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Doc 9849

Global Navigation Satellite System (GNSS) Manual

Third Edition, 2017



Approved by and published under the authority of the Secretary General

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AMENDMENTS

Amendments are announced in the supplements to the *Catalogue of ICAO Publications*; the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

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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 fifth edition of the *Global Air Navigation Plan* (Doc 9750, GANP) presents a high-level summary of ICAO's aviation system block upgrade (ASBU) methodology. The ASBUs define operational objectives that address four specific and interrelated aviation performance areas: airport operations; globally interoperable systems and data; optimum capacity and flexible flights; and efficient flight paths. The GANP and ASBUs recognize the Global Navigation Satellite System (GNSS) as a technical enabler supporting improved services that meet these objectives. Roadmaps in the 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.

Assembly Resolution A32-19 — *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 and the Russian Federation. GPS and GLONASS signals are defined in the Standards and Recommended Practices (SARPs) in Annex 10 — *Aeronautical Telecommunications*.

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 the BeiDou Navigation Satellite System) 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 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 Multifunctional 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 Aided GEO Augmented Navigation System (GAGAN) became operational in 2015. The Russian Federation's System of Differential Correction and Monitoring (SDCM) is under development and is expected to be operational after 2020. These systems have the potential to support seamless guidance where their service areas overlap. As of 2017, almost 5 000 SBAS vertically guided approach procedures were implemented, most of which support Category I (CAT I) minima consistent with instrument landing system (ILS) performance. For technical reasons described in this manual, the current SBAS architecture does not consistently support approaches with vertical guidance in equatorial areas with a high level of availability.

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 2017, approximately 140 GBAS stations were certified and transmitting SARPs-compliant signals, about half of which have published procedures for CAT I operations; a number of prototype stations provide signals for test and evaluation, several of which are used for validation of GBAS approach service types to support Category II/III operations; over 100 airlines have GBAS equipage, totalling over 2 000 aircraft. GBAS is used in daily revenue service in several States.

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) describes implementation processes, and for each navigation application, 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 this 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 cost and benefit 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).

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FOREWORD

The fifth 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: airport operations; 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 methodology 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 in 2001 as part of Amendment 76 to Annex 10 to the *Convention on International Civil Aviation — Aeronautical Telecommunications*, Volume I — *Radio Navigation Aids*. 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	Automatic dependent surveillance
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
APCH	Approach
APNT	Alternative position, navigation and timing
APV	Approach procedure with vertical guidance
ARAIM	Advanced RAIM
ARNS	Aeronautical radionavigation service
ASBU	Aviation system block upgrade
ASRS	Aviation safety reporting system
ATC	Air traffic control
ATM	Air traffic management
ATS	Air traffic services
Baro VNAV	Barometric vertical navigation
BDS	BeiDou Navigation Satellite System
BDSBAS	BeiDou Satellite-based Augmentation System
BDT	BeiDou time
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	Channel of standard accuracy
CW	Continuous wave
DFMC	Dual-frequency, multi-constellation
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
EIRP	Equivalent isotropically radiated power
ELT	Emergency locator transmitter
ETSO	European Technical Standard Order
EU	European Union
EUROCAE	European Organization for Civil Aviation Equipment
EVAIR	Eurocontrol voluntary ATM incident reporting
FAA	Federal Aviation Administration
FAS	Final approach segment
FD	Fault detection
FDE	Fault detection and exclusion
FDMA	Frequency division multiple access
FIR	Flight information region
FMS	Flight management system
ft	Feet
GAGAN	GPS Aided GEO Augmented Navigation
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
HMI	Hazardously misleading information
HPL	Horizontal protection level
Hz	Hertz
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICD	Interface control document
IFR	Instrument flight rules
IGS	International GNSS Service
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	Low 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
NASA	National Aeronautics and Space Administration
NDB	Non-directional radio beacon
NGS	National Geodetic Service
NOTAM	Notice to Airmen
NPA	Non-precision approach
NSP	Navigation Systems Panel
P-code	Precision code
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
PPD	Personal privacy device
PPS	Precise positioning service
PRN	Pseudo-random noise
PZ-90	Parameters of the Earth 1990 coordinate system used in GLONASS
QZSS	Quasi-Zenith Satellite System
RAIM	Receiver autonomous integrity monitoring
RF	Radio frequency
RFI	Radio frequency interference
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
SISE	Signal-in-space error
SOPAC	Scripps Orbit and Permanent Array Center
SPS	Standard positioning service
STAR	Standard instrument arrival
TACAN	UHF tactical air navigation aid
TAWS	Terrain awareness and warning system
TETRA	Terrestrial Trunked Radio
TSO	Technical standard order
UAV	Unmanned aircraft vehicles
UDRE	User differential range error
URE	User range error
USCG	United States Coast Guard

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 — *Aeronautical Telecommunications* 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 (RNP) for the intended operation.

