ICAO

Doc 9849

Global Navigation Satellite System (GNSS) Manual

Third Edition, 2017

Approved by and published under the authority of the Secretary General

INTERNATIONAL CIVIL AVIATION ORGANIZATION

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Published in separate English, Arabic, Chinese, French, Russian
and Spanish editions by the
INTERNATIONAL CIVIL AVIATION ORGANIZATION
999 Robert-Bourassa Boulevard, Montréal, Quebec, Canada H3C 5H7

For ordering information and for a complete listing of sales agents
and booksellers, please go to the ICAO website at www.icao.int

First edition 2005
Second edition 2013
Third edition 2017

Doc 9849, ***Global Navigation Satellite System (GNSS) Manual***
Order Number: 9849
ISBN 978-92-9258-268-5

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

AMENDMENTS		
No.	Date	Entered by

CORRIGENDA		
No.	Date	Entered by

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).

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).

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.

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 altimeter that is independent of SBAS defines the DH; however, for a low bias, the aircraft would reach the DH farther from the runway than the nominal position. The analysis addressed a worst-case, extremely conservative 35 m (115 ft) low vertical error and demonstrated that the aircraft would remain within CAT I ILS obstacle clearance surfaces. Because of various assumptions in the analysis, Annex 10 requires other States to complete a system-level safety assessment before proceeding with LPV-200 operations.

4.3.4 SBAS coverage and service areas

4.3.4.1 GEO satellite footprints define the coverage area of an SBAS. Within this coverage area, States can establish service areas where SBAS supports approved operations. Other States within the coverage area could also establish service areas either by installing integrated reference/monitoring stations in cooperation with the SBAS provider, or by approving the use of SBAS signals. The first option offers improved performance and some degree of control. The second option lacks any degree of control, and performance depends on the proximity of the host SBAS to the service area. In either case, a State that has established an SBAS service area is responsible for designating the types of operations that can be supported within that area, and assumes responsibility for the SBAS signals within that service area.

4.3.4.2 In a fully-implemented SBAS, ranging, satellite status and basic differential correction functions are available throughout the entire GEO coverage area, and are technically adequate to support NPA by providing monitoring and integrity data for core and SBAS satellites.

4.3.4.3 SBAS avionics standards ensure smooth and transparent operations when transitioning from one SBAS service area to another or to an area where no SBAS provides service. In the latter case, the receiver switches automatically to navigation using FDE. The receiver can also switch back to SBAS-based navigation when such a switch is beneficial. This ensures a worldwide navigation capability for PBN en-route, terminal area and approach operations.

4.3.4.4 There will likely be deficits in availability of integrity for APV near the edge of an SBAS service area. States should complete availability studies for airports in these areas, using simulation and in some cases data collection techniques, and refrain from implementing approaches with LPV minima where decreased availability would create operational problems.

4.3.4.5 *Regional SBAS*

4.3.4.5.1 The WAAS, developed by the United States, has been operational since 2003. In 2007, the United States committed to provide "…single frequency WAAS signals on a non-discriminatory basis, free of direct user fees, throughout the area of coverage of WAAS satellites within its prescribed service volume and to provide open, free access to information necessary to develop and build equipment to use these services." Under bilateral agreements, Canada and Mexico host WAAS reference stations, thus supporting SBAS service in all three States.

4.3.4.5.2 The Japanese multi-functional transport satellite (MTSAT)-based augmentation system (MSAS) became operational in 2007. It is planned to be replaced with a new system known as the Quasi-Zenith Satellite System (QZSS). The QZSS will have four satellites consisting of one geostationary satellite and three quasi-zenith orbit satellites. This new SBAS will start operation with a single geostationary satellite configuration in 2020, with plans for a seven-satellite configuration starting in 2023. The system will further evolve to support dual-frequency, multi-constellation (DFMC) SBAS services at a later stage.

4.3.4.5.3 Europe's EGNOS became operational in early 2011. The European Commission (EC) has informed ICAO that the EGNOS Safety of Life service is offered to the international civil aviation community free of direct user charges. It is planned to upgrade EGNOS to provide a DFMC SBAS service.

4.3.4.5.4 India’s GPS Aided GEO Augmented Navigation (GAGAN) was certified for RNP 0.1 and APV-I in 2015. Since then, it has been in continuous operation meeting the operational criteria specified in the SARPs.

4.3.4.5.5 The Russian Federation’s System of Differential Correction and Monitoring (SDCM) is under development and is expected to be operational after 2020; it is designed to provide GNSS users with corrections and integrity for GPS and GLONASS.

4.3.4.5.6 The Chinese BeiDou Satellite-based Augmentation System (BDSBAS) is planned to augment both BeiDou and GPS initially, and is expected to be operational in 2020.

4.3.4.6 Although the architectures of EGNOS, GAGAN, MSAS, SDCM and WAAS are different, they broadcast the standard message format on the same frequency (GPS L1) and so are interoperable from the aircraft perspective. When SBAS coverage areas overlap, it is possible for an SBAS operator to monitor and broadcast integrity and correction messages for the GEO satellites of another SBAS, thus improving availability by adding ranging sources. All SBAS operators are encouraged to implement this system enhancement.

4.3.4.7 SBAS avionics will function within the coverage area of any SBAS. States or regions should coordinate through ICAO to ensure that aircraft do not suffer operational restrictions where there are valid SBAS signals. If a State does not approve the use of some or all SBAS signals for en-route through terminal operations, pilots using SBAS avionics would have to deselect GNSS altogether, since receiver standards do not specify the capability to deselect a particular SBAS for these operations. This would make GNSS operations impossible and could raise significant safety concerns.

4.4 GROUND-BASED AUGMENTATION SYSTEM (GBAS)

4.4.1 GBAS system architecture

4.4.1.1 A GBAS ground station is located at or near the airport served. The ground station monitors core constellation signals and broadcasts locally relevant pseudo-range corrections, integrity parameters and approach definition data to aircraft in the terminal area via a VHF data broadcast (VDB) in the 108.025 – 117.975 MHz band. As of 2017, GBAS as defined in Annex 10 supports CAT I precision approach and the provision of GBAS positioning service in the terminal area. An amendment of the Annex intended to support Cat II/III operation has undergone technical and operational validation and is being proposed for applicability in 2018 (see 6.9.2).

4.4.1.2 GBAS precision approach service provides lateral and vertical deviation guidance for the final approach segment. The optional GBAS positioning service supports two-dimensional PBN operations in terminal areas. GBAS can optionally provide corrections for SBAS GEO ranging signals.

4.4.1.3 GBAS infrastructure includes antennas to receive the satellite signals as well as electronic equipment that can be installed in any suitable airport building. Unlike ILS and the microwave landing system (MLS), antenna location is relatively independent of the runway configuration, but requires the careful evaluation of local sources of interference, signal blockage, airport protection area and multipath. Siting of the VDB antenna should ensure that the coverage area is sufficient for the intended operations.

4.4.1.4 A single GBAS ground installation may provide guidance for up to 49 approaches within its VDB coverage. Guidance on allocation of multiple approaches may be found in Annex 10, Volume I, Attachment D, section 7.

4.4.1.5 The GBAS VDB transmits with either horizontal (GBAS/H) or elliptical polarization (GBAS/E). Transmission of GBAS/H is specified by a Standard. Transmission of GBAS/E is specified by a Recommended Practice. The majority of aircraft will be equipped with a horizontally polarized VDB receiving antenna, which can receive both GBAS/H and

GBAS/E signals. Other aircraft, notably certain military aircraft, will be equipped with a vertically polarized antenna and will be limited to using GBAS/E equipment. GBAS service providers should indicate the type of VDB antenna polarization at each of their facilities in the State AIP.

4.4.1.6 The broadcast FAS data block defines the final approach path. The FAS data block enables the computation of “ILS lookalike” deviation guidance. The FAS data block is associated with a GBAS channel number in the range of 20 001 to 39 999 through a channel mapping formula that also references the associated VDB frequency. Guidance on channel assignments can be found in Annex 10, Volume I, Attachment D, section 7.

4.4.1.7 Unlike ILS, GBAS can provide multiple approaches to the same runway end with a unique channel number identifying each one. These multiple approaches may have different glide path angles and/or may have displaced thresholds.

4.4.1.8 The GBAS datalink includes a provision for authentication of the signal provided by the GBAS ground station. This capability is optional for CAT I but will be a requirement for CAT II/III.

4.4.2 GBAS avionics and operations

4.4.2.1 The term “GBAS receiver” designates the GNSS avionics that meet the minimum requirements for a GBAS receiver as outlined in Annex 10 and the relevant State specifications, such as RTCA/DO-253C, as amended by FAA TSO-C161A/162A.

4.4.2.2 Similar to ILS and MLS, the GBAS receiver provides lateral and vertical guidance relative to the defined final approach course and glide path. The receiver employs a channelling scheme that selects the VDB frequency and identifies the specific FAS data block that defines the approach. Each separate procedure requires a different channel assignment. For a precision approach, the GBAS receiver only uses satellites for which corrections are available.

4.4.2.3 GBAS avionics standards have been developed to mimic ILS to simplify the integration of GBAS with existing avionics. Display scaling and deviation outputs are equivalent to ILS to reduce aircrew training requirements. All avionics will provide final approach course and glide path guidance to all configurations of ground stations.

4.4.2.4 When GBAS positioning service is available, it will provide position, velocity and time data that can be used as input to an on-board navigator or as a source of position information for ADS-B. If this service is not supported by a particular ground station or by the avionics, the receiver will provide position, velocity and time information in accordance with ABAS requirements to support PBN.

4.4.2.5 The term “GBAS landing system (GLS)” is used in the charting of GBAS approaches, both for the chart title (GLS RWY NN) and the GBAS minima line.

4.4.2.6 A more detailed description of GBAS and the performance levels supported by GBAS is provided in Annex 10, Volume I, Attachment D, section 7.

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

Chapter 5

GNSS VULNERABILITY

5.1 GENERAL

5.1.1 GNSS signals from satellites are very weak at the receiver antenna, so are vulnerable to interference. Services provided by conventional aids can also be disrupted by interference, but GNSS typically serves more aircraft simultaneously and the interference may affect wide geographic areas. GNSS signals are also susceptible to ionospheric effects.

5.1.2 GNSS receivers must meet specified performance requirements in the presence of levels of interference defined in Annex 10 and used within International Telecommunication Union (ITU) recommendations. Interference above defined levels may cause degradation or loss of service, but avionics standards require that such interference shall not result in hazardously misleading information (HMI).

5.1.3 Current GNSS approvals use a single frequency band common to GPS, GLONASS and SBAS. This makes it easier to intentionally jam GNSS signals and it also makes unintentional interference more likely. The next generation GNSS will be based on multiple frequencies. This will reduce the likelihood of unintentional interference and will make intentional interference more difficult. Enhanced services depending upon the availability of multiple frequencies would, however, be degraded by interference with one frequency.

5.1.4 GNSS provides precise time information to support the applications described in Chapter 1, 1.4.5. The majority of these applications use GNSS in a non-critical manner; timing receivers are used with other time distribution systems and do not have demanding absolute accuracy requirements. Systems can coast for a considerable amount of time on internal quartz clocks before needing another GNSS time update. The most notable exception is multilateration, which can have a critical dependence on GNSS time.

5.1.5 State regulators and ANS providers can take the measures described in Chapter 7, 7.13 and Appendix F to reduce the likelihood that GNSS service will be lost. When implementing mitigation measures, they should be consistent with the safety and security assessment principles described in Chapter 7, 7.5 and 7.15. The objective of mitigation measures is to ensure that the residual risk remains acceptable in terms of the impact on aircraft operations in the event of a service disruption. Mitigation of GNSS vulnerabilities needs to be balanced in the context of the overall threats to communications, navigation, and surveillance/air traffic management (CNS/ATM) operations to ensure that the applied effort is neither too small (leading to potentially unacceptable risks and/or preventing realization of GNSS-enabled benefits) nor too large (in comparison with the effort expended on mitigating other risks).

5.2 UNINTENTIONAL INTERFERENCE

5.2.1 GPS and GLONASS have filings with the ITU to use spectrum allocated to the radionavigation-satellite service (RNSS) in the 1 559 – 1 610 MHz and 1 164 – 1 215 MHz bands. The RNSS allocation in these bands is shared with the aeronautical radionavigation service (ARNS). There are also filings under the RNSS allocation for SBAS GEOs operating in the 1 559 – 1 610 MHz band. The GBAS VDB, as well as VHF digital link (VDL)-4, which are aeronautical mobile (R)[1] services (AMRS), use the 108.025 – 117.975 MHz band, shared with ILS and VOR, which are ARNS. GPS, GLONASS and SBAS GEOs also have ITU filings in the 1 164 – 1 215 MHz band which is intended for future civil aviation applications. BDS and Galileo also have ITU filings in place.

5.2.2 There are a number of sources of potential interference to GNSS from both in-band and out-of-band emitters, including mobile and fixed VHF communications, harmonics of television stations, certain radars, mobile satellite communications and military systems

5.2.3 Effective spectrum management is the primary way to reduce the likelihood of unintentional and intentional interference with GNSS signals. This comprises creating and enforcing regulations/laws that control the use of spectrum and carefully assessing applications for new spectrum allocations.

5.2.4 Many reported instances of GNSS interference have been traced to on-board systems, including VHF and satellite communications equipment and portable electronic devices. Such interference can be prevented by proper installation of GNSS avionics (e.g. shielding, antenna separation and out-of-band filtering), integration with other aircraft systems and restrictions on the use of portable electronic devices.

5.2.5 The additional GNSS signals in the band 1 164 – 1 215 MHz to be broadcast by second-generation core satellites share the band with DME and the UHF tactical air navigation aid (TACAN). ITU rules require that DME/TACAN must be protected from interference. Compatibility studies based on the current DME/TACAN infrastructure concluded that the impact of interference on the processing of the new GNSS signals is tolerable. The studies also concluded that a high density of DME/TACAN facilities operating in or near the new GNSS band could result in interference with GNSS signals at high altitudes. States should assess whether an increase of the DME/TACAN infrastructure is compatible with expanded use of GNSS and if necessary reallocate DME assignments away from GNSS frequencies.

5.3 INTENTIONAL INTERFERENCE AND SPOOFING

5.3.1 In an era when essentially all conventional navigation aids remain in service, and when all aircraft are still equipped to use them, there is little motivation to deliberately interfere with GNSS-based aviation services. As reliance on GNSS increases, however, the threat of intentional interference could increase.

5.3.2 GNSS is used in many applications: financial, security and tracking, transportation, agriculture, communications, weather prediction, scientific research, etc. Threat analysis must consider the likelihood that jamming directed at non-aviation users could affect aircraft operations. It should also consider the mitigations put in place by non-aviation service providers. Of primary concern is the proliferation of jammers designed to defeat vehicle-tracking systems.

5.3.3 The likelihood of interference depends on such factors as population density and the motivation of individuals or groups in an area to disrupt aviation and non-aviation services. The likelihood will be virtually non-existent in oceanic and sparsely settled areas and will be highest near major population centres. Impact assessment must consider the type of airspace, traffic levels and the availability of independent surveillance and communications services, and must address safety and economic effects. Mitigation will be required when disruption is deemed to be possible and would have a significant impact.

5.3.4 As described in Chapter 7, retaining DME is recommended as part of a mitigation strategy in the case of a GNSS outage. Although DME shares a frequency band with GNSS, the interference threshold of DME is significantly higher than for GNSS, so interference in the common band would not likely affect DME. Furthermore, it is unlikely that interference in this band would jam all DMEs inside an aircraft's radio horizon.

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[1] Route.

5.3.5 Spoofing is the broadcast of GNSS-like signals that cause avionics to calculate erroneous positions and provide false guidance. It is considered that the spoofing of GNSS is less likely than the spoofing of traditional aids because it is technically much more complex. To avoid immediate detection, spoofing requires accurate target aircraft position information. It is very difficult to match the spoofing signal to the dynamics of a target receiver and maintain sufficient signal strength to enable the receiver to remain locked to the spoofing signal. If the avionics did remain locked to a spoofing signal, there are various ways that it could be detected: integrated avionics could annunciate discrepancies between GNSS and IRS or DME-DME positions; pilots could note deviations through normal monitoring of instruments and displays; and in a radar environment, ATC could observe deviations. Moreover, all other aircraft in the area that locked to the spoofing signal would appear to have the same position as the target aircraft. If an aircraft did deviate from track, ground proximity warning systems (GPWS) and airborne collision avoidance systems (ACAS) would provide protection against collision with the ground and other aircraft.

5.3.6 Spoofing of the GBAS data broadcast is at least as difficult as spoofing conventional landing aids. An authentication scheme has been developed that will make spoofing of GBAS virtually impossible.

5.3.7 States must evaluate and address the risk of intentional interference in their airspace. If States determine that the risk is unacceptable in specific areas, they can adopt an effective mitigation strategy as described in Chapter 7, 7.13 and Appendix F. If outage events are detected and reported (Chapter 7, 7.12), States should be ready to inform users in accordance with Chapter 7, 7.11 and deploy reactive measures as described in Appendix F. While GNSS monitoring as described in Chapter 7, 7.8 generally is not intended to serve the purpose of interference detection, potential synergies between performance monitoring and interference monitoring equipment should be taken advantage of to the maximum extent possible.

5.4 SPECTRUM REGULATION

5.4.1 States should prohibit all actions that lead to disruption of GNSS signals. They should develop and enforce a strong regulatory framework governing the use of intentional in-band radiators, including GNSS repeaters, pseudolites, spoofers and jammers. Particular regulatory care is also required to address out-of-band radiators that are harmonically related to GNSS frequency bands, such as certain television broadcast channels and other industrial applications.

5.4.2 GNSS repeaters and pseudolites are systems that transmit signals to supplement GNSS coverage in buildings and other areas where normal GNSS signals cannot be readily received. Aeronautical test equipment may also act as a GNSS signal generator. When such equipment does not operate in accordance with specific conditions, it may interfere with GNSS avionics and ANS providers' ground equipment. In some cases, these systems can cause GNSS receivers within range to calculate erroneous positions. Such cases should be detectable because there would be effects such as sudden, readily evident position shifts.

5.4.3 The use of GNSS repeaters and pseudolites is carefully regulated by some States, but many others have no relevant regulations. To ensure that these systems do not disrupt GNSS-based services, States must create a regulatory framework to ensure that they have a valid application and that their operation is not harmful to existing primary GNSS users. ICAO Electronic Bulletin EB 2011/56 *Interference to Global Navigation Satellite System (GNSS) Signals* provides more information and a list of documents that States can use for guidance in developing regulations.

5.4.4 Cases of harmful interference have been traced to short-range GNSS jammers used to avoid vehicle fee collection or tracking. The mobile nature and short range of these jammers disrupts signals intermittently, making it difficult to identify and locate the source. States should establish regulations that forbid the use of jamming and spoofing devices and regulate their importation, exportation, manufacture, sale, purchase, ownership and use. Some States prohibit all actions that lead to disruption of GNSS signals and prescribe severe penalties for the purchase or use of jammers. States should develop the means to detect interference sources in support of enforcement programmes.

5.4.5 States should take more preventive measures to reduce the likelihood of GNSS disruption to aviation by non-aviation users. This could involve implementing location privacy provisions that are accepted by citizens. Conversely, the design of fee collecting or tracking applications should anticipate interference by including additional sensor integration or other mechanisms to prevent simple jamming from achieving its aim. In most cases, this can be achieved by simple measures.

5.4.6 The ICAO *Convention on International Civil Aviation* (Doc 7300) and ITU Regulations protect GNSS frequencies for aviation use. There is, however, significant demand for electromagnetic spectrum for new applications, such as mobile phone and broadband data services that may emit signals that are much stronger than GNSS signals at the receiver. States must not allocate spectrum adjacent to GNSS bands to proposed systems if there is any possibility that these systems will interfere with currently installed GNSS receivers. While future multi-constellation and multi-frequency GNSS equipment for aviation will be designed to maximize interference robustness as much as reasonably possible, it is important that new spectrum services do not neutralize these improvements.

5.5 EFFECTS OF THE IONOSPHERE AND SOLAR ACTIVITY

5.5.1 The ionosphere is a region of the upper atmosphere that is partially ionized. GNSS signals are delayed by varying amounts of time depending on the density of ionized particles, which itself depends on the intensity of solar radiation and other solar energy bursts. One phenomenon is rapid and large ionospheric delay changes resulting in range measurement errors that must be addressed by system design. Solar storms can cause severe ionospheric scintillation that can cause temporary loss of one or more satellite signals. The likelihood of disruption due to scintillation will depend on the geographic area and will require scientific assessment. Ionospheric phenomena have negligible impact on en-route through NPA operations.

5.5.2 The type and severity of ionospheric effects vary with the level of solar activity, the region of the world and other factors such as time of year and time of day. Rare solar storms can cause large variations in ionospheric delays that can affect receivers over a wide area. Solar activity peaks every eleven years.

5.5.3 Severe scintillation can disrupt satellite signals, but it occurs in patches and does not affect wide areas of the ionosphere simultaneously. It therefore generally affects only a few of the satellites in view of an aircraft. Losses of signal tracking due to scintillation are of short duration, but they may occur repeatedly during periods of several hours. This can cause GNSS service to be degraded or temporarily lost for a duration dependent on the receiver’s ability to rapidly re-acquire a signal following the event. Scintillation affects all GNSS frequencies, so multi-frequency receivers will not offer stronger protection. On the other hand, multi-constellation GNSS would allow the receiver to track more satellites, reducing the likelihood of service disruption.

5.5.4 Scintillation is virtually non-existent in mid-latitudes, except at low to moderate levels, which can occur during rare severe ionospheric storms. Severe scintillation is fairly common in equatorial regions where it typically occurs after sunset and before local midnight. Moderate scintillation occurs frequently in high-latitude regions, and can reach severe levels during ionospheric storms.

