajectories. PBN navigation specifications enabled by GNSS allow aircraft to follow more efficient flight paths, even in areas well served by conventional aids.

1.4.2.6 PBN navigation applications also require error-free navigation databases. States should therefore apply procedures and systems to ensure the integrity of the data as they are processed for use in avionics. As described in Chapter 7, commercial database suppliers process the data provided in State Aeronautical Information Publications (AIPs) for use in avionics.

1.4.3 Automatic dependent surveillance – broadcast (ADS-B)

Improved surveillance performance is the key to reduced separation standards, increased airspace capacity and the ability to support user-preferred trajectories. ADS-B is based on aircraft broadcasting GNSS position, velocity and other on-board data. ADS-B ground stations, which are much less costly than radars, provide ADS-B data for use on controller situation displays. Suitably equipped aircraft can also display these data to enhance aircrew situational awareness. Several States have implemented ADS-B in areas where there is no radar coverage. This has allowed for a reduction in separation from as much as eighty to five nautical miles, thus increasing airspace capacity and supporting significant reductions in fuel burn and emissions. Future concepts include using low Earth orbit (LEO) satellites to receive ADS-B position reports from aircraft, thus making it possible to extend service to oceanic and remote airspace.

1.4.4 Automatic dependent surveillance – contract (ADS-C)

In oceanic and remote areas where it is not possible to install surveillance ground stations, GNSS time-stamped position reports are relayed via satellite to ATC. With ADS-C, ATC specifies in a contract when to provide position reports – typically at significant points or at specified time intervals. Many aircraft already use ADS-C in designated oceanic and non-radar continental airspace, making it possible to reduce separation standards.

1.4.5 Aviation systems using GNSS time

GNSS provides precise time information that is used in many aviation systems to synchronize local clocks to Coordinated Universal Time (UTC). Synchronized clocks may then be used to assign a globally valid and comparable time stamp to events. Examples of current or future applications using GNSS time are: ADS-B and ADS-C, 4D navigation and trajectory synchronization, required time of arrival, multilateration and wide area multilateration, multi-radar tracking systems, air-ground data link, flight data processing and ground communication networks.

1.5 GNSS LIMITATIONS AND OTHER ISSUES

1.5.1 While GNSS offers significant benefits, the technology has some limitations that State regulators and ANS providers must address when introducing GNSS-based services.

1.5.2 This manual explains the vulnerability of GNSS signals to intentional and unintentional sources of interference and to certain ionospheric effects. It describes ways to reduce the likelihood that GNSS-based services will be disrupted by effectively controlling the use of spectrum and by ensuring that these issues are adequately addressed in avionics and augmentation system design. It describes how to mitigate the impact on aircraft operations in the event of the temporary loss of GNSS signals.

1.5.3 GNSS can support straight-in approaches with lower minima to many runways now served by non-directional radio beacons (NDBs) or VORs. Approach minima, however, also depend on the terrain, physical characteristics of the aerodrome and on airport infrastructure, such as lighting. States therefore have to consider the cost of meeting aerodrome standards when planning for new GNSS-based approaches or approaches with lower minima.

1.5.4 Realizing maximum benefits from GNSS-based services in en-route and terminal airspace requires virtually all aircraft to be equipped with GNSS avionics. Implementation decisions must take into account aircraft operators' plans to equip, which depend on cost savings that justify avionics and related costs. ANS providers and aircraft operators must work together and coordinate investments in GNSS technology.

1.5.4

Chapter 2

PERFORMANCE REQUIREMENTS

2.1 GENERAL

2.1.1 PBN navigation specifications define the accuracy, integrity, availability, continuity and functionality needed to support a particular airspace concept. Functional requirements include: displaying position relative to desired track; display of distance, bearing and time to the active waypoint; database requirements; and appropriate failure indications.

2.1.2 In the development of GNSS SARPs, total system requirements were used as a starting point for deriving specific signal-in-space performance requirements. Degraded performance that would simultaneously affect multiple aircraft was also considered.

2.1.3 Detailed design system performance requirements are outlined 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.

2.2 REQUIREMENTS

2.2.1 Accuracy

2.2.1.1 GNSS position accuracy is defined as the difference between a computed and a true position.

2.2.1.2 Ground-based systems such as very high frequency (VHF) omnidirectional radio range (VOR) and ILS have relatively time-invariant error characteristics. These characteristics can therefore be measured during flight inspection and subsequently be monitored electronically to ensure signal accuracy. GNSS errors, however, can change over a period of hours due to satellite movements and the effects of the ionosphere. Augmentation systems are designed to monitor and compensate for these changes.

2.2.2 Integrity and time-to-alert

2.2.2.1 Integrity is a measure of the trust that 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. In the case of a conventional aid like ILS, signal accuracy can be monitored at specific points. In contrast, GNSS integrity is based on avionics performing complex calculations to ensure that the error in computed position will not exceed the maximum allowed for the current operation.