1.1.2 The fifth 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 Assembly Resolution A32-19 — *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 of this manual. These roadmaps, which are 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, the Global Positioning System (GPS) and the Global Navigation Satellite System (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 the BeiDou Navigation Satellite System (BDS)) 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 aircraft-based augmentation system (ABAS), ground-based augmentation system (GBAS) or satellite-based augmentation system (SBAS) as prescribed in Annex 10. There are also Standards and Recommended Practices (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 air traffic control (ATC) procedures, and the fielding of related systems, in compliance with applicable regulations.

1.3.2 Air navigation services (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 automatic dependent surveillance — broadcast (ADS-B), automatic dependent surveillance — contract (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 instrument flight rules (IFR) en-route (domestic and oceanic), terminal and non-precision approach (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. 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 lateral navigation (LNAV) minima and when combined with barometric vertical navigation (Baro VNAV) guidance, supports approaches with vertical guidance down to LNAV/VNAV minima. SBAS supports RNP approach with vertical guidance down to lateral protection level (LPV) minima, and localizer-like guidance down to localizer performance (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 it is processed for use in avionics. As described in Chapter 7, 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 this 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 VHF omnidirectional radio range (VOR). Approach minima, however, also depend on the terrain, on the physical characteristics of the aerodrome and on the 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.

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 — *Radio Navigation Aids*, 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 VOR and instrument landing system (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 (NPA)	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 NPA, LNAV minima are specified on charts. There is another type of NPA based on using SBAS to achieve localizer performance with a 40 m 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 NPA 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 Performance-based Navigation (PBN) Manual (Doc 9613).

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Chapter 3

EXISTING CORE SATELLITE CONSTELLATIONS

3.1 GENERAL

GPS and GLONASS satellites broadcast very precise timing signals and data messages that include their orbital parameters (ephemeris data). If receiver clocks were perfectly synchronized with the very accurate satellite clocks, a receiver could calculate its three-dimensional position by knowing its range from three satellites. In practice, it calculates the “pseudo-ranges” to at least four satellites as well as their positions at time of transmitting. By finding the pseudo-range of the fourth satellite, the receiver is able to calculate the clock offset. Accuracy is dependent on the precision of the range measurements and the relative positions (geometry) of the satellites used. Geometry is ideal when satellites are widely spaced; it is poor when they are grouped in one direction. Joint use of more than one constellation improves GNSS performance.

3.2 GLOBAL POSITIONING SYSTEM (GPS)

3.2.1 The United States Air Force operates GPS for the government of the United States. In 1994, the United States offered the GPS standard positioning service (SPS) to support the needs of international civil aviation, and reaffirmed the offer in 2007 as follows: “The US Government maintains its commitment to provide GPS SPS signals on a continuous worldwide basis, free of direct user fees, enabling worldwide civil space-based PNT services (to include GPS SPS augmentations), and to provide open, free access to information necessary to develop and build equipment to use these services.” The ICAO Council accepted both offers. The United States has published and maintains a GPS performance standard that defines the service commitments.

3.2.2 The nominal GPS space segment is comprised of 24 satellites in six orbital planes. The satellites operate in near-circular orbits at an altitude of 20 200 km (10 900 NM) and an inclination angle of 55 degrees to the equatorial plane; each satellite completes an orbit in approximately 12 hours. The GPS control segment has 17 monitor stations and four ground antennas with uplink capabilities. The monitor stations use GPS receivers to track all satellites in view and accumulate ranging data. The master control station processes this information to determine satellite clock and orbit states and to update the navigation message of each satellite. This updated information is transmitted to the satellites via the ground antennas, which are also used for receiving and transmitting health and control information.

3.2.3 The navigation message is made up of three major components. The first contains the GPS date and time, plus the satellite’s status and an indication of its health. The second contains orbital information called “ephemeris” data that allows the receiver to calculate the position of the satellite. The third, called the almanac, provides the locations and pseudo-random noise (PRN) codes of all the satellites, which allows the receiver to determine which satellites are in view.