5.5.5 In mid-latitudes, severe ionospheric storms may infrequently cause outages of SBAS APV service, but in equatorial regions service outages would be much more frequent due to the formation of wide bands of accumulated ionized particles located approximately 15 degrees north and south of the magnetic equator. Narrow, elongated volumes, called depletions (or bubbles), in which the density of ionized particles can drop well below that in the surrounding ionosphere, often develop in the midst of these bands just after local sunset and persist late into the local night. The combination of these phenomena results in large spatial and temporal variations in ionospheric delay and therefore presents a major challenge to the integrity of SBAS ionospheric corrections. It is therefore not practical to provide single-frequency SBAS APV service in equatorial regions.

5.5.6 Basic GNSS receivers use a simple theoretical ionospheric model and a small set of coefficients broadcast by GNSS satellites to compute ionospheric corrections. This technique has been shown to reduce the pseudo-range errors due to ionospheric delays by a factor of about two. SBAS reduces these errors to a few metres and assures the integrity of the corrections. SBAS can also detect the effects of ionospheric storms that might threaten the integrity of the broadcast corrections and ensure that APV operations do not continue when the system cannot compensate for these effects.

5.5.7 GBAS broadcasts pseudo-range corrections that account for all error sources, as well as integrity information that is effective even when the local ionosphere is severely disturbed. GBAS service would, however, be lost if severe scintillation caused avionics or the GBAS station to lose lock on enough satellite signals. The GBAS VDB is not affected by ionospheric conditions. The ionospheric threat model used by GBAS integrity monitors must, however, be consistent with local conditions, which may result in lower service availability or more siting constraints in equatorial regions than in mid-latitudes. Dual frequency GBAS systems would be able to compensate for ionospheric delay effects, thus allowing for improved performance with fewer constraints.

5.5.8 The sun also has a direct effect on GNSS. Disturbances in the sun's corona can create solar radio bursts that may cause an increase in the level of radio frequency (RF) noise in the GNSS frequency band(s), thereby affecting the reception of signals from all satellites in view on the dayside of the Earth. In some rare cases, the intensity and frequency band of a solar radio burst can cause GNSS receivers to temporarily lose all satellite signals. Experience has shown that these events may last up to an hour. The vulnerability of receivers to such events is highly dependent on their design. While geodesy receivers have been observed to lose all signals for several minutes, so far no significant impact has been detected on aviation receivers.

Chapter 6

GNSS EVOLUTION

6.1 GENERAL

6.1.1 GNSS will evolve by improving existing elements and creating new elements and signals (see Appendix C). This will enhance GNSS performance, but it will also introduce technical complexity that must be managed effectively in order to provide operational benefits.

6.1.2 The key to acceptance by aircraft operators is the business case ─ the value of incremental operational benefits must exceed the cost of new avionics and their share of the cost of GNSS infrastructure. GPS, GLONASS, ABAS, SBAS and GBAS, as well as ADS-B and ADS-C, already provide very significant benefits to aircraft operators. It is not evident that every further technical advance will provide clear incremental benefits. It will be necessary to quantify these benefits before taking decisions to proceed with development and implementation.

6.1.3 If the issues related to GNSS evolution are properly addressed and aircraft operators are satisfied with the business case, the introduction of new constellations and additional signals would resolve some technical and institutional issues and provide operational benefits. Experience has shown that the time required to refine a technical concept, develop standards and develop certified systems is often underestimated. State ANS providers should proceed with PBN and ADS-B based on existing GNSS elements rather than awaiting next generation systems. This will provide significant safety and efficiency benefits and will provide the foundation for more benefits in future.

6.2 MULTI-CONSTELLATION/MULTI-FREQUENCY GNSS

6.2.1 Today's GNSS-based services rely, for the most part, on GPS, providing service on a single frequency. GLONASS, however, is already in operation, and BDS and Galileo are being deployed. All constellations will eventually operate in multiple frequency bands. Related developments are expected in the domain of GNSS augmentation systems.

6.2.2 The use of GNSS signals from multiple constellations broadcasting in multiple frequency bands improves GNSS technical performance. The use of combined signals from independent systems will enhance performance and service coverage. Moreover, combining signals improves robustness and will allow GNSS to meet performance requirements when there is interference or an individual system failure.

6.2.3 Each of the new GNSS signals will be more resistant to interference due to higher power, wider bandwidth and improved signal designs, resulting in better interference rejection capability. All signals intended for safety-of-life applications should benefit from the protection provided through ITU allocation within the ARNS bands.

6.2.4 GNSS performance is sensitive to the number of satellites in view. Multi-constellation GNSS will substantially increase that number. This will improve availability and continuity of service, particularly in areas where ionospheric scintillation can cause loss of lock on individual satellites. Furthermore, availability of more than 30 interoperable ranging sources could allow ABAS to provide worldwide vertically guided approaches with minimal, or potentially no need for, external augmentation signals in the long term.

6.2.5 The availability of a second frequency will allow avionics to calculate ionospheric delay in real time, effectively eliminating a major error source. Future DFMC SBAS systems would be able to support nearly 100 per cent

APV service availability with minima as low as 60 m (200 ft), even in equatorial regions. Moreover, as described in 5.1.3, frequency diversification is a very effective mitigation against unintentional interference, since it is highly unlikely that a source of unintentional interference could simultaneously affect more than one GNSS frequency.

6.2.6 The availability of multiple independent constellations will provide redundancy to mitigate the risk of service loss due to a major system failure within a core constellation, and will address the concerns of some States about reliance on a single GNSS constellation outside their operational control.

6.3 DEVELOPMENT OF STANDARDS

6.3.1 As GNSS elements are added, it will be necessary to develop ICAO SARPs and/or industry standards for new elements and combinations thereof, while taking into consideration technical, operational and economic factors. The choice of combinations will have to take into account the incremental benefits as seen by aircraft operators and ANS providers. Although the PBN concept allows for multiple technical solutions to meet performance specifications, having fewer solutions is more cost-effective because more operators can share certification costs. This is also less time consuming, because individual civil aviation authorities do not have to devote resources to assessing multiple technical options.

6.3.2 The introduction of multi-constellation, multi-frequency GNSS entails a number of new challenges, including: the need for signals of different GNSS constellations to be interoperable; legal liability concerns; the more complex role of augmentation systems potentially dealing with different combinations of GNSS constellations; and the increased complexity of avionics and aircraft integration and operational control. To realize multi-constellation benefits, ICAO, States, ANS providers, standardization bodies, manufacturers and aircraft operators need to coordinate activities to overcome these challenges. Experience has demonstrated the need to devote attention to safety regulation and oversight, since lack of clarity in these processes delays progress.

6.3.3 The GNSS evolutionary process should preserve backward compatibility so that aircraft operators will not incur excessive costs and operational penalties.

6.4 INSTITUTIONAL ISSUES

Current GNSS avionics automatically select satellite and augmentation signals. The PBN concept allows aircraft and avionics manufacturers the freedom to develop effective hardware and software solutions to match airspace requirements. States, in their planning for implementation of GNSS services, should avoid institutionally driven requirements or limitations on the use of specific GNSS elements. Such requirements and limitations would increase avionics complexity, resulting in higher manufacturing, maintenance and training costs. Moreover, a complex avionics interface could increase aircrew workload and create safety risks. The ultimate goal is to establish an institutional and legal framework that would enable the unrestricted use of any GNSS element. Until then, ICAO and the aviation industry will have to develop pragmatic solutions that enable a gradual introduction of multi-constellation GNSS.

6.5 CORE CONSTELLATION EVOLUTION

6.5.1 GPS evolution

6.5.1.1 GPS is evolving to meet the needs of civilian users by making the system more robust, increasing system availability and possibly including features that reduce the complexity of GPS augmentations.

6.5.1.2 L1C will be a civilian-use signal to be broadcast on the L1 frequency (1 575.42 MHz) that currently contains the coded signal used by all GPS users, so it will be backward compatible. The L1C signal will be available with the first Block III launch. It will have higher power and other features to improve tracking by receivers, and it will enable greater compatibility with Galileo. The plan is to have 24 operational satellites with L1C by about 2021.

6.5.1.3 An additional signal (L5) at 1 176.45 MHz was designed considering civil aviation's safety requirements. The L5 signal is more robust than the L1 C/A signal and is transmitted by the Block IIF and Block III satellites. It is planned for broadcast from 24 GPS satellites in the 2024 timeframe.

6.5.1.4 Although the L2 signal at 1 227.60 MHz is not part of the GPS SPS, many civilian users, including SBAS providers, employ codeless or semi-codeless dual frequency receivers to support their requirements. A coded signal (L2C) has been added at the L2 frequency (1 227.60 MHz). L2 is not in a band protected for aviation radio navigation services, so it is not intended for direct use by civil aviation. Users, including SBAS providers, who rely on codeless and semi-codeless access on L2 need to transition to L5 (or L2C) within two years after deployment of 24 L5-capable satellites. The L5 signal is currently planned for broadcast from 24 GPS satellites in the 2024 timeframe and 24 L2C capable GPS satellites by 2021.

6.5.1.5 The GPS III programme includes enhanced L1, L2 and L5 signals to support civilian and military requirements for the next 30 years. Challenges addressed include: representing both civilian and military GPS user requirements; bounding GPS III requirements within operational objectives; providing flexibility for future changes in order to meet user requirements through 2030; and providing robustness for the increasing dependency on precise positioning and timing as an international utility.

6.5.2 GLONASS evolution

6.5.2.1 The long-term (up to 2020) Russian Federation programme for GLONASS development and modernization envisages an upgrade of both space and control segments.

6.5.2.2 The current GLONASS constellation as of 2017 consists of 22 GLONASS-M satellites with a lifetime of seven years and improved technical characteristics; one GLONASS-M satellite transmitting in addition a CDMA signal in the L3 band; and one GLONASS-K satellite transmitting L3 CDMA as a standard option.

6.5.2.3 The next upgrade envisages the development of nine (possibly up to 11) GLONASS-K satellites with better accuracy and a lifetime of more than ten years. The GLONASS-K satellites will transmit, along with CSA navigation signals in the L1 band (FDMA), new CDMA navigation signals in the L1 and L3 bands. They will also introduce the capability to receive and retransmit distress signals of the COSPAS-SARSAT global search and rescue satellite-aided system.

6.6 PLANNED NEW CORE CONSTELLATIONS

6.6.1 Galileo

6.6.1.1 Galileo is a satellite-based radio navigation system that uses precise range measurements from Galileo satellites to determine position and time anywhere in the world. The system is operated on behalf of the European Union.

6.6.1.2 The fully deployed Galileo system (expected in the 2019/2020 time frame) will consist of a constellation of 30 medium Earth orbit (MEO) satellites in three orbital planes (24 operational satellites plus six spares), as well as control centres in Europe and a network of sensor and uplink stations installed around the globe.

6.6.1.3 Galileo’s global signals will support open, commercial and publicly regulated services. Galileo will also provide a search and rescue (SAR) service compatible with COSPAS-SARSAT. The open service signals, which will support aviation applications in combination with standardized augmentation systems, offer three frequencies at 1 575.420 MHz, 1 191.795 MHz and 1 176.450 MHz, known as E1, E5b and E5a, respectively. Early receivers will initially take advantage of the signals broadcast on E1 and E5a.

6.6.1.4 An initial service declaration was made in December for operating the open, publicly regulated and SAR services on the basis of a partially deployed constellation. The service capabilities will then gradually evolve towards their full performance as the constellation deployment nears its completion.

6.6.1.5 It is expected that the Galileo open service will be offered for use by the international aviation community once stable service has been reached.

6.6.1.6 The ICAO Navigation Systems Panel (NSP) work programme includes the development of SARPs for Galileo with a phased approach corresponding to the envisaged service implementation plan for Galileo.

6.6.1.7 Although clearly independent, Galileo is compatible and interoperable with GPS and GLONASS.

6.6.1.8 The Galileo signal-in-space (SIS) interface control document (ICD) and service definition document can be accessed from the GSA web site www.gsc-europa.eu.

6.6.2 BeiDou navigation satellite system (BDS)

6.6.2.1 The BeiDou Navigation Satellite System (BDS) will provide worldwide coverage with a constellation of 35 satellites, including five GEOs and 30 non-GEO satellites (three inclined geosynchronous orbit (IGSO) and 27 MEO). On 27 December 2011, China officially announced that BDS began to provide operational service on a regional basis.

6.6.2.2 The BDS will be implemented in stages. It currently covers the Asia-Pacific area and will have global coverage around 2020.

6.6.2.3 The BDS will provide two global services: Open Service is free and open to users; and Authorized Service ensures high reliability even in complex situations. In addition, the BDS is intended to provide two kinds of regional services: wide area differential service and short-message service.

6.6.2.4 The BeiDou Satellite-based Augmentation System (BDSABS) is an integrated part of BDS. It will utilize three GEO satellites in the BDS constellation to provide SBAS service; the first BDS GEO satellite with the BDSBAS payload is scheduled to be launched in 2018, with all three satellites being in place by 2020. Initial approval of BDSBAS will support en-route through NPA operation. China plans to ensure the system’s compatibility and interoperability adhering to Annex 10 SARPs.

6.6.2.5 The BDS signal-in-space (SIS) interface control document (ICD) (test version) was published on 27 December 2011, while the latest update (ICD version 2.1) was released on 7 November 2016. The complete document and its updates will be released gradually and they can be accessed through the official BDS governmental website: www.beidou.gov.cn or en.beidou.gov.cn (English version).

6.7 ABAS EVOLUTION

The availability of multiple constellations and frequency diversity offers the possibility to develop advanced RAIM (ARAIM) that could support high availability for en-route through NPA and also support APV globally. ARAIM investigations identify the need to refresh core satellite constellation and satellite reliability parameters, or ARAIM integrity support messages, on an hourly basis, which will require an augmentation signal. The ARAIM integrity support messages could be broadcast by the core constellations through an integrity data channel or via SBAS. The ARAIM monitoring algorithms would detect fast-occurring satellite faults and protect the user by excluding faulty satellites from the user position calculations. This concept requires further research, development and validation, but it could simplify integrity requirements for core constellations or SBAS systems in the long term. At least two core constellations would be required to achieve ARAIM-based APV service.

6.8 SBAS EVOLUTION

6.8.1 Some current, and all planned, SBAS GEOs include a ranging signal on L5 as well as L1. The development of dual frequency SBAS and associated avionics would have significant technical benefits.

6.8.2 The evolution of SBAS may also include augmentation of multiple GNSS constellations, with the potential to support CAT II approaches. Because ionospheric delay is a function of frequency, dual frequency avionics will be able to correct for delay when scintillation is not present. This would eliminate the need to broadcast ionospheric grid points, delay values, and estimates of error. It will then become possible to extend APV service to States in the equatorial region.

6.9 GBAS EVOLUTION

6.9.1 GBAS as currently specified in Annex 10 is based on a single frequency band and provides CAT I approach service. The Russian Federation has developed prototype systems that process GLONASS and GPS signals to support GBAS approaches.

6.9.2 An amendment of the Annex intended to support Cat II/III operation has undergone technical and operational validation and is being proposed for applicability in 2018. The amendment introduces multiple GBAS approach service types (GAST) and an associated equipment classification scheme to ensure that future services are compatible with legacy GBAS avionics. New requirements include enhanced monitoring in both the ground station and the avionics to meet CAT IIIB integrity requirements.

6.9.3 The next step in GBAS evolution will be to extend the system to take advantage of multiple frequencies and multiple constellations. Use of multiple frequencies will allow more robust monitoring and detection of errors caused by ionospheric anomalies. Use of multiple constellations will enable higher availability of robust geometries that are required to support CAT II/III operations and mitigate common mode errors.

6.9.4 These evolutionary developments may support a variety of enhanced operational capabilities, such as: surface movement guidance and control; surface surveillance for situational awareness or conflict detection and alerting; low visibility take-off guidance; guided departure procedures; complex approach paths; and CAT I and CAT II approaches to lower than standard minima. The existing GBAS SARPs may support some of these capabilities, but evolutionary developments may facilitate their introduction.

Chapter 7

IMPLEMENTATION OF GNSS-BASED SERVICES

7.1 GENERAL

7.1.1 The growth of aviation and the urgent need to reduce fuel consumption and emissions demand increased airspace and airport capacity and a focus on providing the preferred trajectory (route and altitude) to each aircraft. Aircraft operators also require efficiency gains via approaches with the lowest possible minima and the significant safety benefits of vertical guidance. In fact, controlled flight into terrain (CFIT), in the absence of vertical guidance, is still a frequent accident category, at least for some segments of the aviation community. Another key goal is to reduce the effects of airport noise on populated areas. GNSS-based services can meet these goals and have already provided significant safety and efficiency benefits to aircraft operators. The *Performance-based Navigation* (PBN) *Manual* (Doc 9613) provides the guidance necessary to implement GNSS-based navigation services.

7.1.2 GNSS-based operations were first approved in several States in 1993. Many other States have developed the legal framework for such services, but GNSS-based approaches are not yet approved on a worldwide scale. It is recommended that States follow the precedents set by numerous aviation authorities to allow the use of GNSS-based services. Where this is not deemed currently possible, those States are encouraged to develop a set of preconditions or requirements under which the use of GNSS-based services could become acceptable.

7.1.3 The ultimate goal is a transition to GNSS-based services to the extent that this can be shown to be the most cost-beneficial solution supported by safety and security analyses. Due to the vulnerability of GNSS signals, however, some ground aids (e.g. DME and ILS) will still be required for the foreseeable future.

7.2 INTERNATIONAL IMPLEMENTATION PLANNING

7.2.1 The basis for developing a seamless, global ATM system is through an agreed structure of homogeneous ATM areas and major traffic flows. This requires States to cooperate in assessing current and foreseeable aircraft population and capabilities, predicted traffic and the ATM infrastructure, including personnel availability and requirements. States will then be able to identify gaps in performance and plan improved services that would meet GANP performance objectives.

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

a) ensuring regional and interregional coordination via regional planning groups;

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

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

7.2.3 States should pursue bilateral and multilateral coordination for detailed aspects not covered within the ICAO framework.

7.3 DEVELOPMENT OF A CONCEPT OF OPERATIONS (CONOPS)

7.3.1 After deciding to implement a GNSS-based service, the next step should be the development of a concept of operations (CONOPS). This task should involve all stakeholders at the national and regional levels, and it should start with a high-level description of the service and the enabling technology. A CONOPS is a description of the characteristics of the service from the users' (aircrew and air traffic controllers) perspectives. The CONOPS should state the goals, strategies, policies and constraints affecting the service. It should identify organizations, activities and interactions among participants and stakeholders, including a clear statement of responsibilities. It must support the development of the safety case, business case and regulations. Once there is agreement that the safety case and the business case are valid, the ANS provider can develop a comprehensive implementation plan.

7.3.2 The business case will be key to a decision to implement, so the analysis must focus on defining and quantifying costs and operational benefits and gaining acceptance by all stakeholders, particularly aircraft operators, that the analysis is valid. In the case of en-route and terminal operations, the level of avionics equipage determines benefits. As long as the airspace design has to accommodate equipped and non-equipped aircraft, benefits will be constrained. This does not apply to approach operations, for which equipped aircraft will obtain the full benefit of lower minima.

7.3.3 Safety assessment starts at the first stage of CONOPS development; hazards and risks identified in each phase will have to be mitigated at subsequent stages by adjusting the CONOPS. The CONOPS will eventually reach a point where simulations and proof-of-concept trials can be used to validate assumptions, quantify benefits and costs, and identify safety risk mitigation measures.

7.3.4 When developing a CONOPS, States or regional entities need to consider the following elements, some of which are described in this chapter:

a) current and projected regional and State traffic flows and volumes as described in regional plans;

b) stated requirements of aircraft operators and their current and planned fleet composition and avionics equipage;

c) plans of States in the region;

d) business case analysis;

e) system safety assessment;

f) certification and operational approvals;

g) training of ANS provider staff and aircrews;

h) airspace planning and procedure development;

i) ATM, including airspace and ATC considerations, including ATC standards and procedures and automation systems;

j) aeronautical information services (AIS), including the notification of system failures;

k) GNSS signal vulnerability and anomaly/interference reporting;

l) effects on the environment, including emissions and noise; and

m) transition planning.

7.3.5 States should include participants from the following groups to address the above elements and develop a valid CONOPS that can guide decision making and planning:

a) aircraft operators ─ personnel in decision making roles who can assess benefits and validate the business case;

b) aircraft operations ─ personnel from flight operations and aircrew training within airlines, business aviation and general aviation who can validate operational procedures and the safety assessment;

c) air traffic services ─ personnel responsible for airspace design, ATC procedures and controller training;

d) airworthiness standards ─ personnel responsible for approving avionics and installations;

e) aviation standards ─ personnel responsible for developing the criteria for airspace design and instrument approach procedures, etc.;

f) AIS ─ personnel who are involved with survey, AIS and navigation databases, procedure design, NOTAM, etc.;

g) regulatory ─ personnel responsible for operational and other approvals, aircrew training requirements and flight procedures in order to anticipate regulatory hurdles, since CONOPS development is normally not a regulated activity;

h) aerodrome operators ─ personnel responsible for developing aerodrome infrastructure to support approach operations;

i) engineering ─ personnel responsible for the design of CNS/ATM systems and equipment, including avionics;

j) military representatives;

k) civil aviation officials from States in the region and ICAO officials; and

l) other stakeholder groups, including labour unions and other GNSS users.

7.3.6 A common goal of regulators and ANS providers is to ensure high standards of safety while providing aircraft operators with the benefits of GNSS technology in a timely and effective manner. This requires a cooperative approach to the development of the standards, systems, airspace and procedures, as well as the terms and conditions for regulatory approvals that respond to the needs of the aviation community. This applies whether the ANS provider is a State entity or a private company. Regulatory and ANS provider organizations will have to allocate resources to specific tasks, outlined in Appendix B.

7.4 BUSINESS CASE ANALYSIS

7.4.1 Introduction

7.4.1.1 Before implementing a new air navigation service it is necessary to develop an impact statement detailing the costs to aircraft operators and ANS providers. The benefits of a GNSS-based service will be realized only if aircraft operators equip themselves with the required avionics, which they will only decide to do when they are satisfied that the incremental benefits of the proposed service exceed the incremental costs. Refitting a fleet of aircraft with new avionics is very costly and can take years to accomplish, and operators generally seek a quick return on investment. Experience has shown that aircraft operators with a fleet of older aircraft will often decide to wait until they procure new aircraft. The analysis has to account for a transition period during which benefits will gradually increase until all aircraft are equipped. For these reasons, ANS providers must coordinate the development of a comprehensive business case with aircraft operators, accounting for all the costs and benefits identified by the participants in the CONOPS development. The business case will be credible only if the related CONOPS is credible, and this will require simulation and trials to satisfy participants.