2.2.2.2 The necessary level of integrity for each operation is established with respect to specific horizontal/lateral, and, for approaches with vertical guidance, vertical alert limits (HAL/LAL and VAL). Avionics continuously calculate corresponding protection levels (HPL/LPL and VPL). The terms HAL/HPL are used with ABAS and SBAS, whereas the terms LAL/LPL are used with GBAS. Protection levels are upper confidence bounds on position errors; alert limits define the maximum position error allowed for an operation. When any protection level exceeds the corresponding alert limit, the avionics must provide an alert and the aircrew must comply with prescribed procedures. ADS-B integrity, described in other standards documents, is linked to GNSS alert limits.

2.2.2.3 Time-to-alert is part of the integrity requirement; it is the maximum amount of time allowed from the onset of a failure condition to the annunciation in the aircraft.

2.2.2.4 The type of operation and the phase of flight dictate the maximum allowable horizontal/lateral and vertical errors, associated alert limits and the maximum time to alert the aircrew. These values, which are shown in Table 2-1, are taken from Annex 10 Table 3.7.2.4-1.

2.2.3 Continuity

2.2.3.1 Continuity is the capability of the system to perform its function without unscheduled interruptions during the intended operation, expressed as a probability. For example, there should be a high probability that guidance will remain available throughout an entire instrument approach procedure. In the case of ABAS, continuity depends on the number of satellites in view. For GBAS and SBAS, continuity also depends on redundancy of augmentation system components.

2.2.3.2 Continuity requirements are less stringent for low traffic density en-route airspace and more stringent for areas with high traffic density and airspace complexity where a failure could affect a large number of aircraft. Requirements are also more stringent for approach operations.

2.2.3.3 Where there is a high degree of reliance on GNSS for en-route and terminal area navigation, mitigation against loss of service may be achieved through the use of alternative navigation means or through the use of radar and ATC intervention to ensure that separation is maintained. This is not an option when ADS-B is the only surveillance source because GNSS provides ADS-B position.

2.2.3.4 For GNSS-based APV and CAT I approaches, missed approach is considered a normal operation, since it occurs whenever an aircraft descends to the decision altitude for the approach and the aircrew is unable to continue with visual reference. The continuity requirement for these operations applies to the average risk (over time) of loss of service, normalized to a 15-second exposure time. The specific risk of loss of continuity for a given approach could therefore exceed the average requirements without necessarily affecting the safety of the service provided or the approach. A safety assessment performed for one system led to the conclusion that, in the circumstances specified in the assessment, continuing to provide the service was safer than withholding it. Predicted failures for which a Notice to Airmen (NOTAM) is distributed are not to be considered in the continuity computation.

2.2.4 Availability

2.2.4.1 The availability of a service is the portion of time during which the system is simultaneously delivering the required accuracy and integrity. In fact, integrity always determines availability. Some applications have specific continuity requirements that need to be met to consider the service available. The movement of satellites relative to a coverage area complicates GNSS availability, as does the potential delay associated with returning a failed satellite to service. The level of availability in a certain airspace at a certain time should be determined through design, analysis and modelling, rather than through measurement. Guidance material pertaining to reliability and availability is contained in Annex 10, Volume I, Attachment F.

2.2.4.2 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 setting availability specifications for specific airspace, States should take into account traffic density, available conventional aids, radar surveillance coverage, potential duration and geographical size of outages, as well as flight and ATC procedures.

Table 2-1. Signal-in-space performance requirements

Operation	Oceanic en-route	Continental en-route	Terminal	Non-precision approach	Approach procedure with vertical guidance (APV)		Category I (CAT I)
					APV-I	APV-II	
Horizontal alert limit	7.4 km (4 NM)	3.7 km (2 NM)	1.85 km (1 NM)	556 m (0.3 NM)	40 m (130 ft)	40 m (130 ft)	40 m (130 ft)
Vertical alert limit	N/A	N/A	N/A	N/A	50 m (164 ft)	20 m (66 ft)	35 to 10 m (115 to 33 ft)
Time-to-alert	5 min	5 min	15 s	10 s	10 s	6 s	6 s

Note 1.— For ABAS-based non-precision approach, LNAV minima are specified on charts. There is another type of non-precision approach based on using SBAS to achieve localizer performance with a 40m HAL; LP minima are charted in this case.

Note 2.— APV implemented with SBAS has LPV minima specified on charts. These procedures can be based on APV-I, APV-II or CAT I alert limits. The alert limits are linked to SBAS performance and are stored in the avionics database. A State may design APV procedures with geographically varying alert limits (e.g. APV-I close to the edge of coverage, CAT I elsewhere).

Note 3.— The term APV also encompasses approaches using GNSS lateral guidance with Baro VNAV providing the vertical; associated minima are charted as LNAV/VNAV. In this case, the horizontal alert limit is usually that for ABAS-based non-precision approach, and the vertical alert limit is not applicable, since there is no technical way to establish Baro VNAV integrity. The approach procedure design accounts for the Baro VNAV technical performance, which is defined in the PBN Manual.