3.2.4 The GPS SPS, using a coarse/acquisition (C/A) code on the L1 frequency (1 575.42 MHz), is designed to provide global users with accurate positioning. A precise positioning service (PPS), which uses the precision code (P-code) on L2 (1 227.60 MHz), provides a more accurate positioning capability, but is encrypted to restrict its use to authorized agencies. GPS uses code-division-multiple-access (CDMA), meaning that all satellites broadcast on the same frequency and are differentiated by transmitting unique PRN codes.

3.2.5 The GPS SPS performance standard defines the level of performance commitment to civilian users. The interface specification IS-GPS 200 details the technical characteristics of the SPS L-band carrier and the C/A code as well as the technical definition of requirements between the GPS constellation and SPS receivers. The performance standard is conservative, in that it guarantees only 21 satellites are operational and in the proper orbital slot 98 per cent of the time. GNSS-based service design should be based on the conservative guarantees, but this means that most of the time availability of service will exceed committed availability levels. The number of operational satellites typically exceeds 30. GPS has met existing performance standards continuously since 1993. Additional information can be found on the GPS website (www.gps.gov/system/gps/performance).

3.2.6 GNSS-based services were introduced when GPS reached full operational capability in 1993, and GPS continues to support all such services. Moreover, the availability of the GPS performance standard allows manufacturers, regulators and ANS providers to develop and operate aviation systems.

3.2.7 The United States has developed the following space-based positioning, navigation and timing (PNT) policy (see <http://www.gps.gov>) to guide its efforts in the further development of GPS and augmentation systems:

- a) provide GPS and augmentations free of direct user fees on a continuous, worldwide basis;
- b) provide open, free access to information needed to develop user equipment;
- c) improve performance of GPS and augmentations; and
- d) seek to ensure international systems are interoperable with civil GPS and augmentations or, at a minimum, are compatible.

3.3 GLOBAL NAVIGATION SATELLITE SYSTEM (GLONASS)

3.3.1 The Ministry of Defence of the Russian Federation operates GLONASS. The Federal Space Agency of the Russian Federation is appointed to act as a coordinator of activities on maintenance and development of the GLONASS system, civilian applications and relevant international cooperation. In 1996, the Russian Federation offered GLONASS service to civil aviation as follows: "... to confirm, on behalf of the government of the Russian Federation, the proposal made at the tenth Air Navigation Conference concerning the provision of a standard-accuracy GLONASS channel to the world aviation community for a period of at least 15 years with no direct charges collected from users." The ICAO Council accepted the offer.

3.3.2 The nominal GLONASS space segment consists of 24 operational satellites and several spares. GLONASS satellites orbit at an altitude of 19 100 km (10 310 NM) with an orbital period of 11 hours and 15 minutes. Eight evenly spaced satellites are arranged in each of three orbital planes, inclined at 64.8 degrees to the equator and spaced 120 degrees apart. GLONASS provides three-dimensional position and velocity determinations based upon the measurement of transit time and Doppler shift of radio frequency (RF) signals transmitted by GLONASS satellites.

3.3.3 A navigation message transmitted from each satellite consists of satellite coordinates, velocity and acceleration vector components, satellite health information and corrections to GLONASS system time. GLONASS satellites broadcast navigation signals in the L1 frequency band (1 559 – 1 610 MHz) modulated by channel of standard accuracy (CSA) codes and contain the navigation data message. GLONASS is based upon a frequency division multiple access (FDMA) concept: each satellite transmits carrier signals on a different frequency. 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 an identical CSA code.

3.3.4 The navigation data message provides information regarding the status of the 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 an individual satellite's time and GLONASS system time, which is referenced to Coordinated Universal Time (UTC).

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

3.3.6 The GLONASS control segment performs satellite monitoring and control functions, and determines the navigation data to be modulated on the coded satellite navigation signals. The control segment includes a master control station as well as monitoring and upload stations. The master control station processes measurement data from each monitoring station and computes the navigation data that upload stations broadcast to the satellites. Operation of the system requires precise synchronization of satellite clocks with GLONASS system time. To accomplish such synchronization, the master control station provides the clock correction parameters.

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Chapter 4

AUGMENTATION SYSTEMS

4.1 GENERAL

The existing core satellite constellations require augmentation by ABAS, GBAS or SBAS to meet Annex 10 performance requirements for specific operations. GNSS avionics process signals from core satellite constellations, and, where available, GBAS or SBAS signals, to meet these requirements. Avionics Standards documents are listed in Appendix A.