7.4.1.2 Along with system acquisition, operations and maintenance costs, ANS providers need to fund operational implementation to include procedure development, training, possibly sharing in the cost of avionics development, integration and operational approval. ANS providers need to provide an incentive to equip by designing airspace and procedures that provide operational benefits.

7.4.1.3 In some cases, non-quantifiable benefits (e.g. in a community that relies completely on aviation for supplies and medical evacuation) will drive an implementation decision.

7.4.1.4 The analysis should consider such elements as cost recovery, revenue policy and extra costs during a transition period. Experience has shown, however, that when cost recovery is linked to an individual service, aircraft operators are reluctant to support a CONOPS and will not equip with the required avionics. They will be much more likely to equip if the service is not subject to specific charges/fees. In cases where the State is the ANS provider, the business case could consider benefits to other sectors of the economy.

7.4.1.5 Some ICAO references for developing a business case are listed in Appendix A.

7.4.2 Common cost elements — Basic GNSS, GBAS and SBAS

7.4.2.1 The following costs borne by ANS providers are common to Basic GNSS, GBAS and SBAS services: surveying to the World Geodetic System — 1984 (WGS-84) standard; designing airspace and instrument approach procedures; performing flight checks; developing procedures and phraseology for ATC; developing and delivering training material; developing a notification/NOTAM system; developing approval and information documents for the aviation community; and funding annual costs associated with continuing to provide service.

7.4.2.2 Common costs borne by aircraft operators include: avionics and installation; development of flight procedures; development and delivery of training material to aircrew; development of maintenance material; avionics database subscriptions; and associated recurring costs. The cost of aircraft out-of-service time should be included except when modifications can be completed during scheduled maintenance.

7.4.2.3 Aircraft operators should choose avionics that meet all foreseeable requirements (e.g. ADS-B, ADS-C and PBN). This could mean a higher cost than initially anticipated, but would provide a wider range of future benefits.

7.4.3 Basic GNSS costs and benefits

Many States implemented Basic GNSS operations without developing a detailed business case because the navigation system infrastructure (GPS) came at no cost. Many aircraft operators decided to equip with off-the-shelf TSO-C129 avionics when they calculated the fuel savings provided by direct routings and the cost savings associated with lower approach minima, i.e. fewer diversions, overflights and cancellations, including the cost of accommodating passengers when flights are disrupted. It is suggested that when States are contemplating the introduction of Basic GNSS services, they could take advantage of documentation available from other States and implement Basic GNSS operations without the need for a detailed business case analysis.

7.4.4 SBAS costs and benefits

7.4.4.1 The costs associated with SBAS implementation from the ANS provider perspective, in addition to those listed in 7.4.2 include: system development; ground infrastructure, including reference stations, master stations, terrestrial communications network; and GEO satellite costs. Options for the GEO component include: employing an SBAS transponder on a State GEO that has multiple functions (e.g. weather observation or communications); using a GEO dedicated to the SBAS function; or contracting with a commercial GEO operator to include an SBAS transponder on a GEO satellite in a suitable orbital slot.

7.4.4.2 It is desirable to implement SBAS in regions where multiple States can share costs. This results in a more affordable system, uniform service and benefits for all States in the region. One State could develop the system and others could join later, or States could form a partnership for the development and implementation of a regional SBAS.

7.4.4.3 The benefits of SBAS include:

a) reduced flight disruptions and associated costs by providing lower minima to many runways, including LPV down to 60 m (200 ft) (CAT I minima);

b) reduced delays by providing increased airport capacity during LPV operations because SBAS, unlike ILS, does not have sensitive areas that must be protected;

c) enhanced efficiency by supporting en-route and terminal area PBN procedures, allowing more aircraft to follow preferred trajectories;

d) improved access to runways where siting constraints prevent the use of conventional aids;

e) increased capacity on closely spaced parallel runways by supporting multiple glide path angles and displaced thresholds;

f) reduced costs by allowing for the decommissioning of some conventional aids;

g) reduced costs for periodic maintenance because SBAS ground infrastructure is limited to a few dozen locations, is normally installed in existing ANS facilities and employs redundant line replaceable components;

h) reduced costs for procedure validation compared with ILS and other conventional aids because SBAS approaches do not require periodic flight inspections by aircraft with complex equipment;

i) reduced aircrew training costs when all approaches can be flown using vertical guidance; and

j) SBAS position accuracy and integrity that meet the performance requirements for ADS-B terminal and surface surveillance, as well as surface movement guidance and control systems.

7.4.5 GBAS costs and benefits

7.4.5.1 The costs of GBAS implementation from the perspectives of ANS providers and aircraft operators include the cost of airport ground stations and those listed in 7.4.2. It should be noted that as of 2017, GBAS avionics were only available for large airline and business aircraft, helicopters and small general aviation aircraft.

7.4.5.2 The benefits of GBAS include:

a) reduced cost for ground infrastructure because a single GBAS ground station can provide approach guidance to all runways at an airport, unlike ILS, where each runway requires a dedicated system; cost estimates must, however, account for any requirement to retain ILS to mitigate vulnerability risks;

b) reduced flight disruptions and associated costs by providing lower minima to runways now served by NPAs;

c) increased airport capacity because unlike ILS, GBAS does not have sensitive areas that must be protected; service providers will, however, have to assess how to accommodate a fleet of users equipped with GBAS or ILS avionics and realize that benefits may require runways reserved for GBAS users;

d) enhanced efficiency by supporting terminal area PBN procedures when GBAS positioning service is available, allowing more aircraft to follow preferred trajectories;

e) improved access to runways where siting constraints prevent the use of conventional aids;

f) reduced costs for periodic maintenance and flight inspections compared with ILS;

g) increased capacity on closely spaced parallel runways by supporting multiple glide path angles and displaced thresholds; and

h) in future, the GBAS positioning service which may provide benefits via surface movement guidance and control.

7.4.5.3 Most of the cost for an airport to achieve CAT II/III operations is in airfield lighting, surface movement guidance and control (possibly surface movement radar) and approach design (obstacle clearance surface compliance), regardless of whether GBAS, ILS, or MLS is used. These other costs, unless a runway already supports CAT II/III, must be included in the GBAS business case analysis. Airports with CAT II/III service are typically very busy hubs, serving major cities and playing a significant role in the local economy and in the financial viability of aircraft operators. Even brief service disruptions at such airports can be very costly to operators. The business case for CAT II/III GBAS needs to consider the requirement to retain ILS or MLS on one or more runways to support continued operations in the event of GNSS signal interference.

7.4.6 ADS-B costs and benefits

7.4.6.1 Costs to the ANS provider associated with ADS-B surveillance include: ground stations (or, in future, LEO satellite costs); terrestrial or satellite communications links; modification to ATC automation systems to display ADS-B targets; development of ATC procedures and training material; simulation to quantify benefits; training of ATC staff; and development of approval and information documentation for aircraft operators. ADS-B ground stations are much less costly than radar to purchase and operate.

7.4.6.2 The benefits of ADS-B are significant in areas not currently served by radar. ICAO has established that current ADS-B architecture, from a technical perspective, can support the 5 NM separation standard in en-route airspace currently supported by radar. Starting from this point and considering local traffic density and patterns, several States have completed ADS-B safety assessments that have led to the application of a 5 NM separation standard in non-radar airspace. This requires Basic GNSS avionics and a Mode S transponder capable of broadcasting position information on 1 090 MHz. In remote airspace in Canada and Australia, ADS-B implementation reduced separation standards from as much as 80 NM to 5 NM. In these States, despite the fact that not all aircraft in the ADS-B area are equipped, many operators are realizing the potential for fuel savings based on their aircraft flying preferred trajectories. Airspace simulation can be used to quantify benefits.

7.4.6.3 The United States plans to use ADS-B surveillance for all operations including surface movement guidance and control. For the latter operation, SBAS is currently the only system capable of meeting ADS-B accuracy and integrity requirements.

7.4.7 ADS-C costs and benefits

7.4.7.1 Costs to the ANS provider associated with ADS-C include modifying ATC automation systems to process ADS-C data and display aircraft position on ATC situation displays. ADS-C uses the aircraft communications addressing and reporting system (ACARS) digital datalink used by airlines mainly for operational messages. ATC systems need an interface with ACARS providers to obtain position reports. This communications architecture also supports controller-pilot data link communications (CPDLC).

7.4.7.2 The reduced separation standards supported by ADS-C provide increased airspace capacity. This allows more aircraft to fly at optimum altitudes along optimum tracks, thus saving fuel and reducing emissions.

7.5 SYSTEM SAFETY ASSESSMENT

7.5.1 By approving GNSS-based operations, a State or regional safety oversight organization (RSOO) accepts responsibility to ensure that such operations meet accepted safety standards. States can either provide GNSS signals or can authorize the use of signals provided by other entities. In the latter case, the State retains the responsibility to oversee the safety of the service, as described in the ICAO *Safety Oversight Manual* (Doc 9734). Moreover, States are responsible for the total system, including aircraft, ATC and aircrew performance, aeronautical information and aerodrome elements.

7.5.2 The ICAO *Safety Management Manual (SMM)* (Doc 9859) describes the processes of hazard identification and risk analysis that should be used to assess a proposed service before implementation. The safety assessment should identify all technical and operational hazards and associated risks and develop ways to eliminate hazards and/or reduce the probability or severity of possible outcomes.

7.5.3 Annex 11 — *Air Traffic Services* calls for a safety assessment before making significant safety-related changes to the ATC system. The same principle applies to ANS providers, aerodrome operators, aircraft operators or other regulated organizations. To avoid duplication of effort, more entities could jointly assess the safety of the changes (e.g. implementation of a GBAS where the power supply is provided by the aerodrome operator, where there is a control tower whose procedures will change and where the GBAS operates in an area where SBAS signals are also available).

7.5.4 Each safety assessment normally relies on a number of assumptions, such as the installed avionics have an airworthiness approval and the pilots are trained. It is the responsibility of the State to verify that all the assumptions are substantiated.

7.5.5 SARPs for core constellations and augmentation systems and standards for avionics were developed to meet recognized target levels of safety, so in some cases no further analysis of these elements is required. Procedure design standards in the *Procedures for Air Navigation Services — Aircraft Operations* (PANS-OPS, Doc 8168) have a similar safety foundation.

7.5.6 An effective safety assessment process starts at the first stage of development of a CONOPS and considers all the technical and operational aspects of a proposed service. This supports the development of suitable regulations, training, procedures and the fielding of related systems. The process continues throughout the life cycle of the service. Experience shows that this approach results in the most efficient use of resources by avoiding unanticipated problems that reduce benefits, create safety risks or delay implementation.

7.5.7 In the case of GNSS augmentation and ADS-B systems, safety assessment must ensure that the system design and implementation meets the SARPs. Since the first GNSS approvals in 1993, many States have implemented PBN operations and some have implemented ADS-B. The regulations and operational procedures developed by these States reflect a safety assessment that can be used as a basis by other States, perhaps with a “differences analysis” to address any State-specific issues.

7.5.8 Not all aircraft are equipped with GNSS avionics. The safety assessment must consider the operational procedures that accommodate equipped and non-equipped aircraft.

7.6 CERTIFICATION AND OPERATIONAL APPROVALS

7.6.1 Operational approvals

7.6.1.1 A State can authorize GNSS-based operations in its airspace in a number of ways. The most common alternatives are:

a) by granting GNSS approach privileges to instrument rated pilots;

b) by including the operations in the operational specification attached to the Air Operator Certificate for commercial aircraft operators, having verified the approved flight manual and the aircrew training; and

c) by issuing a document (e.g. specific approval in the form of a letter of authorization) approving specific operations for aircraft with certified equipment.

7.6.1.2 Some States have required the “specific approval” for CAT II and III operations, for other complex operations or for “new” CONOPS. The approval specifies all terms and conditions and limitations on proposed operations.

7.6.1.3 Applying, documenting and obtaining a specific approval, especially for non-commercial operators, will represent an administrative burden. It is therefore recommended that States or RSOOs do not impose such additional processes when all the following eight requirements are fulfilled:

a) the aircraft, including its navigation avionics, has an airworthiness approval covering the proposed IFR operations;

b) the complexity of proposed IFR operations does not present particular challenges;

c) the concept and systems upon which the IFR operations will be carried out are mature enough, as is the case today for GNSS;

d) the risk associated with improper operation is tolerable;

e) accuracy, integrity, availability and continuity of radionavigation signals are ensured;

f) appropriate standards for quality and management of procedure design are established;

g) accuracy and integrity of the navigation database are ensured; and

h) appropriate aircrew training and checking standards and procedures for the proposed IFR operations exist and are implemented.

7.6.1.4 The wide variety of GNSS avionics and pilot interfaces dictates a tailored approach to aircrew training and certification. In the case of aircraft equipped with flight management systems (FMS), the transition to GNSS-based operations will be relatively simple. In the case of stand-alone GNSS avionics, the authorization of GNSS operations could include provisions for specific training, aircrew certification requirements and the handling of airborne databases. Many States have developed training material addressing GNSS-based services, and publish this material on the Internet.

7.6.2 Avionics certification

7.6.2.1 As described in Doc 9613, aircraft require avionics that meet the prescribed navigation specification. Avionics used for GNSS-based services must be of an approved type and be installed in accordance with specific criteria. Any new installation should be validated by a series of tests, measurements and inspections. Certification and check procedures are based on the performance standards contained in RTCA and EUROCAE documentation and in State documents. Avionics installations can be approved as part of the original aircraft type design (type certificate) or as a modification to the original aircraft type design (supplemental type certificate).

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

7.6.2.3 Pilot procedures, contained in aircraft operating manuals, need to address the characteristics of GNSS and minimize aircrew and ATC workload. General flight procedures for the use of GNSS are included in the PANS-OPS.

7.6.2.4 For ADS-B operations, the integration of GNSS sensors with the transponder or other medium used for broadcasting position information must be shown to operate properly. This can be evaluated by ANS providers who are able to observe ADS-B performance.

7.6.2.5 Since many States apply FAA or EASA standards, harmonization of these standards is essential and is, in practice, pursued whenever possible by both agencies.

7.6.3 Use of non-IFR GNSS receivers for VFR navigation

7.6.3.1 Many pilots use receivers that do not meet the standards for IFR operations to supplement visual flight rules (VFR) navigation, particularly in areas where there are few landmarks and where conventional aids are not available or reliable.

7.6.3.2 Non-IFR receivers provide accurate guidance most of the time, but they do not provide the fault detection afforded by RAIM, so a faulty satellite signal could produce a significant position error without any warning to the pilot. Other potential problems may result from poor antenna location with portable receivers, the inability to update receiver databases in some cases, and the use of map data other than WGS-84.

7.6.3.3 Pilots using non-IFR receivers must remain in visual meteorological conditions (VMC) and apply pilotage or dead reckoning to ensure safety. They must resolve any difference between the GNSS position and maps or navigation data available from other sources. There have been accidents in which VFR pilots who relied excessively on GPS continued in deteriorating weather conditions without visual references and lost control or became the victims of a CFIT accident. Some States have published safety material on this subject.

7.6.3.4 Some States have adopted the use of VFR reporting points around airports where there is a significant level of light aircraft traffic. GNSS assists in navigating to these VFR reporting points in VMC. This enhances situational awareness and affords pilots more time to watch for other aircraft.

7.6.4 GBAS and SBAS system safety oversight

Ultimately, a GBAS or SBAS must meet the SARPs. Typically, States contract for the provision of SBAS or GBAS, and a contractor must demonstrate:

a) that its system safety assessment process has adequately identified and assessed all system safety hazards and that the design can be shown to meet the top-level safety requirements (e.g. integrity and continuity of service);

b) that its testing and requirements verification processes confirm compliance with each specification requirement. Typical areas of review under this activity include the applicant's system level verification/test plans, procedures and reports. States will also typically complete verification testing with the contractors' equipment; and

c) that its hardware and software development processes comply with the appropriate standards.

7.7 SYSTEM TESTING AND PROCEDURE VALIDATION

7.7.1 The *Manual on Testing of Radio Navigation Aids* (Doc 8071), *Volume II — Testing of Satellite-based Radio Navigation Systems* provides guidance on the testing of GNSS. This testing is designed to confirm the ability of GNSS signals to support flight procedures in accordance with Annex 10.

7.7.2 ANS providers must also assess the suitability of a procedure for publication, as detailed in PANS-OPS (Doc 8168), Volume II, Part I, Section 2, Chapter 4, Quality Assurance. The *Quality Assurance Manual for Flight Procedure Design* (Doc 9906), Volume 5 — *Validation of Instrument Flight Procedures* provides the required guidance for GNSS-based procedures. Flight validation for GNSS-based procedures is less costly than for conventional aids because there is no need for complex signal measurement and recording systems and there is no requirement to check signals periodically.

7.8 MONITORING AND RECORDING OF GNSS DATA

7.8.1 Introduction

7.8.1.1 Annex 10, Volume I, 2.1.4.2 recommends that a State that approves GNSS-based operations should monitor and record relevant GNSS data to support accident and incident investigations. This data can also be used periodically to verify GNSS performance. It should be noted that this verification of GNSS performance is not intended to support a real-time notification process.

7.8.1.2 The Twelfth Air Navigation Conference (AN-Conf/12) recommended that, for future use of multiple constellations, States publish information specifying the GNSS elements that are approved for use in their airspace. In order to do this, States would need a clear understanding of the performance of these signals with respect to related standards (such as SARPs and/or specific local requirements) enabling their operational use in combination with augmentation systems used in a specific phase of flight. Therefore, States may need an assessment of the performances of GNSS core constellations to decide on their approval status within their respective flight information regions (FIRs). The approval status of a GNSS signal in any State or region could change depending on the measured performance, and therefore States or regions may decide that it would be appropriate to monitor signals from GNSS core constellations in order to periodically assess system performance.

7.8.1.3 The purpose of this section is to clarify the concept of GNSS monitoring, with particular regard to GNSS performance assessment, to identify performance parameters appropriate for GNSS monitoring and data recording, to explain potential benefits in conducting periodic performance assessments, and to provide guidance on implementation aspects.

7.8.2 GNSS monitoring

The following activities involve a GNSS monitoring function:

a) GNSS performance assessment: a periodic off-line activity, that may be performed by a State or delegated entity, aiming to verify that GNSS performance parameters conform to the relevant Annex 10 SARPs. This activity can be done for the core constellation, the augmentation system or a combination of both. GNSS performance assessment is discussed in section 7.8.3;

b) GNSS operational status monitoring: an activity performed by a State or delegated entity, with the main objective of providing timely information to technical staff and ATC services on the operational status of GNSS services in relation to a defined operation in a particular airspace (and to therefore inform the user of any operating restrictions that may be required). Operational status monitoring is discussed in the PBN Manual, Volume II, Part A, 4.3.1 and in Annex 10, Volume I, Chapter 2, 2.3;

c) GNSS data recording: an activity performed by a State or delegated entity with the objective of collecting historical data of GNSS parameters which can be used to support post-incident/accident investigations. GNSS data recording is discussed in section 7.8.4; and

d) GNSS interference monitoring: an activity performed by a State or delegate entity with the objective of identifying sources of radio frequency interference that may constitute a threat to GNSS, with a view to preventing or removing the threat. GNSS interference monitoring is discussed in Appendix F.

7.8.3 GNSS performance assessment

7.8.3.1 GNSS performance assessment may be used by States in order to:

a) periodically verify the performance of signals that have already been declared operational (such as GPS L1 and GLONASS L1); and/or

b) collect statistical data on technical elements to support decisions for operational approvals in a particular airspace based on new GNSS signals and/or constellations (such as GPS L5, GLONASS L3, BDS and Galileo).

7.8.3.2 Navigation performance requirements are specified in terms of accuracy, integrity, continuity and availability. These parameters are applicable to the total system performance, which includes the SIS, the airborne equipment and the ability of the aircraft to fly the desired trajectory, and are not just referring to the SIS itself (Annex 10, Volume I, Attachment D, 3.1).

7.8.3.3 Of these parameters, integrity is the most critical due to its link to the classification of safety events and therefore is the most stringent of the requirements. It is applicable and measurable only with regard to the total system and not just to the core constellation itself.

7.8.3.4 Methods of performing integrity monitoring differ depending on the augmentation system as discussed below.

7.8.3.4.1 For ABAS, integrity monitoring is performed within the aircraft receiver using RAIM (see 4.2). RAIM is based on protecting aircraft with the minimum required capabilities on board, without taking into account other forms of aircraft-based augmentation, such as IRS integration. Receivers that are certified in accordance with relevant State standards (such as those based on minimum operational performance standards (MOPS) and technical standard orders (TSO)) are designed to meet the integrity requirement defined in Table 3.7.2.4-1 of Annex 10, Volume I, Chapter 3, assuming that GPS is compliant with key parameters defined in the GPS SARPs and in the GPS SPS Performance Standard (see Annex 10, Volume I, Attachment D, 4.1). The compliance with the integrity requirement of $1\text{-}1\times10^{-7}$/hr for NPA is based on the assumption that the probability of satellite failure (less than 10^{-4}/hr)[1] is met, that there are no simultaneous satellite failures (this probability is less than 10^{-9}/hr and is therefore assumed negligible), and that the RAIM algorithm has a certain probability of missed detection (less than 10^{-3}/event).

7.8.3.4.2 For SBAS, integrity monitoring is performed by ground-based systems with assurance provided by design and specific monitoring. Verification of performance with respect to associated requirements in Table 3.7.2.4-1 is ensured by the SBAS service providers in their respective service areas.

7.8.3.4.3 For GBAS, the same principle applies as for SBAS and monitoring is the responsibility of the GBAS service providers.