4.2 AIRCRAFT-BASED AUGMENTATION SYSTEM (ABAS)

4.2.1 ABAS is an avionics implementation that processes core constellation signals with information available on board the aircraft. Many States have taken advantage of GPS/ABAS to improve service without incurring any expenditure on infrastructure.

4.2.2 There are two general classes of integrity monitoring: receiver autonomous integrity monitoring (RAIM), which uses GNSS information exclusively, and aircraft autonomous integrity monitoring (AAIM), which also uses information from additional on-board sensors such as inertial reference systems (IRS).

4.2.3 ABAS provides integrity monitoring using redundant range measurements to support fault detection (FD) or fault detection and exclusion (FDE). The goal of FD is to detect a potential position error caused by a satellite exceeding tolerances. Upon detection, the navigation function is lost. Avionics with FDE identify and exclude the faulty satellite, thereby allowing GNSS navigation to continue without interruption, provided that sufficient healthy satellites with good geometry remain in view.

4.2.4 An essential element of ABAS is a Basic GNSS receiver that supports en-route, terminal and NPA operations and provides, as a minimum, RAIM FD. To enhance the overall performance of the aircraft navigation system, the GNSS receiver may be incorporated into an integrated navigation system as a sensor.

4.2.5 A Basic GNSS receiver meets the requirements for a GPS receiver as outlined in Annex 10 and the specifications of RTCA/DO-208 or EUROCAE ED-72A, as amended by United States Federal Aviation Administration (FAA) TSO-C129A or European Aviation Safety Agency (EASA) ETSO-C129c (or equivalent). These documents specify the minimum performance standards for en-route, terminal and NPA operations. RAIM satisfies the PBN requirement for on-board performance monitoring and alerting prescribed in RNP specifications. Combined GLONASS/GPS airborne receivers are used in the Russian Federation.

4.2.6 In addition to RAIM FD, a Basic GNSS receiver must support turn anticipation and the retrieval of approach procedures from a read-only electronic navigation database. Receiver design does not allow for approaches with user-defined waypoints, and if the aircrew changes or deletes any waypoint that is part of an approach, the receiver will not enter the approach mode.

4.2.7 RAIM requires redundant satellite range measurements (at least five satellites with good geometry) to detect a faulty signal and alert the aircrew; FDE requires six. The availability of RAIM and FDE is slightly lower for mid-latitude operations and slightly higher for equatorial and high-latitude regions due to the nature of core constellation

orbits. The requirement for redundant signals means that navigation guidance with integrity provided by RAIM may not be available 100 per cent of the time, so GPS/RAIM approvals usually have operational restrictions.

4.2.8 A barometric altimeter may be used to provide an additional measurement that reduces by one the number of satellites in view required for RAIM and FDE. Barometric aiding can also help to increase availability when there are enough visible satellites, but their geometry is not adequate to support the integrity function. Note that RAIM barometric aiding is different from the Baro VNAV function used to support approaches with vertical guidance to LNAV/VNAV minima.

4.2.9 The inputs to the RAIM and FDE algorithms are the standard deviation of the measurement noise, the measurement geometry and the maximum allowable probabilities for a false alert and a missed detection. The output from the algorithm is the horizontal protection level (HPL), which is the radius of a circle centred at the true aircraft position that is guaranteed to contain the indicated horizontal position within the specified integrity requirement. It should be noted that the value of HPL is normally significantly larger than any position error, but its value is the key to position integrity.

4.2.10 A RAIM alert occurs when there is poor satellite geometry, causing HPL to exceed horizontal alert limit (HAL). In this case, the ability to detect a failed satellite is lost. The type of operation determines HAL, specifically, 2 NM for en-route, 1 NM for terminal and 0.3 NM for the final approach segment of an NPA procedure. RAIM availability is therefore highest for en-route and lowest for NPA. The detection of a satellite fault by the RAIM algorithm also triggers an alert which results in the loss of GNSS navigation capability unless the receiver has FDE capability.

4.2.11 Some States have approved the use of GPS as the only navigation service in domestic airspace and in oceanic and remote areas. In these cases, the avionics require FDE. Under such approvals, commercial aircraft may be required to carry dual systems and, to ensure continuity, operators must perform pre-flight predictions to make certain that there will be enough satellites in view to support service throughout the planned flight.

4.2.12 Until 1 May 2000, the United States applied a feature called selective availability (SA) that degraded GPS accuracy. The discontinuation of SA resulted in an immediate GPS accuracy improvement. As described in 4.3.2, this also results in a higher availability of integrity for some receiver designs.

4.2.13 GNSS information can be integrated with non-GNSS information to enhance navigation performance. An IRS or an area navigation system using multiple distance measuring equipment (DME) inputs can be used to coast through short periods of poor satellite geometry or when the aircraft structure shadows the GNSS antennas while manoeuvring. The combination of GNSS FD or FDE, along with the short-term accuracy of IRS, mitigates the effects of signal jamming or loss of service due to ionospheric events. These airborne augmentations may be certified in accordance with United States FAA TSO-C115A.

4.3 SATELLITE-BASED AUGMENTATION SYSTEM (SBAS)

4.3.1 SBAS system architecture and operation

4.3.1.1 An SBAS augments core satellite constellations by providing integrity and correction information; some systems also provide additional ranging signals. SBAS reference stations, distributed over a large area, monitor core constellation satellite signals and continuously provide data to master stations. Master stations use this data to assess satellite signal validity and compute corrections to the broadcast ephemeris and clock data for each satellite. SBAS master stations also estimate the ranging delay introduced by the Earth's ionosphere, and compute the corrections applicable at predetermined ionospheric grid points. In addition to providing corrections, master stations assess parameters that bound the uncertainty in the corrections. The user differential range error (UDRE) for each satellite describes the uncertainty in the clock and ephemeris corrections for that satellite. The grid ionospheric vertical error (GIVE) for each ionospheric grid point describes the uncertainty in the ionospheric corrections around that grid point.

4.3.1.2 Master stations generate SBAS messages that uplink stations transmit to geostationary earth orbit (GEO) satellites. Transponders on the GEO satellites rebroadcast the SBAS messages on the GPS L1 frequency using a unique PRN code. A GEO satellite appears to be stationary over the equator at a specific longitude, so its signals cover virtually a complete hemisphere except for polar areas.

4.3.1.3 SBAS can send a “DO NOT USE” message if it detects a faulty satellite or a “NOT MONITORED” message if a satellite is not visible to any monitoring station. 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/FDE mode.

4.3.1.4 Ionospheric corrections are key to providing the accuracy and integrity needed to support APV. This requires a widespread network of reference stations to measure ionospheric delays. As an example, the wide area augmentation system (WAAS) uses 38 reference stations in Canada, Mexico and the United States to meet these requirements. As described in Chapter 5, the ionosphere is very active in equatorial regions, making it technically challenging for the current generation of SBAS to provide vertically guided approaches in these regions.

4.3.1.5 The GNSS SARPs allow for three levels of SBAS capability that provide: core satellite status and GEO ranging; clock and ephemeris corrections; and clock, ephemeris and ionospheric corrections. The first two levels support PBN en-route through NPA, while the third also supports APV.

4.3.2 SBAS avionics

4.3.2.1 The term “SBAS receiver” designates the GNSS avionics that meet the minimum requirements outlined in Annex 10 and the specifications of RTCA/DO-229D with Change 1.

4.3.2.2 There are four classes of SBAS avionics that support different performance capabilities. Class I equipment supports en-route, terminal and LNAV approach operations. Class II supports en-route through LNAV/VNAV approach operations. Classes III and IV support en-route, terminal and four approach minima levels: LPV, LP, LNAV/VNAV and LNAV.

4.3.2.3 The SBAS receiver produces differentially corrected three-dimensional positions by applying the broadcast ephemeris and clock corrections, and by interpolating between grid points to calculate the ionospheric correction along its line-of-sight to each satellite. This provides the position accuracy needed for APV approaches.

4.3.2.4 The SBAS receiver combines UDRE and GIVE error estimates with estimates of the uncertainties in its own pseudo-range measurement accuracy and in its tropospheric delay model to compute HPL and VPL. These values are continuously compared with HAL, and for APV approaches, vertical alert limit (VAL). When either alert limit is exceeded, the avionics alert the aircrew.

4.3.2.5 For approach operations, SBAS avionics are required to annunciate the highest level of service supported by the combination of the SBAS signal integrity level and the receiver certification, using the naming conventions on the minima lines of the approach procedure chart. SBAS avionics support flying the complete RNAV procedure and also can operate in a vector to final mode.

4.3.2.6 SBAS avionics can also provide advisory vertical guidance when flying NDB and VOR approaches and GNSS NPAs in areas where an SBAS supports this level of service, thus providing the benefits of a stabilized descent. In this case, the aircrew is responsible for complying with all minimum altitudes specified on the approach chart.