7.8.3.5 It should be noted that availability, integrity, accuracy and continuity, as used by aviation, may have a different meaning to the same or similar terms used in performance standard documents published by core constellation service providers (such as the GPS SPS Performance Standard). These differences have to be considered when identifying parameters to be used in performance assessment.

7.8.3.6 For ABAS, reliable measurements of GNSS operational performance taking as reference the targets identified in Table 3.7.2.4-1 may be difficult to implement due to the different results that can be obtained depending on the specific RAIM algorithm being used. Nevertheless, a State may still find it useful to get an appreciation of achieved performance at the user level, as long as the associated limitations due to different aircraft system integrations are understood.

7.8.3.7 A more practical approach would be to assess the parameters specified for GNSS core constellations in SARPs independently from the augmentations considered. As not all of these parameters have a direct impact on operations, it is important to focus on parameters whose performance could trigger further investigations and/or escalation of actions, giving priority to those parameters related to safety and integrity which are key for RAIM design (such as the probability of simultaneous satellite failures).

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[1] In RAIM, the probability that an individual GPS satellite is in a faulted state at any given instant is taken to be 10^{-5}/hr, and assuming that there are on average 10 satellites per a positioning solution, a probability of satellite failure of 10^{-4}/hr can be derived for a constellation. Based on a probability of missed detection of 10^{-3}/event or less, an integrity better than 10^{-7}/hr can be achieved. This applies to current RAIM with GPS only.

7.8.3.8 *Core constellation performance parameters*

7.8.3.8.1 Table 7-1 lists a basic set of core constellation performance parameters suitable for periodic verification. The performance parameters of the table below are focused on GPS and GLONASS. It is expected that the table will be extended to other constellations (BDS and Galileo) when the related SARPs will be available.

7.8.4 GNSS data recording

7.8.4.1 Recording systems can be implemented in line with the requirements reported in Annex 10, Volume I, 2.1.4.2 and the related activities can be delegated to other entities and/or States by means of specific agreements. Criteria for the localization of recording stations could be the same as the ones used for performance assessment.

7.8.4.2 The recording system need not be independent of the GNSS service. To enable future reconstruction of position, velocity and time indications provided by specific GNSS configurations, it is recommended to log data continuously, generally at a 1 Hz rate.

7.8.4.3 For GNSS core systems, the following monitored items should be recorded for all satellites in view:

a) observed satellite carrier-to-noise density (C/N_0);

b) observed satellite raw pseudo-range code and carrier phase measurements;

c) broadcast satellite navigation messages, for all satellites in view; and

d) relevant recording receiver status information.

7.8.4.4 For SBAS, the following monitored items should be recorded for all GEO satellites in view in addition to the GNSS core system items listed above:

a) observed geostationary satellite C/N_0;

b) observed geostationary satellite raw pseudo-range code and carrier phase measurements;

c) broadcast SBAS data messages; and

d) relevant receiver status information.

7.8.4.5 For GBAS, the following monitored items should be recorded in addition to the GNSS core system and SBAS monitored items listed above:

a) VDB power level;

b) VDB status information;

c) broadcast GBAS data messages; and

d) relevant reference receiver status information.

Table 7-1. Core constellation performance parameters

Performance parameter	*Definition*	*Targets (Annex 10, Volume I, reference)*	*Notes*
Positioning accuracy	95th percentile of the position error measured, intended as difference between the estimated position by the receiver and the reference position, calculated over any 24-hr interval, for any point considered within the service volume.	3.7.3.1.1.1 (GPS) 3.7.3.2.1.1 (GLONASS) The targets refer to space/control segment only and do not take into account atmospheric or receiver errors.	
Range domain accuracy/ Instantaneous SIS user range error (URE)	Difference between the pseudo-range measured at a given location and the expected pseudo-range as derived from the navigation message.	3.7.3.1.1.3 (GPS) 3.7.3.2.1.3 (GLONASS) The targets refer to space/control segment only and do not take into account atmospheric or receiver errors.	A recommended method to compute accurate URE is to subtract the broadcast ephemeris (received by the user receiver in the navigation message) from a precise real-time orbit and clock solution available on public websites (such as USCG, NGS, SOPAC). A second possibility to compute the URE is to use the user receiver capabilities to exclude propagation-related (ionosphere, troposphere) and user receiver-related (multipath, receiver noise, receiver clock error) pseudo-range error components. The precision of the computed URE value depends on the selected user receiver (single/dual frequency, error correction algorithms).
Service availability	Percentage of time over any 24-hr interval that the predicted 95 per cent position accuracy is less than a specified value within the service volume.	3.7.3.1.2 (GPS) 3.7.3.2.2 (GLONASS) The targets do not take into account atmospheric or receiver errors.	The term "predicted" may refer to the usage of the broadcast navigation message that, when used for any real-time processing, provides an estimation of future (predicted) satellite position (ephemeris) and clock values.
Probability of major service failure	Probability that over a specific time interval, a healthy satellite's ranging signal error (excluding atmospheric and receiver errors) exceeds the broadcast range error limit by a given factor.	3.7.3.1.4 (GPS) 3.7.3.2.3 a) (GLONASS)	This parameter is verified over a period of one year. It is suggested to use a sliding window methodology for the computation, using any consecutive period of twelve months. This parameter is derived from other measurements such as the SISE.
Continuity	Probability that healthy SIS per satellite will continue to be healthy without unscheduled interruptions over a specified time interval.	3.7.3.1.5 (GPS) 3.7.3.2.3 b) (GLONASS)	Healthy SIS conditions are defined in corresponding core constellation performance standards or interface documents.
Probability of simultaneous major failures of two or more satellites	Probability of simultaneous failure (under the same conditions defined for major service failure) of two or more satellites.	1×10^{-9}/hr (currently valid only for GPS)	This probability includes the probability of two or more independent, unannounced single failures occurring at any time; and the probability of two or more dependent satellite failures, for example failures from ground segment leading to a major failure in several satellites or even in the whole constellation.

7.8.5 Implementation aspects

7.8.5.1 Considering the current GNSS evolution roadmap, including the upcoming new core constellations, States may start to implement performance assessment activities based on the guidelines described in this chapter. Once a core constellation is deployed, it is expected that it will provide global performance monitoring reports. The following roadmap can be envisaged:

1. States considering a performance assessment and data recording capability may use any of the following approaches:

    a) use public reports provided by GNSS service providers or other organizations;

    b) establish or use existing regional/global monitoring networks by means of agreements with neighbouring States or data providers;

    c) establish agreements with neighbouring States that are publishing performance reports that cover the area of interest; and

    d) implement a dedicated national network.

2. In the future, all core constellation service providers (GPS, GLONASS, BDS and Galileo) may provide global periodic performance reports including the relevant parameters identified in Annex 10, Volume I. These reports can be used by States in combination or substitution of capabilities previously implemented.

7.8.5.2 The selection and siting of monitoring receivers are essential and should take into account all factors that may adversely affect measurement results such as atmospheric effects (ionosphere and troposphere), receiver noise, obstructions, radio frequency interference and multipath.

7.8.5.3 Another important point to be considered when implementing a monitoring and data recording system is the density and number of stations required. The criteria for the determination of the density of stations to be deployed over a given area need to take into account satellite geometry, tropospheric delay and ionospheric delay models. Alternatives solutions available to States include the use of different sources such as the International GNSS Service (IGS), scientific/research institutions and dedicated stations.

7.9 AIRSPACE PLANNING AND PROCEDURE DEVELOPMENT

7.9.1 General

7.9.1.1 Doc 9613 explains the strategic objectives that define the airspace concept for a particular area, the links to navigation functional requirements and the resulting navigation specification. In most cases, GNSS provides the only way to satisfy the technical performance required by an RNAV or RNP navigation specification. “Off-the-shelf” systems that comply with Annex 10 and related avionics standards meet these specifications. GNSS makes PBN affordable and accessible for all aircraft operators.

7.9.1.2 Doc 9613 also provides guidance for the design of flight procedures, including the construction of routes, arrivals, departures and approaches based on navigation specifications.

7.9.1.3 PANS-OPS, Volumes I and II, includes criteria for GNSS terminal, NPA and departure operations, developed in line with Basic GNSS receiver performance. Standard instrument departure/standard instrument arrival (SID/STAR) criteria have also been published. PANS-OPS also addresses APV SBAS, APV Baro VNAV and GBAS procedures.

7.9.2 GNSS-based approach procedures

7.9.2.1 When GNSS was first approved for NPA procedures, many ANS providers designed new GPS stand-alone approaches. These offer significant benefits because they often provide lower minima, do not require a course reversal and provide the aircrew with precise position information throughout the procedure. They also provide a safety benefit by providing straight-in approaches to runways where conventional aids could only support circling procedures.

7.9.2.2 In some States, pilots are authorized to fly suitable VOR, VOR/DME, NDB and NDB/DME NPA procedures using GPS guidance. These “GPS overlay” approaches allow operators to benefit from better accuracy and situational awareness without the need for the ANS provider to design a new approach. This is seen as an interim step bringing early benefits to users. This may in particular allow users without automatic direction finder (ADF) avionics to fly in airspace where NDBs support some operations. Using GPS guidance, pilots follow the path defined by the conventional aids and comply with the charted minimum descent altitude. Some VOR- and NDB-based procedures are not suited to the overlay programme because certain approach legs cannot be adapted to the RNAV data coding system.

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

7.9.2.4 Certain operational restrictions were deemed necessary for the initial implementation of ABAS-based NPA procedures flown using TSO-C129 avionics. The reasons for and nature of these restrictions vary from State to State and include: the lack of 100 per cent RAIM availability; the availability of conventional aids as a backup; traffic density; and regulations for avionics redundancy. A common operational restriction in some States is that the pilot shall not take into account GPS approaches at an alternate airport when determining alternate weather minima requirements.

7.9.2.5 The introduction of GNSS created a strong demand for PBN approach procedures, and some States have experienced difficulty meeting this demand. These procedures are, however, well suited to computer-aided design, which increases productivity and makes it possible to quickly evaluate alternatives and find the best available design in a given situation.

7.9.3 Minimum en-route altitude (MEA)

Conventional navigation aid coverage limitations affect minimum en-route altitude (MEA) on airways. In some cases, this requires aircraft to fly at higher altitudes where oxygen may be required or where icing conditions exist. As opposed to conventional navigation aids, GNSS provides coverage to the ground, so MEA can be based on considerations of terrain, obstructions and communications coverage.

7.10 AERONAUTICAL INFORMATION SERVICES

7.10.1 Information about GNSS-based operations

7.10.1.1 When a State approves GNSS-based operations it must provide a clear statement of terms and conditions, procedures and such things as training requirements in the State AIP.

7.10.1.2 States also need to provide background information about GNSS technology and its operational applications. Experience has shown that aircraft operators require detailed information to ensure compliance with regulations as well as ensure the most effective and efficient use of GNSS. Many States have developed such information and it is available on their websites.

7.10.1.3 Due to the pace of development of GNSS technology and operations, aircraft operators require current information that can assist them in planning for the acquisition of avionics. This can be achieved by involving them in CONOPS and business case development.

7.10.1.4 Information updates may be published in an Aeronautical Information Circular (AIC), State AIP or, in some cases, an advisory circular.

7.10.2 WGS-84 coordinate system

7.10.2.1 Performance-based navigation guidance depends on the accurate definition of waypoint coordinates based on a common geodetic reference system.

7.10.2.2 Annex 10 specifies that GNSS position information shall be expressed in terms of WGS-84. Additional information on the use of WGS-84 may be found in Annex 4 — *Aeronautical Charts*, Annex 11 — *Air Traffic Services*, Annex 14, and Annex 15 — *Aeronautical Information Services*, as well as the *World Geodetic System — 1984 (WGS-84) Manual* (Doc 9674).

7.10.2.3 Doc 9674 contains guidance material regarding the transformation of existing coordinates and reference data to WGS-84. It should be noted that this is a mathematical process that does not take into consideration the quality and accuracy of the original coordinates. Many States have elected to re-survey to WGS-84 standards due to the lack of integrity of existing surveys, and resurveying is considered to be the preferred option.

7.10.2.4 Annex 10 specifies that the GLONASS coordinate system shall be PZ-90, and it provides conversion parameters used to obtain coordinates in WGS-84. In 2007, the PZ-90 datum was updated to differ from WGS 84 by less than 40 cm in any given direction.

7.10.3 Airborne navigation database

7.10.3.1 The safety of GNSS navigation and approach guidance depends on the integrity of the data in the airborne navigation database. States must ensure that the quality (accuracy, integrity and resolution) of position data is retained from the time of the survey to the submission of the information to database suppliers who, with avionics manufacturers, create the airborne navigation database. States can ensure database integrity through certification and oversight of data providers or by delegating oversight responsibility to certified aircraft operators. This process should also ensure consistency with the data used in ATC flight data and radar systems.

7.10.3.2 Navigation specifications in the Doc 9613 identify database requirements for specific operations. Two harmonized EUROCAE/RTCA documents are available to assist in the production and handling of aeronautical data: *Standards for Processing Aeronautical Data* (RTCA/DO-200A/EUROCAE ED-76) and *Standards for Aeronautical Information* (RTCA/DO-201A/EUROCAE ED-77). These documents provide a framework for developing valid waypoint coordinates and for ensuring that only correct coordinates reside in airborne navigation databases. Provisions relating to aeronautical data are contained in Annex 11, Chapter 2, and Annex 15, Chapter 3.

7.10.3.3 Maps and charts used by aircrew must be consistent with airborne navigation databases. The path to be followed when flying a procedure is defined by waypoint coordinates and leg-type designators coded by database suppliers. Designers must therefore have an appreciation of data coding standards and States should validate all waypoint coordinates and essential leg-type designators, particularly those used in instrument approach and departure procedures.

7.10.3.4 The airborne navigation database must be valid with respect to the effective aeronautical information regulation and control (AIRAC) cycle, which generally requires that a current database be loaded into the avionics every 28 days. The use of expired navigation databases creates a safety risk.

7.11 GNSS SERVICE STATUS NOTIFICATION

7.11.1 General

7.11.1.1 State ANS providers have the responsibility to report the status of air navigation services. If the status of a service changes or is predicted to change, users should be notified via direct communications from ATS and/or via a NOTAM or aeronautical information system (see Annex 15 and the *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, Doc 4444)).

7.11.1.2 With conventional aids, service is directly related to equipment status. Therefore, a NOTAM stating that an ILS is out of service indicates that the associated precision approach will not be available.

7.11.1.3 In the case of GNSS, when a core constellation satellite or an SBAS reference station fails or is removed from service for maintenance, there is no direct relationship to a loss of service. In such cases, ANS providers and aircraft operators can determine the general effects of outages using mathematical models. There are commercial and State entities that can assist States in developing systems to serve their airspace. As described below, however, such models cannot define service availability with precision for all aircraft in an area.

7.11.2 Core satellite system status NOTAM

7.11.2.1 Operators of GNSS core constellations should provide information on actual and projected outages of their satellites. The United States provides advisories via Notice Advisory to NAVSTAR Users (NANUs) and the Russian Federation provides advisories via Notices Advisory to GLONASS Users (NAGUs). ANS providers and some aircraft operators require this information in NOTAM form to support service status modelling. Systems operated by ANS providers typically generate service status notifications and NOTAM without human intervention.

7.11.2.2 It is not possible to precisely establish the performance at the aircraft level everywhere within a service area using monitor receivers or mathematical models for the following reasons:

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

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

c) aircraft dynamics can affect satellite signal reception;

d) terrain masking can affect the aircraft or monitor;

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

f) aircraft receivers may apply unique techniques that improve on basic RAIM/FDE availability.

7.11.2.3 Given the variety of avionics designs, one service status model cannot meet all operators' requirements. A conservative model would produce false alarms for some aircraft. A less conservative model would lead to missed detection of a service outage for some and false alarms for others. Regardless, only the aircrew, not ATC, is in a position to determine whether, for example, it is possible to continue an ABAS-based instrument approach. In contrast, ATC has access to ILS monitor data and can deny an ILS approach clearance based on a failure indication. The real-time monitor concept is neither practical nor required for GNSS ABAS operations. It may be practical for SBAS and GBAS, but implementation would depend on a valid operational requirement.

7.11.2.4 Aircraft operators with access to prediction software specific to their particular ABAS/RAIM avionics will find it advantageous to employ that software rather than use the general notification service. In the case of SBAS and GBAS, operators will rely on service status notifications.

7.11.2.5 AIS providers may choose to provide all service status notifications via NOTAM, but based on experience in some States, the Internet provides an alternative that has certain advantages. These include: the ability to graphically display predicted outages within a service area; the ability to automatically display notifications pertinent to a specified route of flight; and the widespread acceptance of the Internet as a source of preflight planning information. The Internet is not acknowledged in some States for service status notification, however, because it does not meet the same security standards as a NOTAM system.

7.11.2.6 Regardless, service providers should use the NOTAM system to disseminate the information on the following:

a) core satellite system status;

b) GNSS interference;

c) widespread SBAS service outages (e.g. due to a GEO failure); and

d) GBAS outages.

7.11.3 Interference NOTAM

7.11.3.1 ANS providers must be prepared to act when anomaly reports from aircraft or ground-based units suggest signal interference. If an analysis concludes that interference is present, ANS providers must identify the area affected and issue an appropriate NOTAM.

7.11.3.2 In some States, military authorities test the capabilities of their equipment and systems occasionally by transmitting jamming signals that deny GNSS service in a specific area. This activity is normally coordinated with State spectrum offices and ANS providers. Military and other authorities operating jamming devices should coordinate with ANS providers to enable them to determine the airspace affected, advise aircraft operators and develop any required procedures.

7.11.4 "SBAS UNAVAILABLE" NOTAM

7.11.4.1 An "SBAS UNAVAILABLE" NOTAM would be used in a case when all GEO satellites serving an area failed. SBAS users would then be dependent upon RAIM/FDE for integrity monitoring. This NOTAM would alert SBAS users to perform preflight predictions of RAIM availability.

7.11.4.2 The failure of an SBAS reference station near the edge of a service area could lead to APV unavailability at airports in a region. This could also be subject to an SBAS UNAVAILABLE NOTAM specifying the region affected, or users could be advised about the affected airports as described in 7.11.6.

7.11.4.3 Although very unlikely, it is possible that the number of core constellation satellites could be greatly reduced (e.g. fewer than 21 available) or that failure of components of the SBAS system could result in low availability of

SBAS en-route through NPA (LNAV) service. Thus, SBAS service could still be "available", but there would be service outages. In this case, the SBAS UNAVAILABLE NOTAM should instruct SBAS users to perform preflight RAIM checks.

7.11.5 GBAS station outage NOTAM

If a GBAS station is out of service or predicted to be out of service, an outage NOTAM is required. It may be possible for a GBAS element failure to result in downgraded service (e.g. CAT II/III to CAT I) rather than a complete service interruption.

7.11.6 PBN service status notifications

7.11.6.1 Service status models should reflect all service levels approved in the State based on ABAS/RAIM or SBAS, but not including those that require special authorization based on a proprietary avionics design. Ensuring that service status models reflect appropriate service levels entails modelling for the various integrity alert limits associated with PBN navigation specifications and those associated with TSOs governing Basic GNSS and SBAS operations.

7.11.6.2 Where multiple core constellation signals are used operationally, it will be necessary to model joint use of these constellations.

7.11.6.3 In view of the fact that SBAS avionics (TSO-C145/C146) and TSO-C196 avionics can function as TSO-C129 avionics with better availability, the model should cater to users with SBAS avionics flying outside SBAS service areas.

7.11.6.4 ANS providers should adopt conservative models compatible with avionics meeting basic standards. This does not preclude providing a feature that allows users to input such things as mask angle and barometric aiding capability to obtain predictions that are better matched to specific avionics performance.

7.11.6.5 Table 7-2 provides an example of the service levels and related predictive integrity alert limits for Basic GNSS (e.g. TSO-C129) and SBAS (e.g. TSO-C145/146) avionics.

7.11.6.6 As additional service levels emerge they will have to be included in modelling and notifications by adding appropriate alert limit calculations. This could include levels associated with ADS-B implementation.

Table 7-2. Service levels and alert limits

	En-route	*Terminal*	*LNAV LNAV/VNAV*	*LP*	*LPV**	*CAT I**
Alert limit	HAL=2 NM	HAL=1 NM	HAL=0.3 NM	HAL=40 m	VAL=50 m	VAL=35 m
GPS avionics	Provided	Provided	Provided	N/A	N/A	N/A
SBAS avionics	Provided**	Provided**	Provided	Provided	Provided	Provided

* SBAS LPV and CAT I both have an HAL of 40 m, but the VAL may be assumed to be the dominant component for service prediction.

** With a functioning SBAS, predictions for en-route and terminal service are not required because availability will be 100 per cent. These predictions are required to serve aircraft with SBAS avionics outside an SBAS service area or in the case where there is a widespread SBAS failure.

7.12 ANOMALY REPORTING

7.12.1 From the perspective of the aircrew, a GNSS anomaly occurs when navigation guidance is lost or when it is not possible to trust GNSS guidance. In this respect, an anomaly is similar to a service outage. An anomaly may be associated with a receiver or antenna malfunction, insufficient satellites in view, poor satellite geometry or masking of signals by the airframe. The perceived anomaly may also be due to signal interference, but such a determination requires detailed analysis based on all available information.

7.12.2 Pilot action(s) may include:

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

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

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

7.12.3 Controller action(s) may include:

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

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

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

d) forwarding information to the designated authority; and

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

7.12.4 States should designate a national or regional office to collect anomaly related information and to determine the course of action required to resolve reported anomalies that can be traced to signal interference. This office should analyse and distribute information to the appropriate agencies within the State and/or other international agencies. Some actions that the focal point unit may take are:

a) evaluating the anomaly reports;

b) advising ATS and providing situational updates;

c) notifying the agency responsible for frequency management;

d) ensuring the issuance of appropriate advisories and NOTAM as necessary;

e) coordinating with States/agencies that provide core satellite constellation(s) or other GNSS element(s);

f) attempting to locate/determine the source of the interference;

g) implementing national policy to mitigate the anomaly; and

h) tracking and reporting all activities relating to the anomaly until it is resolved.

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

7.12.6 Should analysis of aircrew reports conclude that interference is present, ANS providers must identify the area affected, issue an appropriate NOTAM, advise aircrew via direct communications, apply mitigation as described in 7.13, then locate the source and resolve the problem. ANS providers or other responsible organizations may also use ground-based systems to detect interference.

7.13 GNSS VULNERABILITY: MITIGATING THE IMPACT ON OPERATIONS

Note.— Additional guidance on GNSS radio frequency interference (RFI) mitigation is contained in Appendix F.

7.13.1 Risk assessment

7.13.1.1 As described in Chapter 5, States can take measures to reduce the likelihood of service outages due to unintentional and intentional signal interference. ANS providers must still, however, complete a risk assessment by determining the residual likelihood of service outages and the impact of an outage on aircraft operations in specific airspace.

7.13.1.2 The likelihood of interference depends on such factors as population density and the motivation of individuals or groups in an area to disrupt aviation and non-aviation services. The likelihood will be very low to non-existent in oceanic and sparsely settled areas and will be highest near major population centres. Impact assessment will consider the type of airspace, traffic levels and the availability of independent surveillance and communications services, and will address safety and economic effects. The likelihood of disruption due to scintillation will depend on the geographic area and will require scientific assessment. Mitigation will be required when disruption is deemed to be possible and would have a significant impact.

7.13.1.3 In future, the availability of multi-constellation/multi-frequency GNSS along with advanced avionics will reduce the likelihood of service disruption.

7.13.2 Mitigation strategies

7.13.2.1 The disruption of GNSS signals will require the application of realistic and effective mitigation strategies to both ensure the safety and regularity of air services and discourage those who would consider disrupting aircraft operations. There are three principal methods which can be applied in combination:

a) taking advantage of on-board equipment, such as IRS;

b) taking advantage of conventional navigation aids and radar; and

c) employing procedural (aircrew and/or ATC) methods.

7.13.2.2 Several States, in view of the remaining GNSS vulnerabilities, have identified the need for an alternative position, navigation and timing (APNT) strategy with the goal of maintaining services to the maximum extent possible in the event of a GNSS signal outage. To be effective, an APNT strategy must have global application and must be affordable. It must also be possible to implement the strategy within a relatively short time. This implies taking advantage of systems and avionics in use today, then defining a realistic evolution path as necessary.

7.13.2.3 IRS provides a short-term area navigation capability after the loss of GNSS updating. Many air transport aircraft are equipped with IRS and these systems are becoming more affordable and accessible to operators with smaller, regional aircraft. Most of these systems are also updated by DME. An APNT strategy should therefore consider architectures that include an IRS component and consider the availability of DME updating.

7.13.2.4 Conventional aids can provide alternative sources of guidance. DME is the most appropriate conventional aid available in the near- to mid-term for supporting PBN operations, since it currently provides input to multi-sensor navigation systems that allow area navigation in both en-route and terminal airspace. VOR/DME currently provides a useful backup capability for en-route flight. The most appropriate alternative for precision approach service is ILS. Depending on the threat assessment, traffic levels and weather conditions, an ANS provider might find it appropriate to retain some or all of the existing ILS operations at an airport or within an area under consideration.

7.13.2.5 Procedural (aircrew or ATC) methods can provide effective mitigation in combination with those described above, taking due consideration of:

a) the airspace classification and the availability of radar;

b) the avionics in aircraft using the airspace (e.g. most aircraft in high-level airspace will have IRS and/or DME/DME updating of navigation systems);

c) aircrew and air traffic controller workload implications and the availability of controller decision support tools;

d) the impact that the loss of GNSS will have on other functions, such as surveillance in an ADS-B or ADS-C environment; and

e) the potential for providing the necessary increase in aircraft route spacing and/or separation in the airspace under consideration.

7.13.2.6 By adopting an effective strategy using one or more methods identified in this section, an ANS provider will not only ensure safe aircraft operations in case of GNSS outages, but will also discourage intentional interference attempts by reducing the operational impact of interference.

7.14 TRANSITION PLANNING

7.14.1 Conventional navigation infrastructure

7.14.1.1 The current infrastructure comprising VOR, DME and NDB aids was initially deployed to support navigation along routes aligned between VOR and NDB facilities.

7.14.1.2 As traffic levels increased, additional aids were installed to support new routes. This produced a non-uniform distribution of navigation aids. Some areas have a high density of aids while others have a low to very low density. This does not imply, however, that new conventional aids are required in the latter areas as States implement GNSS-based services.

7.14.1.3 As States implement PBN and more aircraft equip with GNSS avionics, regions with high traffic levels will no longer need a high density of VORs and NDBs. This presents an opportunity to rationalize conventional infrastructure.

7.14.1.4 Networks of DMEs enable aircraft equipped with suitable RNAV avionics to fly RNAV routes and procedures. DME will likely be part of the long-term mitigation strategy to allow continued RNAV operations in the event of a temporary loss of GNSS signals.

7.14.2 Rationalization of conventional aids

7.14.2.1 The implementation of GNSS-based services offers an opportunity to rationalize conventional navigation aids and radar. The pace of rationalization will depend on the level of GNSS avionics equipage, on airspace and procedure development and on the vulnerability risk assessment.

7.14.2.2 Equipage depends to a great extent on demonstrating capacity, efficiency and environmental benefits, and to a lesser extent on ANS infrastructure cost-savings, which will be greatest when aids reach the end of their life cycle and require replacement.

7.14.2.3 Avionics equipage is complicated by the stage-by-stage approach to implementation, by the introduction of new features (e.g. multiple frequencies) and by the addition of new GNSS elements. States need to work closely with operators to develop a coordinated strategy and a plan that is practical and achievable from both ANS providers' and aircraft operators' perspectives. This process must identify all of the avionics requirements to meet PBN, ADS-B and the requirements of any other operational systems.

7.14.2.4 In some States or regions, and at some point in the future, it may be necessary to mandate equipage to ensure the efficient use of airspace. All such decisions require close coordination with aircraft operators.

7.14.3 Future conventional infrastructure planning

7.14.3.1 Initial rationalization plans in several States followed a "top-down" process based on the expectation that the implementation of PBN would make conventional aids redundant. While PBN benefits are acknowledged in principle, it is not always easy to justify full implementation of PBN unless PBN can resolve airspace capacity and efficiency issues. Even when PBN is implemented, avionics equipage can dictate the need to retain conventional aids and routes.

7.14.3.2 A "bottom-up" process may be more appropriate, considering that the greatest economic benefits come from avoiding the replacement of aids at the end of their life cycle (typically 20 to 25 years).

7.14.3.3 This should be done by identifying rationalization opportunities, evaluating necessary route changes and ascertaining whether a limited PBN implementation would be more cost-effective than replacing the aids. This strategy would provide a catalyst to start the airspace transition to a full PBN environment.

7.14.3.4 Many airports have multiple instrument approach procedures based on conventional aids. These all incur maintenance and training (aircrew and ATC) costs. The implementation of PBN approach procedures provides an opportunity to decommission some of these procedures and the aids that support them.

7.14.3.5 The primary source of precision approach guidance is currently ILS, and ILS will serve as the main backup to GNSS-based approaches for the foreseeable future. Several States have recently initiated ILS replacement projects, and some have installed MLS.

7.14.3.6 The ultimate goal of rationalization is to evolve to a minimum operational network of aids that will make it possible to maintain a level of continuity and efficiency of operations that meet aircraft operators' expectations to the extent possible.

7.14.3.7 As an example, one State with a high density of VOR facilities has developed a strategy with the goal of maintaining an alternate means of navigation for VOR-equipped aircraft in case of a GNSS outage. This would support non-GNSS guidance for aircraft operating at or above 1 500 m (5 000 ft) to an airport within 100 NM that has an ILS or VOR approach procedure. This strategy will permit the State to decommission a very significant number of VORs. At the same time, this State will enhance DME facilities to support RNAV operations in Class A airspace and in the vicinity of major airports.

7.14.3.8 ADS-B is already providing significant benefits in non-radar airspace where radar would have been much more costly. The implementation of ADS-B in busy terminal and en-route airspace now served by radar will not necessarily result in the elimination of radar. Some States have concluded that primary and secondary radar coverage will be required for the foreseeable future in such areas to address: the threat of interference with GNSS signals that would result in a loss of navigation and surveillance capability; the need to detect aircraft without transponders or ADS-B; and the requirement to detect hazardous weather. Nevertheless, ADS-B promises to provide operational benefits in such areas, and the implementation of ADS-B could avoid the cost of redundant radar coverage.

7.14.3.9 States and regions need to tailor rationalization and mitigation strategies to existing and planned traffic levels, aircraft capabilities, threat levels and aircraft operators' expectations. Major air carriers will likely require a near-normal service with minimal impact on capacity. General aviation and helicopter operators who generally operate in accordance with VFR will be better able to tolerate outages.

7.15 PROGRAMMATIC AND SECURITY ISSUES

7.15.1 The security of conventional aids is the responsibility of State authorities. GNSS coverage extends over the territory of many States, so security should be addressed at a regional or global level. It is important to protect the GNSS elements used by civil aviation against terrorism or hostile acts.

7.15.2 States must anticipate the possibility of GNSS and conventional navigation aid service interruption or degradation during a national emergency situation (Article 89 of the *Convention on International Civil Aviation* refers). States must also have contingency plans in the event of an international conflict or if a neighbouring State jams GNSS signals in such a way that service is disrupted beyond its borders. GNSS security aspects are being addressed by some States and may result in new procedures to protect the safety and efficiency of aircraft operations.

7.15.3 Programmatic issues, including a lack of resources, launch failures or unanticipated satellite failures could result in insufficient satellites being available to support specific GNSS-based services. Control segment failure or human error could also potentially cause service outages and common-mode errors on several satellites of a single constellation. The provision of reliable services from core satellite constellations requires robust system management and funding.

7.16 REALIZING GNSS POTENTIAL

7.16.1 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 re-organizing airspace for increased efficiency based on PBN, ADS-B and ADS-C, and have designed approaches that enhance safety and improve airport accessibility.

7.16.2 The rate of equipage with GNSS avionics is one key to realizing maximum benefits. The full benefits of PBN in en-route and terminal airspace depend on virtually all aircraft being equipped. Aircraft operators will invest in avionics only if proposed services promise significant operational benefits and cost savings. ANS providers and regulators must work with aircraft operators to identify the technical solutions and services that will satisfy their safety and business cases.

7.16.3 Ideally, GNSS would support the decommissioning of all conventional aids, allowing aircraft operators to eliminate the capital and training costs associated with maintaining conventional and GNSS avionics. It would also mean cost savings for ANS providers. GNSS signal vulnerability issues, however, necessitate the retention of some conventional aids for the foreseeable future. In the meantime, ANS providers can reduce costs by rationalizing networks of these aids.

7.16.4 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. The ASBUs and the navigation and PBN roadmaps in the GANP provide a planning framework that States can adapt to their operational environment while ensuring global compatibility.

Appendix A

REFERENCES

1. RELEVANT ICAO PUBLICATIONS

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

Assembly Resolutions

A32-19:	Charter on the Rights and Obligations of States Relating to GNSS Services
A32-20:	Development and elaboration of an appropriate long-term legal framework to govern the implementation of GNSS
A35-15:	Consolidated statement of continuing ICAO policies and practices related to a global air traffic management (ATM) system and communications, navigation and surveillance/air traffic management (CNS/ATM) systems.
A37-11	Performance-based navigation global goals

Annexes to the Convention on International Civil Aviation

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

Documents

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

Doc 8071	*Manual on Testing of Radio Navigation Aids,* Volume II — *Testing of Satellite-based Radio Navigation Systems*
Doc 8126	*Aeronautical Information Services Manual*
Doc 8168	*Procedures for Air Navigation Services — Aircraft Operations* Volume I — *Flight Procedures* Volume II — *Construction of Visual and Instrument Flight Procedures*
Doc 8400	*Procedures for Air Navigation Services — ICAO Abbreviations and Codes*
Doc 8697	*Aeronautical Chart Manual*
Doc 9161	*Manual on Air Navigation Services Economics*
Doc 9426	*Air Traffic Services Planning Manual*
Doc 9613	*Performance-based Navigation (PBN) Manual*
Doc 9660	*Report on Financial and Related Organizational and Managerial Aspects of Global Navigation Satellite System (GNSS) Provision and Operation*
Doc 9674	*World Geodetic System — 1984 (WGS-84) Manual*
Doc 9689	*Manual on Airspace Planning Methodology for the Determination of Separation Minima*
Doc 9718	*Handbook on Radio Frequency Spectrum Requirements for Civil Aviation,* Volume I — *ICAO spectrum strategy, policy statements and related information*
Doc 9734	*Safety Oversight Manual*
Doc 9750	*Global Air Navigation Plan*
Doc 9859	*Safety Management Manual (SMM)*
Doc 9906	*Quality Assurance Manual for Flight Procedure Design,* Volume 5 — *Validation of Instrument Flight Procedures*
Doc 10007	*Report of the Twelfth Air Navigation Conference*

2. OTHER PUBLICATIONS

ICAO EB 2011/56	Interference to Global Navigation Satellite System (GNSS) Signals
International Telecommunication Union (ITU)	Radio Regulations
ITU-R M.1318-1	Evaluation model for continuous interference from radio sources other than in the radionavigation-satellite service to the radionavigation-satellite service systems and networks operating in the 1 164 – 1 215 MHz, 1 215 – 1 300 MHz, 1 559 – 1 610 MHz and 5 010 – 5 030 MHz bands

ITU-R M.1639-1	Protection criterion for the aeronautical radionavigation service with respect to aggregate emissions from space stations in the radionavigation-satellite service in the band 1 164 – 1 215 MHz
ITU-R M.1642-2	Methodology for assessing the maximum aggregate equivalent power flux-density at an aeronautical radionavigation service station from all radionavigation-satellite service systems operating in the 1 164 – 1 215 MHz band
ITU-R M.1787-2	Description of systems and networks in the radionavigation-satellite service (space-to-Earth and space-to-space) and technical characteristics of transmitting space stations operating in the bands 1 164 – 1 215 MHz, 1 215 – 1 300 MHz and 1 559 – 1 610 MHz
ITU-R M.1903	Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) and receivers in the aeronautical radionavigation service operating in the band 1 559 – 1 610 MHz
ITU-R M.1905	Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) operating in the band 1 164 – 1 215 MHz
ITU-R M.2030	Evaluation method for pulsed interference from relevant radio sources other than in the radionavigation-satellite service to the radionavigation-satellite service systems and networks operating in the 1 164 – 1 215 MHz, 1 215 – 1 300 MHz and 1 559 – 1 610 MHz frequency bands
ITU-R SM.1009-1	Compatibility between the sound-broadcasting service in the band of about 87 – 108 MHz and the aeronautical services in the band 108 – 137 MHz
RTCA/DO-200A/EUROCAE ED-76	Standards for Processing Aeronautical Data
RTCA/DO-201A/EUROCAE ED-77	Standards for Aeronautical Information
RTCA/DO-235B	Assessment of Radio Frequency Interference Relevant to the GNSS L1 Frequency Band
RTCA/DO-292	Assessment of Radio Frequency Interference Relevant to the GNSS L5/E5A Frequency Band
ECC Report 129	Technical and operational provisions required for the use of GNSS repeaters
ECC Report 145	Regulatory framework for global navigation satellite system (GNSS) repeaters
ECC Recommendation (10)02	A framework for authorization regime of global navigation satellite system (GNSS) repeaters
IS-GPS-200	GPS Interface Specification

Avionics standards documents

Augmentation systems	*United States FAA Technical standard order (TSO)*	*RTCA (EUROCAE) minimum operational performance standards/minimum aviation system performance standards (MOPs/MASPs)*
ABAS	TSO-C129A Level 2 (en-route/terminal) TSO-C129A Levels 1 or 3 (NPA) TSO-C196 EASA ETSO-C129c	RTCA/DO-208 EUROCAE ED-72A RTCA/DO-316
SBAS*	TSO-C145 TSO-C146A EASA ETSO-C145c, C146c	RTCA/DO-229D with Change 1 EASA ETSO-C145c, C146c
GBAS	TSO-C161A TSO-C162A	RTCA/DO-245A RTCA/DO-246D RTCA/DO-253C EUROCAE ED-95

* SBAS avionics meet all ABAS requirements.

Appendix B

ROLES OF ANS PROVIDERS AND REGULATORS

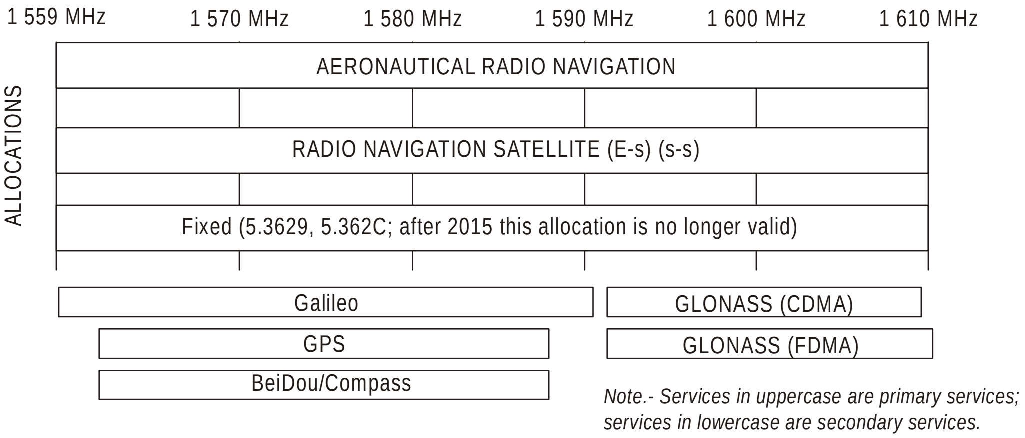
Air navigation service provider	*Regulator*
Lead the development of a CONOPS aimed at meeting aircraft operators' goals for a proposed GNSS-based service that defines performance requirements and that proposes system architecture.	Participate in CONOPS development to identify requirements for new or modified regulations.
Develop and adhere to a safety management plan to cover its GNSS-based services.	Conduct safety oversight of the service provider's GNSS-based services.
Complete trials, simulations and studies to validate the CONOPS.	Consider the service provider's recommendations for operational approvals based on study conclusions.
Coordinate provision of GNSS-based service with aircraft operators and the regulator.	Develop aircrew training and certification standards for the use of GNSS avionics by commercial and business aircraft operators. Approve the operational use of GNSS by commercial and business aircraft operators. Develop guidance material and processes for the operational approval of GNSS. Establish requirements for specific operator approvals, aircrew training and certification.
Assist aircraft operators in making informed decisions on the acquisition of avionics for GNSS-based services.	Develop national standards and guidance material for the certification and installation of GNSS avionics in nationally registered aircraft. Where necessary, the development of standards and guidance may be accomplished as a joint effort with other airworthiness authorities to avoid duplication of effort and to maximize harmonization. Certify or oversee the certification, as applicable, of GNSS avionics equipment designed and manufactured nationally as well as the installation of GNSS equipment in nationally registered aircraft. Develop guidance material and approval processes covering the installation of GNSS avionics. Identify equipment and installation standards, including provisions in supplements to aircraft flight manuals.

Air navigation service provider	*Regulator*
Coordinate the development of business cases for GNSS-based services to support decision making by aircraft operators and service providers.	
Establish appropriate strategies for fielding GNSS-based infrastructure, mitigating GNSS outages and decommissioning ground aids, as appropriate. This includes safety oversight of contractors.	Validate the safety aspects of mitigation strategies.
Coordinate the development of survey methodology and implement the WGS-84 standard.	
Develop and implement data-handling processes to meet the accuracy and integrity requirements of GNSS-based operations.	
Develop status monitoring, notification and NOTAM systems to support GNSS-based operations.	
Publish instrument approach and other GNSS-based procedures. Provide aeronautical information on GNSS procedures to database suppliers and chart producers.	Develop GNSS-based instrument procedure design standards, or approve the use of existing PANS-OPS or other recognized criteria. Oversee the certification of GNSS-based systems and related airspace procedures.
Establish flight check requirements and procedures, acquire the needed equipment and carry out necessary flight checks for GNSS-based operations.	
Monitor and record GNSS performance.	
Develop and publish guidance and training material related to the operational use of GNSS-based services to support the training of aircrew and ATS personnel.	Publish the terms and conditions associated with the approval to use GNSS via the State AIP, AICs and advisory circulars. Develop flight instructor guidelines and flight training standards for the use of GNSS-based services.
Define ATS requirements, airspace and procedures, including application of separation standards.	
Establish training and certification requirements for procedure designers and ATS personnel. Train ATS staff to support GNSS-based operations.	Approve training and certification requirements.
Develop technical specifications for GNSS-related infrastructure.	
Procure and field GNSS augmentations and validate system performance against SARPs.	Conduct safety oversight for the implementation of GNSS-based infrastructure.

Air navigation service provider	*Regulator*
Identify GNSS-related spectrum management issues.	Provide spectrum management to protect GNSS frequencies.
Monitor threats, assess risks and mitigate GNSS vulnerability to RFI and atmospheric effects as far as practicable	Provide regulatory support to RFI mitigation activities, specifically by interfacing with telecommunications or other authorities and organizations as appropriate to regulate transmissions in GNSS frequency bands and enforce compliance with regulations if so required.

Appendix C

GNSS SPECTRUM



Note.- Services in uppercase are primary services; services in lowercase are secondary services.