4.3.2.7 The integrity of APVs depends on the validity of the data used to define the approach. For all approaches with vertical guidance, SBAS avionics use data from a final approach segment (FAS) data block in the avionics database. FAS data is protected with high integrity using a cyclic redundancy check, which employs a computational algorithm to validate the data, specifically to detect any change in data values since they were originally defined.

4.3.2.8 SBAS avionics standards prescribe a significantly improved and more standardized pilot/avionics interface compared with Basic GNSS avionics. This reduces aircrew workload and is particularly beneficial during missed approaches and other high workload phases of flight.

4.3.2.9 In virtually every SBAS avionics installation, the aircrew will load specific approaches from the database by selecting airport, runway and approach. If, however, the avionics have a very basic pilot interface, there is the option of selecting an approach by entering the SBAS approach channel number that appears on each approach chart.

4.3.2.10 SBAS avionics are required to track the GEOs that are broadcasting corrections for current position and must be capable of rapidly switching between the SBAS data from one GEO to another GEO to maximize continuity of function. A method of computing SBAS continuity for APV-I and Category I service, taking into account this switching capability, is described in Appendix G. Minimum avionics requirements permit the use of any SBAS service provider as well as the mixing of information from more than one SBAS service provider for en-route, terminal and LNAV approach procedures. For APV and Category 1 operations, SBAS avionics must use only the SBAS defined in the FAS data block. This feature provides a measure of control to ANS providers in areas where augmentation signals from two or more SBAS could provide service.

4.3.2.11 Regardless of the availability of SBAS service in a State, SBAS avionics provide a considerable increase in availability for en-route through NPA compared with Basic GNSS receivers by taking advantage of the fact that SA is discontinued, by including FDE functionality and by using GEO satellite ranging. This allows States to remove operational restrictions required when using Basic GNSS receivers.

4.3.2.12 Most TSO-C129 avionics assume SA is present, and for these the average RAIM availability is 99.99 per cent for en-route and 99.7 per cent for NPA with a 24-satellite GPS constellation. FDE availability ranges from 99.8 per cent for en-route to 89.5 per cent for NPA. For SBAS and RTCA/DO-316/TSO-C196 avionics (which do not have SBAS functionality), the availability of RAIM is 100 per cent for en-route and 99.998 per cent for NPA; FDE availability ranges from 99.92 per cent for en-route and 99.1 per cent for NPA.

4.3.3 SBAS operations

4.3.3.1 In most cases, SBAS approaches increase airport usability via lower minima while providing the safety benefits of vertical guidance. These improvements are affordable at most airports because an SBAS approach does not require any SBAS infrastructure at the airport. Minima do, however, depend on the physical environment (obstacles, runway and lighting). SBAS availability levels allow operators to take advantage of SBAS instrument approach minima when designating an alternate airport.

4.3.3.2 There will be only one approach with LPV minima to a runway end, based on the level of service that SBAS can support at an airport. The FAS data block defines the HAL and VAL for the associated procedure, but these values are transparent to the aircrew, who will use the published LPV minima. Approach charts that include SBAS procedures are entitled RNAV(GNSS) RWY NN, and can have up to four minima lines: LPV (or LP), LNAV/VNAV, LNAV and Circling. Charts will have either LPV or LP minima lines, not both. LP minima will appear only when it is not possible to design a procedure with vertical guidance due to terrain or obstacles.

4.3.3.3 It was originally expected that 75 m (250 ft) would be the lowest decision height (DH) supported by SBAS. Experience with WAAS demonstrated that this assumption was conservative, and that a 35 m (115 ft) VAL would support a 60 m (200 ft) DH (LPV-200), equivalent to ILS CAT I. The United States completed an analysis that compared recorded WAAS vertical errors with ILS glideslope monitor limits. The ILS glideslope displacement at a nominal 60 m (200 ft) DH location can be as large as 17 m (55 ft) and remain within monitor limits. Alternatively, flight inspection tolerance at the 60 m (200 ft) DH location is 12 m (40 ft). Based on more than 1.76 billion observations with a VAL less than or equal to 35 m (115 ft), the maximum observed WAAS signal-in-space vertical error was 8.9 m (29 ft). Similar containment was observed by the European Geostationary Navigation Overlay Service (EGNOS). An SBAS vertical error on approach results in a vertical path that is parallel to the design path but that is biased high or low. A barometric