Figure C-1. Frequency allocations in the 1 559 to 1 610 MHz band

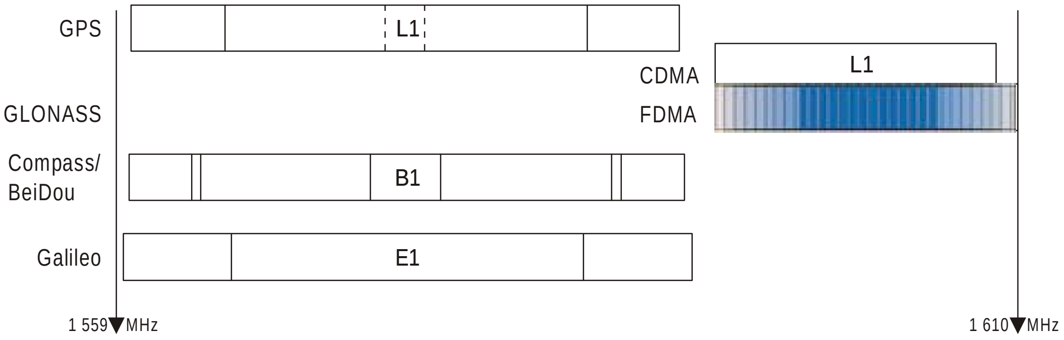


Figure C-2. Frequencies used by core constellations

Note.— Additional frequencies are used by core constellations in the 1 164 to 1 215 MHz band (see Chapter 6, 6.5). ICAO standardization of the relevant signals is underway.

Appendix D

NAVIGATION ROADMAP

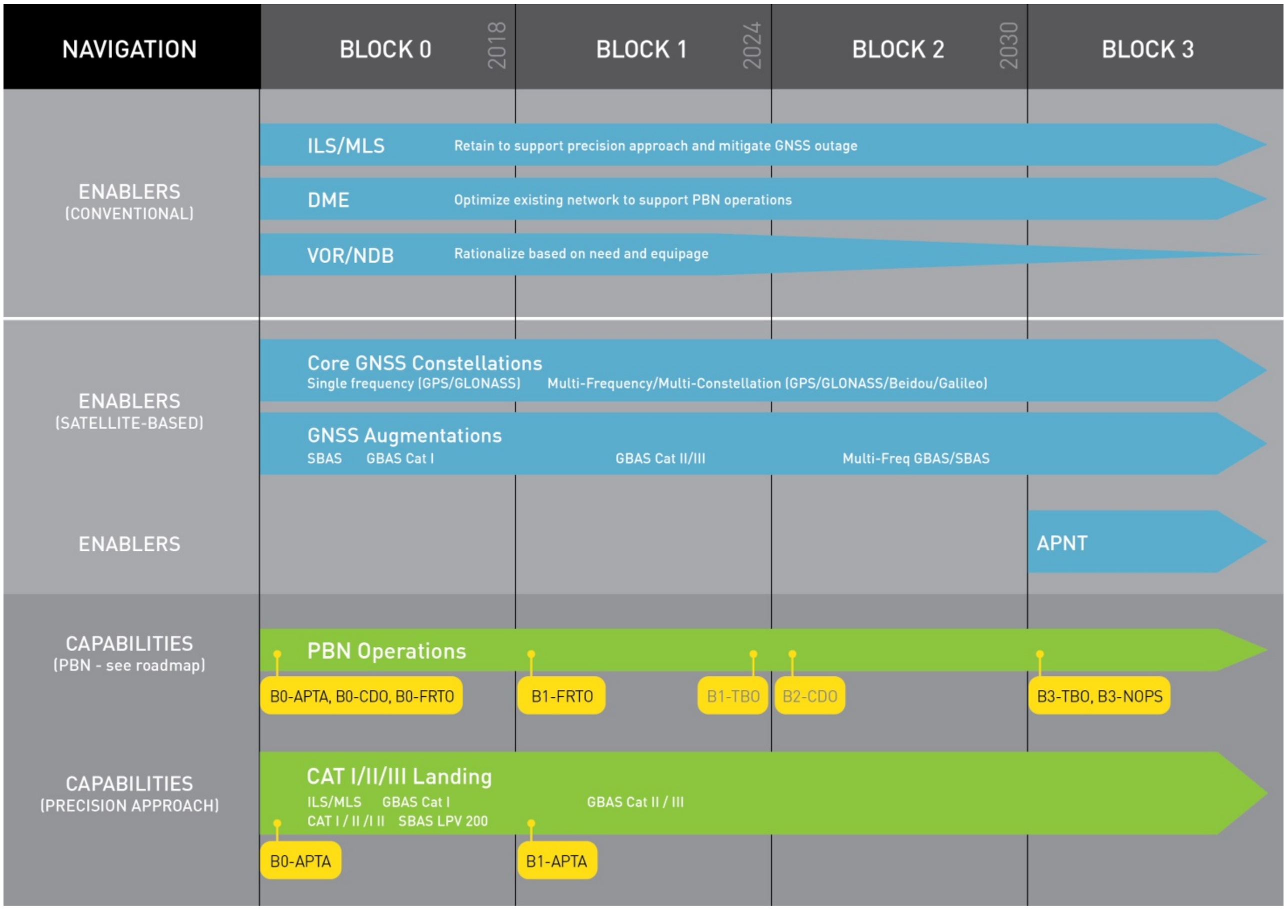


Figure D-1. Navigation roadmap

Appendix E

PBN ROADMAP

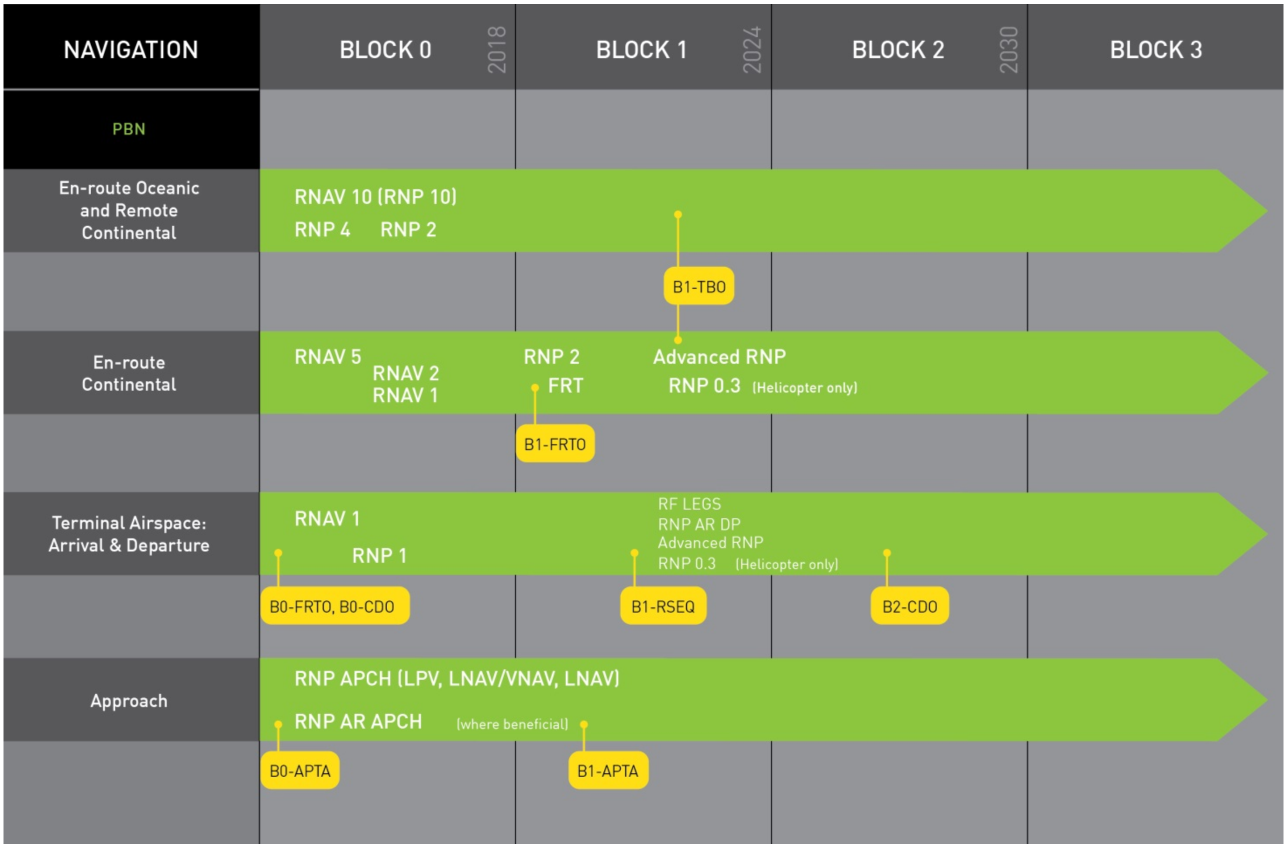


Figure E-1. PBN roadmap

Appendix F

GNSS RADIO FREQUENCY INTERFERENCE MITIGATION PLAN

1. INTRODUCTION

1.1 Concerns over GNSS vulnerability, such as those discussed in Chapter 5 of this manual, were re-emphasized at the Twelfth Air Navigation Conference in 2012, which approved the following recommendation to States (*Report of the Twelfth Air Navigation Conference,* (Doc 10007) refers):

> **Recommendation 6/8 — Planning for mitigation of global navigation satellite system vulnerabilities**
>
> That States:
>
> a) assess the likelihood and effects of global navigation satellite system vulnerabilities in their airspace and apply, as necessary, recognized and available mitigation methods;
>
> b) provide effective spectrum management and protection of global navigation satellite system (GNSS) frequencies to reduce the likelihood of unintentional interference or degradation of GNSS performance;
>
> c) report to ICAO cases of harmful interference to global navigation satellite system that may have an impact on international civil aviation operations;
>
> d) develop and enforce a strong regulatory framework governing the use of global navigation satellite system repeaters, pseudolites, spoofers and jammers;
>
> […]

1.2 This appendix contains guidance for ANS providers and related organizations, such as State aviation and telecommunication authorities, on the development of a GNSS radio frequency interference (RFI) mitigation plan supporting compliance with items a) and b) from the Recommendation. The purpose of the development of the mitigation plan is to ensure the implementation of a list of measures that give confidence that the RFI risk is reduced as far as practicable, consistent with the responsibility of the ANS provider, in order to fully enable the operational benefits achievable where GNSS-based operations are implemented.

1.3 Guidance on interference reporting in line with item c) of the Recommendation can be found in the attachment to this appendix.

1.4 Initial guidance for development of a regulatory framework supporting compliance with item d) of the Recommendation can be found in section 5.4 of this manual and in ICAO Electronic Bulletin EB 2011/56, *Interference to Global Navigation Satellite System (GNSS) Signals*.

Note 1.— This appendix only addresses GNSS vulnerability due to "artificial" RFI, as opposed to "natural" RFI, such as space weather effects. Furthermore, it does not cover security threats due to network or software-based attacks or any other form of attack that is not carried out using radio waves.

Note 2.— Intentional RFI is generally also considered as being within the scope of cyber-security activities. ICAO Annex *17* — Security — Safeguarding International Civil Aviation against Acts of Unlawful Interference, provides further guidance on security issues.

2. IMPACT OF RFI ON AIRCRAFT OPERATIONS

2.1 Depending on avionics integration, the impact of RFI on an aircraft receiver and resulting cockpit displays can differ. Typically, RFI will first cause a reduction in carrier-to-noise density ratio (C/N_0), possibly accompanied by small increases in position error (normally not noticeable for an aircraft in flight). If the RFI becomes too strong, the receiver will not be able to track a sufficient number of satellites to calculate a position. Especially in integrated navigation system computers, this normally does not lead immediately to a loss of position updating in the cockpit.

2.2 Examples of reported impact from suspected cases of RFI, as annunciated on cockpit displays, include those listed below, several of which may occur simultaneously:

a) GPS 1 Invalid/GPS 2 Invalid;

b) degraded PBN capability;

c) switching to an alternate navigation mode (such as IRS updating or DME/DME);

d) observation of a “map shift” on navigation display;

e) enhanced ground proximity warning alerts;

f) sustained loss of automatic dependent surveillance (ADS) reporting capabilities; and

g) loss of GNSS-based landing capability.

2.3 This list is not exhaustive since, depending on how GNSS receiver data (position, velocity and time) has been integrated in additional avionics functions, there can be additional impact. However, normally any additional cockpit effects should always be accompanied by messages related to navigation performance. Annunciations as a consequence of equipment malfunction will be similar, especially when they are of a transient nature.

2.4 How quickly aircraft avionics will recover from experiencing an RFI-related GNSS outage is also dependent on individual receiver architecture. Pilots must be able to understand the impact of RFI-related GNSS outages and always be prepared to use alternate navigation. Pilots are also encouraged to report cases of experienced RFI-related GNSS outages in accordance with section 7.12.

2.5 In addition to direct impacts on aircraft operations, there can be indirect impacts through communications, navigation, and surveillance/air traffic management (CNS/ATM) systems, including GNSS reference receivers of augmentation systems or timing receivers used for synchronization and time distribution.

3. DEFINITION OF RFI

3.1 The International Telecommunication Union (ITU) Radio Regulations define interference and harmful interference as follows:

> **1.166** ***Interference***: The effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radiocommunication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy.
>
> **1.169** ***Harmful interference***: Interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with Radio Regulations.

3.2 The Radio Regulations make a distinction between interference in general and harmful interference. Within the definition of harmful interference, two separate cases are identified, one which applies to radionavigation and other safety services, and the other to all other radio services. In the former case, endangerment of the functioning is sufficient to identify harmful interference, whereas in the latter case a higher level of disturbance (serious degradation, obstruction or repeated interruption) is required.

3.3 GNSS operates under a radionavigation-satellite service (RNSS) allocation[1]. Because of the multimodal nature of GNSS, not all applications it supports are safety applications. However, aeronautical applications intended for the benefit and safe operation of aircraft and supported by GNSS as standardized in Annex 10 are considered to be safety applications.

3.4 When considering compatibility between multiple aeronautical services or services used for aeronautical purposes, ITU provisions may determine the priority of each service, as is the case in the 1 164 – 1 215 MHz band which is shared by GNSS and DME. DME has priority over GNSS; therefore, GNSS may not claim protection from interference that can be caused by DME. Spectrum and frequency planning by aviation will ensure that receivers meeting appropriate standards (which may require specific mitigation measures such as pulse blanking) using GNSS signals in the 1 164 – 1 215 MHz band can operate while being subject to interference from DME.

3.5 The diversity of aviation certified equipment means that a specific receiver may not have a problem with one type of interference whereas another one will. The only recourse to avoid this problem is to tie the interference definition to minimum equipment performance standards. Another aspect is the aviation safety margin[2]. An infringement of the aviation safety margin should also be considered as an event that requires mitigating actions. ICAO policy on the application of the safety margin to GNSS is contained in the *Handbook on Radio Frequency Spectrum Requirements for Civil Aviation,* Volume I — *ICAO spectrum strategy, policy statements and related information* (Doc 9718).

3.6 Minimum equipment performance standards in the presence of interference are defined in Annex 10, Volume I, Chapter 3, 3.7.4.1. It requires that GNSS equipment shall comply with the applicable performance requirements in the presence of the interference environment defined in Appendix B, 3.7 in terms of interference thresholds (“masks”) for continuous wave (CW) interference, band-limited noise-like interference and pulsed interference. While some aircraft GNSS receivers may still be able to continue operation when encountering interference signals exceeding the Annex 10

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[1] ITU-R Recommendations M.1903 and M.1905 provide further guidance on this matter for the GNSS 1 559 – 1 610 MHz and 1 164 – 1 215 MHz bands respectively. ITU-R Recommendations M.1318-1, M.1639-1, M.1642-2, M.1787-2 and M.2030 provide additional details and compatibility assessment criteria.

[2] Aeronautical safety applications are required to have continued operation through worst case interference, so all factors which contribute to harmful interference should be considered in analyses involving those applications. An aviation safety margin is included in order to address the risk that some such factors cannot be foreseen (for example, impacts of differing modulation schemes). This margin is applied to the system protection criteria to increase the operational assurances to the required level. Traditionally, for aviation systems/scenarios, an aviation safety margin of 6–10 dB is applied.

thresholds, this cannot be assumed in general. What the Annex 10 provisions do ensure is that all Annex 10-compliant aircraft GNSS receivers can reliably receive GNSS signals when interference remains below the thresholds.

3.7 Consequently, for the purposes of GNSS RFI mitigation for aviation services, the Annex 10 interference thresholds, augmented by an appropriate safety margin, should be used to define what is considered RFI requiring mitigation. While the Annex 10 criteria are currently only defined for the 1 559 – 1 610 MHz band, it is expected that these definitions will be extended when ICAO SARPs applicable to the 1 164 – 1 215 MHz band are introduced.

3.8 In some cases of actual RFI signal measurements it may be difficult to decide which interference mask applies (CW, band-limited noise-like or pulsed). In such cases, the CW masks should be applied because they are the most demanding. The rationale for this is that it is not possible to define criteria for every form of modulation that may be encountered. An exception to this principle are code-division-multiple-access (CDMA)-type interference signals, which may require special consideration as they may interact with the spreading codes of GNSS.

3.9 It must be noted that the interference criteria defined in Annex 10 for the L1 frequency band are consistent with RTCA/DO-235B which assessed what can be considered a “reasonably achievable” spectrum environment. The document is very useful to illustrate RFI encounter scenarios and analyze required separation distances between emitters and receivers. A similar assessment is available for the L5 frequency band (RTCA/DO-292).

3.10 Finally, a distinction must be made between interference and spoofing. While interference is understood to be caused by signals which are not specifically designed to mislead, and merely cause a service interruption instead of misleading information, GNSS spoofing uses counterfeit signals designed to create misleading information. Because spoofing signals by design look like desired GNSS signals, they can cause problems to GNSS receivers at levels much weaker than the interference mask. This appendix does not address the mitigation of GNSS spoofing.

4. CLASSIFICATION OF RFI THREATS

4.1 Unintentional RFI

4.1.1 Unintentional RFI is often the result of an equipment malfunction. This may originate from many sources such as power line transmissions, industrial foundries or television broadcast stations. These RFI sources are difficult to control and aviation will need to be prepared to deal with such failures as they will occur occasionally. They are of specific concern because the interferer power and related impact radius may be significant. One example of particular concern is television channel S32, in the UHF band, whose harmonics could fall into both the 1 559 – 1 610 MHz and the 1 164 – 1 215 MHz bands. Fortunately, there do not appear to be any television broadcast stations operating on that channel in most regions of the world. The channel is mostly used by the government/public safety terrestrial trunked radio (TETRA) communication system.

4.1.2 The key mitigation to unintentional RFI is to ensure that the RFI is detected and can be eliminated efficiently. Based on experience over recent years, unintentional RFI has not been a significant problem. What may have helped limit these cases, is the widespread non-aviation use of GPS, especially for timing. Broadcast stations often use GPS timing and so do many other industrial activities; thus, any failure (e.g. filter malfunction) creating unintentional emissions in the GNSS bands and causing interruptions of such non-aviation GNSS services would be quickly detected and resolved by the entities concerned. However, several cases have been recorded, and their resolution can sometimes be difficult, especially if an RFI case is intermittent or relatively weak in power.

4.1.3 Due to the potential risk to aviation operations, it remains necessary for ANS providers to have access to suitable land-based and airborne measurement capabilities to help ensure efficient detection and localization of the RFI source. Such capabilities may also be provided by State aviation and telecommunication authorities or other organizations.

4.2 Intentional RFI, not directed at aviation

4.2.1 Due to the multi-modal use of GNSS, intentional RFI can be further classified according to whether the intended victim of the RFI attack is aviation or another user. Intentional RFI targeting non-aviation users of GNSS may nonetheless impact aviation. In such cases, while the RFI itself is intentional, any collateral impact on aviation is not. The most publicized devices causing this type of RFI are the so-called personal privacy devices (PPD). Most States forbid the manufacture of such devices for sale in domestic markets. In Europe, the devices themselves have been declared illegal through European Union legislation. Similar legislation exists in most other regions. Despite such legislation, there are normally very few other obstacles to exporting and owning them, so that the sale of such devices continues. These devices are typically obtained by Internet mail order, and can operate in any GNSS band. As a consequence of the existence of these devices, while originating this kind of RFI would previously have required some expert knowledge, it has now become possible even without such expertise.

4.2.2 The motivations to interfere vary widely. The most common cases appear to involve professional drivers of company vehicles which have installed a GPS-based fleet tracking system. This may include government services. Drivers that do not want to be subject to constant surveillance through a fleet-tracking system may disable the system by using a GNSS jammer. The provision of appropriate location privacy laws may contribute to reducing the motivation to interfere with GNSS. Other cases involve car thieves interfering with car tracking equipment and criminals on parole ordered to wear a GNSS-enabled ankle bracelet.

4.2.3 Other potential factors which could motivate the use of PPD include road tolling systems based on GNSS, car insurance fees based on distance driven as measured by a GNSS-based device, etc. More generally, the current ubiquity of GNSS has led to constant development of new GNSS-based applications, potentially creating new motivation to generate RFI to disable such applications.

4.2.4 While in many cases it can be a simple design matter to prevent the success of the interference objective, this cannot be guaranteed in all cases. For example, trucks can be fitted with trip recorders that are typically tied to wheel and speed sensors so that a simple integration logic can be used to verify the location information based on the GPS input. This approach works quite well in professional and regulated applications but is more difficult in applications that are purely commercially driven and/or mass-market oriented.

4.2.5 What ultimately helps the most in limiting the collateral impact of this RFI on aviation is that the non-aviation services targeted by the RFI cannot succeed in the long run if RFI becomes an excessive problem, and will therefore take measures to reduce the motivation to create RFI. Nonetheless, based on recent measurement campaigns, PPD and other jamming devices remain in operation and it cannot be expected that they will disappear. Furthermore, the impact of these devices is not limited to the 1 559 – 1 610 MHz band, as multi-frequency PPD are already available covering also the 1 164 – 1 215 MHz band.

4.2.6 Given that a certain level of such devices may need to be tolerated, a key question is their impact radius. For most typical scenarios, the available power supplied to a PPD from a car or other battery will be limited, thereby also limiting the impact radius. However, these devices may differ widely from their stated specifications. In general, though, the impact radius of such locally limited jammers should not exceed a few hundred meters, so that aircraft in en-route and higher altitude terminal area operations will not be affected. However, for operations near airports, vigilance is necessary. This may include runway and other surface operations as well as the final stages of the approach and the take-off and initial departure. One identified concern are GBAS reference stations, for which specific mitigation measures may be necessary and have already been implemented successfully in some cases.

4.2.7 While current airport PPD monitoring efforts have focused on nearby major roads, there are today no obstacles for PPD-equipped maintenance vehicles to enter an airport perimeter and stop very close to a runway. The need for RFI monitoring equipment at (non-passenger) airport access gates is being evaluated.

4.2.8 If the range of PPD starts to extend beyond what can be interpreted as “privacy”, then the concern becomes more significant. Devices powered by 110-220V household mains are available on Internet shops, some of them with highly directional antennas. If the intent of those jammers is to provide “location privacy” in a large area, then the severity of the threat can be major. In this scenario, the distinction between being directed at aviation or not becomes more difficult and less relevant since the threat has to be dealt with in either case.

4.3 Intentional RFI, directed at aviation

4.3.1 The level of impact created by this type of RFI can range from benign to severe. At the benign end of the range, PPD may be misused as a protest measure by residents inconvenienced by airport noise. There is also no obstacle to the carriage of PPD onto an aircraft where they could be accidentally or intentionally left on. In this case, a single aircraft would be affected during its complete movement whereas locally limited RFI would affect all aircraft but only while in the concerned area.

4.3.2 More severe levels of impact could be due to full-blown attacks using targeted jammers in an aircraft final approach area, possibly operating intermittently from unmanned aircraft vehicles (UAV). Such attacks would border on acts of terrorism or even of war and there are obviously limits to the extent to which aviation alone could mitigate their impact. While there are reasons to believe that this type of RFI is highly unlikely, such threats should nevertheless be taken seriously as even a low probability threat does needs to be taken into account if the potential consequences are severe.

4.4 Military testing

Peacetime testing of navigation warfare capabilities includes the testing of military GNSS jamming and spoofing equipment targeting military users. Some of this equipment has been reported to cause GNSS RFI within a radius exceeding 300 NM from the source. Such testing requires previous authorization and coordination with civil aviation authorities so that location, duration and size of this type of RFI event can be known and coordinated with relevant aviation authorities, ANS providers and airspace users beforehand. As part of the coordination, an assessment must determine if there is an aviation impact, triggering the publication of NOTAM, activation of military no-fly zones and other measures as appropriate. The pre-coordinated nature of the event (assuming that such pre-coordination is functioning well) may limit the impact of these types of events using existing mitigation processes. It is reasonable to expect that relevant military agencies will continue to recognize the unintended side-effects of the testing and to exercise extreme caution and adopt effective measures to limit the impact from these activities on civil aviation.

4.5 Re-radiators/Repeaters

4.5.1 As mentioned earlier, this manual does not specifically address the mitigation of spoofing. One exception, which may be categorized as a special case of (unintentional) spoofing, is given by GNSS re-radiators or repeaters. These provide GNSS signals inside buildings as collected by the GNSS repeater receive antenna. They are used for maintenance activities or when a fast position fix is needed such as for emergency service vehicles. If a GNSS repeater is not correctly installed and configured so that it broadcasts too much power, nearby GNSS receivers could output unacceptably large position errors.

4.5.2 Depending on the power ratio between the spoofing GNSS repeater signal and the desired signals from the GNSS satellites at the input of a GNSS receiver, three scenarios are possible:

a) the GNSS repeater signal power is lower than the power of the direct signals received from the GNSS satellites. Such a scenario results in an elevated level of noise for the GNSS receiver, quite similar to multipath;

b) the power of both signal sources, the GNSS repeater signal and the direct satellite signals, have similar magnitudes. Some GNSS receiver channels may lock on the signal received from the GNSS repeater, while other channels are still tracking the direct satellite signals. The position output of a GNSS receiver can jump and position errors can be larger than the distance between the GNSS repeater and the GNSS receiver; and

c) the GNSS repeater signal has more power than the direct signals. The GNSS receiver switches to a fixed position coincident with the location of the GNSS repeater's receive antenna. Such events should be the easiest to detect.

4.5.3 Unacceptable position errors can be avoided by ensuring that GNSS repeater installations are carefully tested and independently verified by the appropriate engineering authorities to ensure that requirements set by regulation are respected. This is especially appropriate near airports and underneath approach or departure paths where GNSS-based operations take place. Regulations in Europe limit the equivalent isotropically radiated power (EIRP) of any amplified GNSS signal of a legal GNSS repeater installation to -77 dBm EIRP and a total gain (antenna gain + amplification – losses) of 45 dB.

Note.— See ICAO EB 2011/56.

5. GNSS RFI MITIGATION FRAMEWORK

5.1 The previous sections defined what interference is and classified each type of RFI according to its motivation and characteristics. Once the different types of RFI are understood, a mitigation framework can be set up. The intent of the framework described here is to provide a harmonized basis for local RFI assessments.

5.2 The framework should follow established risk management practices. This can be summarized as a continuous three-step process:

a) threat monitoring;

b) risk assessment; and

c) deployment of mitigation measures.

5.3 The process must be continuous because the threat space is evolving. Furthermore, its evolution, being linked to a large variety of non-aviation activities, is in general less predictable than that of the threats normally handled by aviation safety management systems. It should be noted that this process is not meant to put an undue burden on aviation stakeholders. In many cases, relatively simple measures can reduce the risk significantly.

5.3.1 Threat monitoring

5.3.1.1 The classification of RFI threats given in section 4 is useful for the purpose of designing an effective threat monitoring system and ensuring its continued adequacy. Each threat class should be addressed by a specific risk monitoring mechanism.

5.3.1.2 Threat monitoring should not be limited to waiting for the occurrence of events with significant aviation impact (and subsequent reporting and sharing). This may be sufficient for the monitoring of unintentional interference, but the monitoring of intentional interference requires a more active approach. This concerns, in particular, the threat stemming from PPD as well as more powerful or sophisticated devices. A number of research projects have set up monitoring systems on busy major roads near airports and detected the presence of active PPD. This monitoring has led to an understanding of the sources of these PPD and the underlying causes for their use.

5.3.1.3 Monitoring of the actual spectrum environment (actual emissions at strategic locations) is not the only means to monitor RFI threats. For preventive purposes, obtaining an awareness of non-aviation application development can also be very effective. For example, current and future developments in the use of GNSS for non-aviation applications such as road tolling, usage-based car insurance, law enforcement (ankle bracelets, covert suspect monitoring, geo-fencing), employer fleet or asset monitoring, booster/repeater systems and indoor and outdoor pseudolites (and for other applications yet to be conceived) can provide valuable insight into the RFI threat potential.

5.3.1.4 Beyond the actual applications, it will also be useful to consider the associated legal and regulatory provisions such as the protection of personal privacy rights and the law enforcement provisions addressing intentional interference including confiscation of illegal devices. This should be done in cooperation with the appropriate local authorities.

5.3.1.5 In general, threat monitoring has both preventive and reactive aspects. Preventive monitoring considers the broader use of GNSS in its societal, economic and regulatory context, and is primarily a communication activity that ensures that all associated parties cooperate appropriately. Conversely, reactive monitoring is achieved by deploying actual GNSS monitoring systems. GNSS monitoring systems can measure emissions in the GNSS bands with high sensitivity, capturing signals both in the frequency and time domain. They should not be restricted to simple detection of RFI emissions, but should also aim to identify and locate the source of the emission. Guidance on the design and setup of such monitoring systems as well as appropriate measurement procedures will be included in future editions of Doc 8071, Volume II. It is important to note that any such systems should be supported by a corresponding risk analysis to ensure an efficient mitigation capability without incurring undue cost.

5.3.1.6 GNSS monitoring can be airborne or ground-based, stationary or mobile. It can be continuous or on an intermittent basis. Currently, it is generally not possible to provide continuous airborne monitoring other than through pilot reporting. However, by using passive recording devices, it may be possible to collect significant amounts of data on GNSS signal quality, for instance through aerial work flights or other fleet recording capabilities. The feasibility of monitoring GNSS service availability through analysis of ADS-B reported parameters is also being investigated. Having airborne intervention capabilities is useful to enable efficient detection and localization of RFI events. These capabilities can narrow the search space to a limited area on the ground, such that ground-based localization efforts can be more effective and efficient.

5.3.1.7 Fixed ground-based recording may also be very useful, in particular at strategic locations such as near high density traffic roads in airport proximity or at locations where GNSS RFI reports are routinely received. A combination of both stationary and mobile monitors is recommended. A mobile measurement unit should be deployed, for example, when a new GNSS approach procedure is being implemented at an airport. In some States, continuous monitoring over a period of up to two weeks is considered sufficient to achieve a reasonable initial survey of the local spectrum environment. It is also recommended to cooperate with local frequency monitoring agencies that survey compliance with telecommunication regulations in general.

5.3.1.8 In addition to deploying actual monitoring systems, analysis of reports from airspace users can also be an effective way to detect and monitor preliminary trends.

5.3.1.9 Finally, effective risk monitoring depends on economies of scale. Through various international working arrangements (including the ICAO Navigation Systems Panel) it is possible to share information about RFI events. This allows States to refine their risk monitoring by assessing whether they could be affected by types of events reported by other States.

5.3.2 Risk assessment

5.3.2.1 Risk assessment must build on the data obtained through both preventive and reactive threat monitoring. The objective of the risk assessment is to evaluate which threats can become operationally relevant. Concerning preventive monitoring data, the risk assessment must be done analytically. This may lead to a refinement of threat monitoring strategies. The risk assessment must judge the potential impact both before and after any mitigation actions.

It will also be useful to consider an escalation or a variation of actually encountered RFI scenarios. For example, if a particular jamming device is modified (for instance, by connection to an amplifier or because of a component failure), its impact range could increase substantially.

5.3.2.2 GNSS receivers have been designed such that an RFI event will normally not lead to HMI being provided to either the pilot or flight control systems. In other words, in terms of navigation system performance, an RFI event may affect continuity of service, but normally not integrity. Receivers are tested against specific masks (as described in section 3) which are normally used to evaluate if a particular event could lead to an interruption of service. Both analytical and measurement capabilities that allow an assessment of the impact of a particular RFI encounter scenario on systems meeting these receiver standards are necessary.

5.3.2.3 If at all possible, the risk assessment should also include a judgement of continuity impact, which is linked to the event frequency of occurrence or probability of occurrence. However, in many situations the available data will be too scarce to support a conclusive assessment or even to bound the probability of the event. In such cases, the only thing that can be done is to limit the severity of the potential consequences. Given the unpredictable nature of RFI events, this is especially appropriate if the feasibility of the threat is high, i.e. if it is easy to imagine that a particular scenario could take place. The severity of impact should always be evaluated in the context of the local operational environment. This may include consideration of user fleet equipage levels. For example, if many users have a PBN capability that requires the use of GNSS, then the impact will be more significant compared to a situation where most airspace users are equipped with multi-sensor avionics and ANS providers make available a suitable alternative terrestrial navigation infrastructure. It is also important to recognize that, as the worldwide deployment of ADS-B is continuously increasing, the adverse impact of GNSS RFI can extend beyond aircraft navigation to ATM surveillance and other CNS applications.

5.3.2.4 Risks will scale from benign to severe. PPD operated in cars are generally considered a benign risk since their impact radius is limited and vehicles normally have metal roofs. More significant risks occur if the range of the PPD is extended, or if the vehicle is near ground-based GNSS facilities (e.g. GBAS reference stations). If there is an actual intent to harm aviation, intermediate severity scenarios such as citizen protest against nearby airport operations, or high-severity ones such as threats driven by terrorist intentions, are possible. In any case, safe reversion always needs to be ensured (even if capacity may be lost as a result). Significant non-intentional threats are normally limited to high power interfering signals such as those emitted by radio or television broadcast stations.

5.3.2.5 The objective of the risk assessment is to describe the relevant threats as well as the available mitigations. The risk must then be evaluated in light of available mitigations, and lead to a recommendation of mitigation measure deployment that will reduce the residual risks to acceptable levels. In many cases, it will not be possible to quantify exactly what it means to reduce risk to acceptable levels. In such cases, the recommended approach is to aim to ensure that the risk level be kept as low as reasonably practicable. Depending on the severity of the risks, it may be necessary to link RFI risk mitigation to particular safety and security management systems.

5.3.2.6 An aspect to be taken into account in the assessment of risks due to intentional interference is the relationship between risk probability of occurrence and severity of impact. In traditional safety risk assessments, probability and severity of risks are thought of as independent variables and the safety assessment seeks to limit the product of both factors to reasonable levels. In security assessments, probability and severity are dependent variables. In other words, if a specific threat scenario can lead to a very severe impact, this also increases its probability of occurrence. The only mitigation in this case is to limit the severity of impact. This is normally achievable through established contingency planning measures supported by appropriate operating procedures and infrastructure.

5.3.3 Deployment of mitigation measures

5.3.3.1 RFI mitigation actions can be thought of in three sequential stages, discussed in the following three sections. The ideal mitigation is to prevent the occurrence of RFI (first stage). If RFI cannot be prevented, then the aim should be to prevent adverse impact on the service, i.e. to be able to continue navigation and other services supported by GNSS despite the presence of RFI (second stage). Finally, if the RFI does lead to a service interruption, reactive measures need to be put in place to detect, identify, locate and eliminate the RFI source within a suitable timeframe (third stage). Feedback and sharing of information on actual cases will again assist in ensuring that an effective defence is achieved on a larger geographic scale than otherwise possible.

5.3.3.2 Mitigation of non-intentional RFI has to rely on a reactive approach. Mitigation of intentional RFI, on the other hand, should be based on the principle of preventively reducing the motivation to interfere. By intentionally generating RFI, an individual risks exposure to prosecution. In order to justify the risk, some certainty must exist that the original aim pursued by generating RFI can be achieved. The purpose of the mitigation measures is therefore to reduce perpetrator motivation by making it as unlikely as possible that a particular service interruption or other detrimental effect can be achieved.

5.3.3.3 *Preventing the occurrence of RFI*

5.3.3.3.1 Prevention of RFI is primarily a regulatory and legal matter. Normally, regulations and laws are in place to make any interference device illegal. National legislation should facilitate enforcement. Ideally, the unauthorized possession of an illegal device, regardless of its use, should be sufficient grounds for confiscation. Suitable interfaces between airports, ANS providers, telecommunication regulators and law enforcement must be set up to enable reaction to service interruption. Regulatory and legal provisions should aim to achieve the following:

a) satisfy citizens’ concerns over location privacy. For example, employers using fleet tracking systems should ensure that tracking functions are not inappropriately used against employees;

b) make providers of GNSS-based fee collection systems or similar revenue streams design their systems in such a way that GNSS jamming will not result in avoidance of fees. For example, road tolling systems relying exclusively on GNSS should be able to detect RFI, identify the source vehicle and take remedial action;

c) factor RFI considerations into law enforcement provisions. For example, it should not be possible to disable electronic monitoring devices used for law enforcement purposes by using a PPD;

d) prevent manufacture, sale and export of RFI devices, except for authorized national defence purposes. Exported devices must be appropriately labelled to allow recognition by the importing State;

e) allow aviation stakeholders and associated entities to conduct RFI testing as required with the aim to develop and deploy appropriate mitigations; and

f) concerning installations with significant RFI risks (e.g. repeaters or re-radiators, outdoor pseudolites):

  - identify areas where installations with significant RFI risks at airports as well as underneath approach and departure paths have the potential to cause operational impact;

  - limit such installations in those areas to static applications and a limited number of professional applications and professional users (aircraft/avionics maintenance, emergency services);

  - actively inform potential users of such installations about the existing regulations to avoid illegal and unchecked installations;

  - require professional and independent verification measurements of such installations to ensure compliance with regulations; and

  - conduct mobile interference testing as part of Doc 8071, Volume II ground testing to detect any illegal and unchecked installations with significant RFI risk.

5.3.3.3.2 Finally, any public awareness activity related to the points listed above should be carefully designed so as to create a real deterrent to intentional RFI, as opposed to advertising its potential uses.

5.3.3.4 *Preventing adverse impact*

5.3.3.4.1 If RFI cannot be prevented, its adverse impact can be prevented at two levels. The first level involves hardening GNSS receivers to make them more resistant to RFI. However, this is a long-term possibility which would only be applicable to new equipment to be standardized. The second level involves further integration of GNSS using redundant systems and capabilities. Alternate navigation capabilities such as VOR, DME and IRS are important to ensure that safety and, if possible, continuity of operations can be maintained even in the presence of RFI. Similar principles apply to other avionics uses of GNSS. Therefore, ANS providers should take into account the local risks of GNSS RFI when undertaking rationalization of the conventional navigation and surveillance infrastructure. If no alternate navigation sources are available, the other CNS functions need to be used to cope with a loss of navigation. For instance, surveillance and communication systems capabilities must enable air traffic controllers to provide suitable vectoring assistance to all affected users. In particular in the area of approach and landing, it is recommended that suitable alternate capabilities remain available within reasonable range.

5.3.3.4.2 Training of airspace users and air traffic controllers to be able to recognize GNSS anomalies and react appropriately also contributes to mitigating the adverse impact of the RFI event.

5.3.3.4.3 It is also very important that airspace users be promptly informed in advance about the scope and timing of military testing of GNSS jamming and spoofing equipment. Such peacetime military testing, if necessary, needs to be conducted recognizing the unavoidable interruption to flight and ATM operations, and suitable cautions should be exercised to limit adverse operational impact to civil aviation. Alternative operational procedures and, if necessary, additional CNS infrastructure need to be put in place and the process needs to be coordinated between relevant air traffic control units and airspace users.

5.3.3.5 *Reacting to GNSS service interruptions*

5.3.3.5.1 If a GNSS service interruption due to an RFI event cannot be prevented, it must be ensured that the event is detected and stopped as quickly as possible, especially if it has a detrimental operational impact. This requires the ability to detect, identify, locate and eliminate the RFI source. Detection will be provided either by monitoring systems or by operational personnel directly. However, it may not be easy for operational personnel to establish whether a navigation service interruption is due to RFI or to other causes. Ideally, suitable systems should be deployed that do not depend on the ability of operational staff to identify such events. Nonetheless, as shown in section 2, it is important that pilots and air traffic controllers understand the potential adverse impact of RFI to GNSS and react appropriately. Effective reporting lines must also be in place to ensure that any navigation service anomaly can be investigated. Technical guidance on RFI detection and localization is under preparation and will be included in Doc 8071, Volume II.

5.3.3.5.2 Once it is positively confirmed that an RFI event has occurred, relevant airspace users and air traffic controllers should be promptly and appropriately informed. Information relevant to the RFI cases should include, if available, the location and duration of the RFI event and related alternative operational procedures. Additionally, ANS provider engineering staff should contact the appropriate national radio regulatory and enforcement authority to resolve the RFI event. It will be helpful if as much data as possible is collected to allow the identification and classification of the RFI. Identification means association with a likely signal source in order to narrow the search space. For example, harmonic emissions from broadcast stations are a common potential source of unintentional RFI. Being able to identify the RFI as due to a broadcast signal and knowing the location of broadcast stations can significantly speed up the search for the signal source.

5.3.3.5.3 Furthermore, the signal source can also be triangulated using either an airborne or ground mobile platform. While airborne capabilities are likely to be able to locate a source most quickly, they may also be prohibitively expensive. Consequently, the deployed countermeasures depend on the magnitude of the impact caused. In the case of smaller events such as those due to individual PPD, identification of the source through monitoring conducted over several weeks may be acceptable, whereas larger events may require specific measurement flights into the affected area. It should, however, be noted that RFI source localization by measurement flights can be more challenging because measurement flights themselves may be affected by the RFI.

5.3.3.5.4 Once an RFI event has been resolved, States and/or ANS providers are encouraged to share lessons learned in corresponding aviation forums (spectrum-related working groups).

6. REGIONAL AND GLOBAL SUPPORT PROCESSES

6.1 Spectrum-related matters are generally a State's responsibility. Consequently, this material is primarily written with activities at the State level in mind. However, GNSS is a global system with regional components. Furthermore, aviation is also a global operation that benefits from harmonized processes. The efforts of States in mitigating RFI can be greatly facilitated by taking advantage of these structures. This requires that corresponding organizational interfaces be set up.

6.1.1 Compilation of a comprehensive threat picture

6.1.1.1 One key challenge of RFI mitigation is the limited observability of events, especially when considering events that impact aircraft in flight. When equipped with multi-sensor avionics, in some cases a pilot may not even notice a GNSS outage. Even when an outage is noticed by the aircrew, there is no obligation to report it, especially if there were no operational consequences. Information about such events does represent a very valuable source of threat monitoring data, however, and greatly facilitates infrastructure service provision.

6.1.1.2 If pilots report GNSS outage events, there are many different options. They can file pilot reports with a local ANS provider, or the operators reporting may contact a global or regional organization such as IATA or EUROCONTROL. They could also contact GNSS user support centers. These centers are operated by core constellation and augmentation service providers and support all user segments (i.e. are not unique to aviation). How such reports are followed up will depend on the seriousness of the event as well as the level of understanding of the personnel involved. This multitude of reporting streams may make it difficult to have a complete picture of the actual threat situation since relevant data is either not reported or reported to many different entities. It is recommended to coordinate such reporting to ensure that operationally relevant events can be assessed based on an as complete a picture as possible. Especially when encountering repeated events in a specific area, operators are encouraged to file pilot reports with the relevant AIS.

6.1.1.3 As an example, in Europe a reporting mechanism has been set up through the EUROCONTROL Voluntary ATM Incident Reporting (EVAIR) scheme. This is a general safety reporting function with confidentiality arrangements in place and operating in coordination with IATA. A similar mechanism exists in the United States, the National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS). GNSS outage events are reported to EVAIR on a regular basis. The data obtained so far indicates that GNSS outage events are a regular occurrence but that these events normally do not lead to severe operational issues. While not all events are necessarily reported, the real number of events can be expected to be of a similar order of magnitude as the number of events reported and provides a meaningful indication of probability of occurrence, geographic distribution and frequency. The data also provides an essential risk assessment link in terms of operational relevance. Most of all, this mechanism ensures that any significant changes in RFI environment can be detected.

6.1.1.4 Because reporting of aviation safety events is an established process in place for many other issues, extension of the process to include RFI is relatively easy to set up. Evidence of aviation-specific RFI events should be further corroborated by coordination with GNSS user support centers. If such regional or global threat monitoring detects multiple significant events in a given area and time, it should be reported to the responsible State authorities and ANS providers.

6.2 Determination of probable cause of GNSS outages

6.2.1 When regional or global threat monitoring leads to the detection of an operationally significant number of events, specific reactive mitigation measures can be considered. This is done in cooperation with airspace users, regulators and ANS providers as appropriate. However, normally there will be very sparse data on the event itself and no confirmation that the event is due to RFI even if the aircrew may in some cases suspect it.

6.2.2 In such cases, the probable cause must be determined through a process of elimination. First, an outage could be due to a problem with the GNSS service, which may be either due to core constellation (or augmentation system if applicable) or signal malfunction. Second, an outage may be caused by unusual solar activity. Third, the problem may also be caused by the receiver itself as opposed to the GNSS signal.

6.2.3 GNSS user support centers can provide GNSS service status to concerned users as well as to staff conducting outage event assessments. They normally also have connections with atmospheric monitoring organizations and contacts with receiver manufacturers, which can greatly assist in determining if a given GNSS outage is due to any of the three causes mentioned above. If these causes can be excluded, then the event is likely caused by RFI.

6.2.4 Once it is determined that RFI is the likely cause, further assessment and classification can take place as described in section 4. If significant RFI events occur, reactive measures can be implemented as described in section 5. This may also need to include providing information to aircraft operators through NOTAM and other available channels. Coordinating with regional and global organizations can greatly facilitate and accelerate RFI event confirmation and resolution.

7. SUMMARY

7.1 A GNSS RFI risk mitigation framework has been described. Many potential actions have been identified and summarized in checklists listed in section 8. The approach is to mitigate risks down to a level as low as reasonably practicable, by iteratively using the three step process of threat monitoring, risk assessment and deployment of mitigation measures.

7.2 While it is difficult to assess in detail what level of effort can be considered “reasonable”, it will be important to take an overall CNS/ATM system view. Especially with regard to the security aspects of RFI risk mitigation, associated efforts need to be balanced across the CNS/ATM system, taking into account that the CNS/ATM security chain is only as strong as its weakest link which is not necessarily always GNSS. Nonetheless, continued vigilance is appropriate as the navigation service evolves to one that is primarily enabled by GNSS while subject to risks emanating from non-aviation sectors. Establishing the described process in a step-by-step fashion will enable maintaining risks within tolerable levels.

7.3 National mitigation plans and regional coordination

Given the global nature of aviation operations, it is desirable that a relatively homogeneous level of protection from RFI events be achieved. For this purpose, data sharing is essential. This needs to happen in appropriate forums that can handle potentially sensitive data. Mitigation plans at the national level should be coordinated with the aviation and telecommunication regulators and other suitable partners. For example, a State may choose to designate GNSS as a national critical infrastructure or as a key element of such infrastructures and launch more coordinated protection actions that benefit all user segments.

7.4 Implementation planning, testing and training

7.4.1 Many States already have processes in place to mitigate RFI at the national level. Others may wish to improve their capabilities accordingly. If conducted in line with other GNSS implementation activities and in coordination with all relevant parties, implementation of RFI mitigation processes and capabilities is not expected to create an undue resource burden. While some investment in technical capabilities is likely to be required, it should be possible to build these up over time by gradually upgrading contingency plans and procedures as implementation progresses.

7.4.2 As GNSS RFI events are currently relatively rare in most regions of the world, technical and operational staff may lack direct experience of such events. Appropriate testing and training activities should ensure that, in particular, reactive mitigation measures can be deployed promptly when required.

7.5 Long-term spectrum management actions

7.5.1 Introduction of GNSS dual-frequency, multi-constellation (DFMC) capabilities may also lead to increased RFI robustness. However, this is only the case if the full DFMC capability itself does not become a minimum requirement to achieve a more demanding service with less infrastructure. In other words, if the desired operation cannot be supported by a single frequency (or single constellation) configuration, even a partial outage of the DFMC capability may still lead to operational disruption.

7.5.2 Careful balancing of future developments should ensure that a maximum of GNSS resilience can be achieved. This could encompass the following measures:

a) strengthen the protection of critical GNSS spectrum bands for aviation taking into account growth and threats from systems inside and outside the aviation sector;

b) ensure that GNSS equipment can detect RFI events. Ideally, this information is transmitted to technical service provision experts without a need for interaction by pilots or controllers;

c) improve RFI resilience in future GNSS receivers as far as practicable;

d) ensure that multi-band antennas are as insensitive as possible to out-of-band and illegitimate in-band signals;

e) establish a database that provides data on interference sources in order to facilitate their identification by suitably authorized personnel; and

f) update guidance material concerning GNSS receiver RFI masks (specifically relating to the L5 frequency band).

8. CHECKLISTS

8.1 The purpose of the checklists is to provide a quick assessment of risk mitigation status. Depending on the actual environment, it may not be necessary to implement all items mentioned because many aspects are outside of aviation control. However, these factors should be considered in aviation risk assessments.

8.2 Preventive measure checklist

a) possession of a jamming device is illegal;

b) adequate personal location privacy provisions exist, removing motivation for citizens to consider using GNSS jamming capabilities;

c) market survey mechanisms are in place to detect relevant evolutions in GNSS applications and usage;

d) national policy ensures that providers of (non-aviation) GNSS-based fee collection systems or similar revenue streams design their systems in such a way that GNSS jamming will not result in the avoidance of fees;

e) devices with associated RFI risks (such as outdoor pseudolites, repeaters or boosters) are carefully controlled and installations are independently verified by measurements for compliance to international standards;

f) mitigation plans including agreements, processes and equipment capabilities for reactive mitigation actions are in place, tested and exercised regularly; and

g) contact points for RFI mitigation activities are established between ANS providers, airports, telecommunication regulators and other organizations as necessary.

8.3 Reactive measure checklist

a) measurement capabilities exist for all potentially required monitoring tasks;

b) where supported by a corresponding risk analysis, airports perform monitoring for RFI at critical points within or near airport perimeter;

c) capabilities to detect, locate and identify RFI sources are in place;

d) capabilities to stop RFI (law enforcement) are in place;

e) alternate navigation capabilities and operational procedures are available to safely deal with GNSS area outages;

f) mechanisms to generate a NOTAM, if necessary, are clear for all relevant parties;

g) all involved personnel is trained to recognize and deal with RFI events as appropriate; and

h) lessons learned are shared with relevant aviation spectrum working groups.

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Attachment to Appendix F

REPORTING OF GNSS RFI

1. INTRODUCTION

This attachment provides guidance on reporting cases of GNSS outages which are suspected to be due to RFI. Normally, GNSS outage or anomaly reports should be filed with the State where the outage occurred. Section 2 of this attachment includes two reporting forms that can be used for that purpose. Section 3 contains guidance on reporting to ICAO abnormal cases in which the State or States concerned cannot resolve the anomaly locally or bilaterally.

2. EXAMPLE FORMS FOR GNSS RFI REPORTING TO STATES

In order to compile a comprehensive threat picture as discussed in section 6 of this appendix and facilitate coordination as described in section 7.12.4 of this manual, it is advisable to ensure that reporting from all relevant sources is collected by a single entity at the State or regional level. Two examples of reporting forms are provided in this section. One is intended for use by ATS personnel, the other for use by pilots. The forms list all the information which could be helpful in resolving outage or anomaly reports. The use of the example forms is not mandatory: a State or international organization may consider it better to integrate GNSS outage reports into existing safety reporting systems with more generic forms.

Example form for use by ATS personnel

GNSS RFI REPORTING FORM FOR USE BY ATS PERSONNEL	
Originator of report	
Organization	
Department	
Street address	
Zip code/city	
Name/surname	
Phone No.	
E-Mail	
Date and time of report	

GNSS RFI REPORTING FORM FOR USE BY ATS PERSONNEL (continued)	
Description of interference	
Affected GNSS element	[ ] GPS [ ] GLONASS [ ] other constellation [ ] EGNOS [ ] WAAS [ ] other SBAS [ ] GBAS (VHF data-link for GBAS)
Observability of the interference	Interference was noticeable: [ ] only on board aircraft [ ] only on ground [ ] both
Source of initial interference report	[ ] Pilot [ ] Engineer/technician [ ] other
Degradation of GNSS performance	[ ] Large position errors (details): [ ] Loss of integrity (RAIM warning/alert) [ ] Complete outage [ ] Loss of satellites in view (details): [ ] Lateral indicated performance level changed from___ to ___ [ ] Vertical indicated performance level changed from ___ to ___ [ ] Indicated dilution of precision changed from ___ to___ [ ] Information on PRN of affected satellites (if applicable) [ ] Low signal-to-noise (density) ratio [ ] other
In case of report by pilot	
Airline name	
Aircraft type and registration	
Flight number	
Airway/route flown	
Coordinates of the first point of occurrence/Time (UTC)	UTC: ___ Lat: ___ Long: ___
Coordinates of the last point of occurrence/Time (UTC)	UTC: ___ Lat: ___ Long: ___
Flight level or altitude at which it was detected	
Affected ground station (if applicable, e.g. GBAS)	Name/indicator: Lat: ___ Long: ___

GNSS RFI REPORTING FORM FOR USE BY ATS PERSONNEL (continued)	
In case of report by ATS personnel	
Coordinates of the first point of occurrence/Time (UTC)	UTC: ___ Lat: ___ Long: ___
Coordinates of the last point of occurrence/Time (UTC)	UTC: ___ Lat: ___ Long: ___
Affected area	
Affected flight route	
Problem duration:	Days, hours, minutes, seconds ____________ [ ] continuous [ ] intermittent
Information on presumed source of interference	
Presumed location of interference source	Lat: ___ Long: ___ or Nearest city or landmark:
Interfering frequency (if known)	
Signal strength and reference bandwidth (if known)	
Further descriptions of the interference case	[ ] Spectrum plot [ ] Map Other material:

Example form for use by pilots

GNSS RFI REPORTING FORM FOR USE BY PILOTS	
Originator of report	
Organization	
Department	
Street address	
Zip-Code/city	
Name/surname	
Phone No.	
E-Mail	
Date and time of report	

GNSS RFI REPORTING FORM FOR USE BY PILOTS (continued)	
Description of interference	
Affected GNSS element	[ ] GPS [ ] GLONASS [ ] other constellation [ ] EGNOS [ ] WAAS [ ] other SBAS [ ] GBAS (VHF data-link for GBAS)
Aircraft type and registration	
Flight number	
Airway/route flown	
Coordinates of the first point of occurrence/time (UTC)	UTC: ___ Lat: ___ Long: ___
Coordinates of the last point of occurrence/time (UTC)	UTC: ___ Lat: ___ Long: ___
Flight level or altitude at which it was detected	
Affected ground station (if applicable, e.g. GBAS)	Name/indicator:
Degradation of GNSS performance	[ ] Large position errors (details): [ ] Loss of integrity (RAIM warning/alert) [ ] Complete outage [ ] Loss of satellites in view (details): [ ] Lateral indicated performance level changed from ___ to ___ [ ] Vertical indicated performance level changed from ___ to ___ [ ] Indicated dilution of precision changed from ___ to ___ [ ] information on PRN of affected satellites (if applicable) [ ] Low signal-to-noise (density) ratio [ ] other
Problem duration	[ ] continuous [ ] intermittent

3. GUIDANCE ON GNSS RFI REPORTING TO ICAO

3.1 GNSS RFI reporting to ICAO does in no way replace the reporting requirements identified within an individual State. It shall be limited to the reporting of cases with cross-border impact that cannot be solved nationally or internationally through routine procedures, including the application of all suitable measures for dealing with interference laid down in Article 15 of the ITU Radio Regulations.

3.2 In such cases, the provisions of a Memorandum of Cooperation (MoC) between ICAO and ITU) apply. The MoC establishes a framework for enhanced cooperation between ICAO and ITU in matters related to harmful interference to GNSS with a potential impact on international civil aviation safety. The following cooperation procedure is defined in the MoC:

a) ICAO will institute a process whereby ICAO Member States and relevant aviation stakeholders will report to ICAO cases of harmful interference to international civil aviation uses of GNSS;

b) ICAO will perform a prompt analysis of the interference reports with regard to their impact on safety, regularity and efficiency of air navigation;

c) in cases where the analysis determines that there is a significant impact on air navigation with an international scope, ICAO will transmit the results of the analysis to ITU without delay;

d) ITU will duly consider and, as appropriate, take into account the information received from ICAO when providing assistance to administrations to ensure a prompt resolution of the problem of interference pursuant to Article 15 of the ITU Radio Regulations;

e) ICAO will make aeronautical expertise available to ITU on request, if needed to assist ITU in settlement of the problem;

f) ITU will keep ICAO informed of the progress in application of the procedure defined in Article 15 of the ITU Radio Regulations, Section VI, for the cases of harmful interference to GNSS identified by ICAO; and

g) ITU will notify ICAO as soon as the interference incident can be considered as settled.

3.3 The following details may be provided when reporting GNSS interference cases to ICAO:

a) originator of report: originating State, organization, address;

b) description of interference:

    1) affected GNSS service (GNSS constellation, SBAS, GBAS);

    2) observability of the interference (interference was noticeable only on board aircraft, only on ground, both);

    3) degradation of GNSS performance (large position errors, loss of integrity, loss of single/multiple satellites in view);

    4) problem duration (duration time, continuous/intermittent impact);

    5) affected area (local/widespread);

    6) operational impact (loss of navigation, need to change the navigation procedure);

    7) information on presumed source of interference:

        i) actions taken to rule out that the interference source is domestic;

        ii) presumed location of interference source/State;

        iii) interfering frequency;

        iv) interference signal strength and reference bandwidth;

        v) presumed possible causes;

c) actions taken to mitigate the interference;

d) was a report of an irregularity or infringement submitted to ITU (as foreseen in Article 15 with a reporting form provided in Article 9 of the ITU radio regulations); and

e) attachments (spectrum plot, map, log entries, recorded GNSS data).

Appendix G

SBAS CONTINUITY COMPUTATION METHOD

1. APV-I AND CATEGORY I CONTINUITY REQUIREMENTS IN ANNEX 10

Annex 10, Volume I, Attachment D, 3.4.1 states that "Continuity of service of a system is the capability of the system to perform its function without unscheduled interruptions during the intended operation." For APV-I and Category I, Annex 10, Volume I, Table 3.7.2.4.-1 specifies a continuity requirement of $1 - 8 \times 10^{-6}$ per 15 s.

2. METHOD OF COMPUTING SBAS APV-I AND CATEGORY I CONTINUITY

2.1 The level of continuity performance achieved by different SBAS systems is determined by applying a continuity computation method. Several such methods exist and a need for harmonization among the methods used by different SBAS service providers has been recognized. Accordingly, this appendix describes the method of computing SBAS APV-I and Category I continuity agreed by the SBAS Interoperability Working Group (IWG).

2.2 The method for computing continuity described in this section applies a sliding window, taking into account the use of dual GEO satellites, SIS and disregarding predictable outages for which a NOTAM has been issued.

2.3 With this method, continuity during a given time interval is computed as one minus the continuity risk where:

a) continuity risk is defined as the ratio between the number of continuity events and the total number of available samples within the time interval;

b) the number of continuity events is defined in paragraph 2.3.1; and

c) the total number of available samples is defined in paragraph 2.3.2.

2.3.1 Number of continuity events

2.3.1.1 For a given epoch, a single continuity event is defined to occur if:

a) the service is available at that epoch; and

b) it becomes unavailable in at least one of the following 15 seconds (e.g. signals are lost for more than four seconds or a protection limit exceeds the corresponding alert limit for more than one second). It should be noted that, consistent with this definition, if at a given epoch the system is not available, an outage occurring during the following 15 seconds is not to be counted as a continuity event.

2.3.1.2 The method computes the number of continuity events by assessing the availability of the service using a 16-second sliding window. The epoch at which continuity is assessed corresponds to the first second of the window. The interval of time in which availability of the service is tested corresponds to the following 15 seconds. Continuity at successive epochs is assessed by sliding the window to the right at one-second steps.

2.3.1.3 An example of application of the method is illustrated in Figure G-1. The figure shows two service interruptions (due to a protection level exceeding the corresponding alert limit[1]), occurring during intervals of time separated by 12 seconds. As the sliding window passes over the first interval, 15 continuity events will occur. As the sliding window passes over the second interval, 12 continuity events will occur

2.3.1.4 Other examples:

a) a single isolated outage will generate 15 continuity events, regardless of its duration;

b) two separate outages will generate a number of continuity events equal to 15 plus the number of seconds in the separating interval, or equal to 30, whichever is less; and

c) six outages, each lasting one second, occurring within a 15-second interval will generate a number of continuity events ranging from 15 (if the six outages are contiguous) to 24 (if the six outages are non-contiguous); the first outage occurs in the first second of the 15-second interval and the last outage occurs in the last second of the interval.

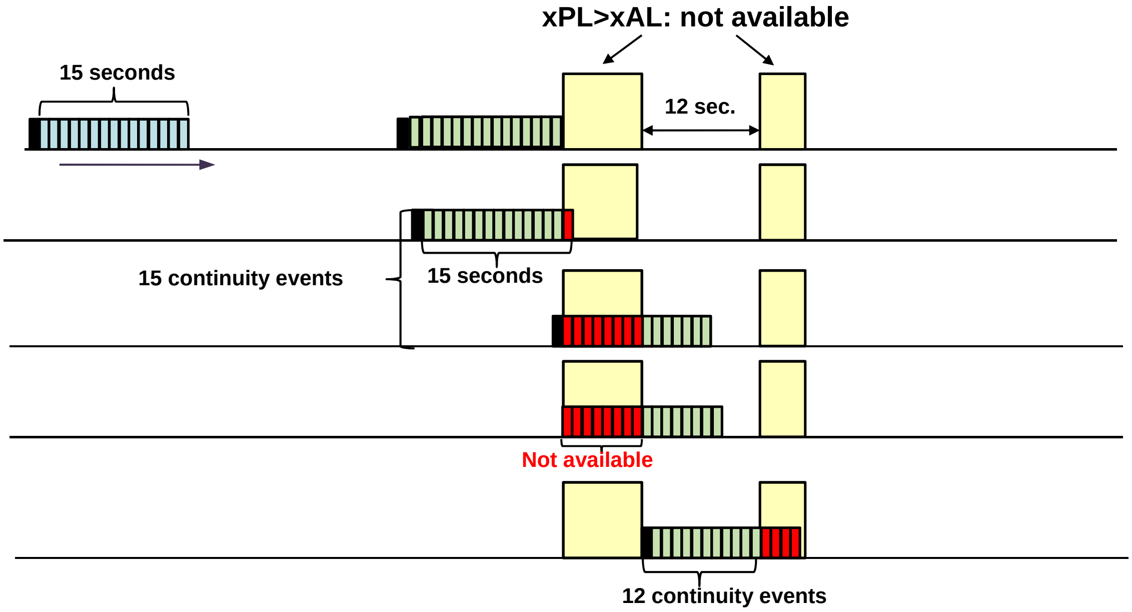

Figure G-1. Example of application of the SBAS continuity method

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[1] The caption "xPL > xAL: not available" in the figure refers to the fact that during the two outages either the vertical protection limit (VPL) or the horizontal protection limit (HPL) exceeds the corresponding alert limit (VAL or HAL), and as a consequence the service is not available.

2.3.2 Total number of available samples

A sample is considered to be available when a valid protection level can be computed and is lower than the alert limit. Therefore, the total number of available samples during a measurement period is equal to the duration of the period in seconds multiplied by availability[2] over that period. As an example, taking as measurement period a year during which APV-I availability was 99 per cent, the total number of samples would be 31 220 640 seconds (365×86 400×0.99).

2.4 Use of dual GEO satellites SIS for continuity measurement

2.4.1 All receivers conforming with RTCA DO-229D with Change 1 (see Annex 10, Volume I, Attachment D, 3.2.9) are expected to be tracking at least two SBAS GEO satellites, when available, and to use one of them. The receiver implementations are based on instantaneous receiver switching between available GEO satellites to ensure continuity of service. Use of dual GEO satellites SIS when available is taken into account in the computation method. The reasons to switch between two GEO satellites that are considered in the method are:

a) loss of four consecutive messages from one of the satellites, either due to reception problems or due to uplink stations switchovers; and/or

b) loss of safety-of-life service (for example: reception of message Type 0).

2.4.2 Switching when a protection level exceeds the corresponding alert level is not considered in the method as this capability is not a requirement in RTCA DO-229D with Change 1.

2.5 Removal of predictable outages

2.5.1 A NOTAM service can be used to inform aviation users of predictable outages (with a duration greater than 15 minutes) affecting specific locations. NOTAM are issued as required by Annex 15 and the PANS-ATM (Doc 4444).

2.5.2 Outages for which a NOTAM is issued at least 72 hours in advance in accordance with Annex 10, Volume I, Attachment D, 9.3 can then be removed from the computation of the number of continuity events. Likewise, available samples during the period of an issued NOTAM should be removed from the total number of available samples. These removals apply to the computation of continuity for the specific locations for which the NOTAM was issued (e.g. a specific airport).

2.5.3 Only NOTAM that could have an impact on the operations should be considered in the continuity computation, excluding the warning type of NOTAM (e.g. “SBAS service may not be available”).

2.6 Continuity measurement period

The duration of the period to measure continuity should be commensurate with the acceptable frequency of continuity events. Note that the continuity risk requirement of 8×10^{-6} is equivalent to one outage in 22 days. Historical data (e.g. continuity events collected over several months or years as relevant) should be used to have more representative and reliable results.

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[2] Annex 10, Volume I, Attachment D, 3.5.1 states that, “The availability of GNSS is characterized by the portion of time the system is to be used for navigation during which reliable navigation information is presented to the crew, autopilot, or other system managing the flight of the aircraft.” For APV-I and Category I, Annex 10, Volume I, Table 3.7.2.4-1 specifies availability requirements ranging from 0.99 to 0.99999, depending on the operational need. For a given period, availability relates to the accumulated duration of outages, whereas continuity relates to the number of outages.

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ISBN 978-92-9258-268-5

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