



The European Organisation for Civil Aviation Equipment
L'Organisation Européenne pour l'Équipement de l'Aviation Civile

HIGH-LEVEL PERFORMANCE REQUIREMENTS FOR A GLOBAL NAVIGATION SATELLITE SYSTEM / GROUND BASED AUGMENTATION SYSTEM TO SUPPORT PRECISION APPROACH OPERATIONS

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FOREWORD

1. This document, prepared by EUROCAE Working Group 28, was accepted by the Council of EUROCAE on 8 October 2007.
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CHAPTER 1

GENERAL

1.1 PURPOSE, SCOPE AND OVERVIEW

This document contains high-level performance requirements for a Ground Based Augmentation System (GBAS), as part of the Global Navigation Satellite System (GNSS), to support CAT I, II and III precision approaches and landing.

Primary performance parameters are accuracy, integrity, availability, and continuity. The document also defines some additional system level performance requirements. These parameters are specified at the system level in this document but are not allocated to the major subsystems. Because it only addresses high-level requirements without subsystem allocations, this document does not replace or update EUROCAE ED-95. It is anticipated that a new, complete MASPS covering precision approach applications will not be completed until the high-level requirements are agreed at ICAO level and the implementation of GBAS CAT I has progressed further.

The specifications of this document have been derived from ILS standards in order to simplify aircraft integration and certification, without regard to specific GNSS elements and associated performance. Hence, they do not imply a specific architecture, nor do they dictate the use or combination of specific GNSS core constellation elements. However, since Galileo signals will be available in the anticipated timeframe of GBAS CAT III implementation, it is expected that GBAS will take full advantage of both GPS and Galileo signals on all frequencies usable for aviation in order to provide a robust and reliable service. This necessitates that CAT III operations remain viable even in a single frequency, single constellation fall back mode. Future architectural development and refinement of associated requirements will have to take these considerations into account.

The specifications in this document also do not impose any supplemental restrictions on aircraft FTE performance beyond those existing in the ILS standards.

This document is not expected to be implemented by regulatory documents; it is intended to be a tool to support the further development of standards for GBAS to support all categories of precision approach and landing. The methodology used to develop the Category II and III performance requirements is identical to that used previously for Category I. This methodology derives the requirements from the ILS standards with additional validation provided by aircraft certification requirements. In particular it interprets the alert limits as the largest navigation system error which can be experienced without an alert, where the probability of a navigation system error larger than the alert limit is defined by the integrity requirement. The resulting requirements are generic and no credit is taken for system monitors which may limit the magnitude of errors for some failure modes. This may result in more stringent navigation system requirements than those derived for specific systems taking these monitors into account.

Chapter 2 of this document provides a system description and definitions needed to understand the requirements stated in the remaining sections. It describes typical equipment applications and operational goals and forms the basis of the specifications in Chapter 3.

Chapter 3 contains the minimum system performance specifications for the complete system, including requirements to support CAT I, II and III operations.

Appendices A through D are informative and contain rationales for the requirements and allocations given in section 3 on, respectively, accuracy, continuity, integrity and availability.

1.2 APPLICATIONS

1.2.1 Definitions

Alert Limit: For a given measured parameter, the error tolerance not to be exceeded without issuing an alert within the Time-to-Alert.

Flight Technical Error (FTE): The accuracy with which the aircraft is controlled as measured by the indicated aircraft position with respect to the desired position along the flight path.

Navigation System Error (NSE): The difference between the indicated position and the true position.

Total System Error (TSE): The difference between true position and desired position.

1.2.2 Abbreviations

ABAS	Aircraft Based Augmentation System
ACJ	(Joint) Advisory Circular
A/P	AutoPilot
ARINC	Aeronautical Radio, Incorporated
ATC	Air Traffic Control
ATM	Air Traffic Management
AWO	All Weather Operation
AWOP	All Weather Operation Panel (ICAO)
CAT	Category (of precision approach operation)
CDF	Cumulative Distribution Function
COS	Continuity of Service
CRM	Collision Risk Model
CW	Continuous Wave
D	Distance
DCP	Datum Crossing Point
DDM	Differential Depth of Modulation
DH	Decision Height
EASA	European Aviation Safety Agency
FAS	Final Approach Segment
FAA	Federal Aviation Administration (United States)
F/D	Flight Director
ft	feet
FTE	Flight Technical Error
GBAS	Ground Based Augmentation System
GLONASS	Global Navigation Satellite System
gnd	Ground
GNSS	Global Navigation Satellite System
GP	Glide Path
GPA	Glide Path Angle

GPIP	Glide Path Intercept Point
GPS	Global Positioning System
H	Height
HAT	Height Above Threshold
ICAO	International Civil Aviation Organisation
ICD	Interface Control Document
ILS	Instrument Landing System
JAA	Joint Aviation Authorities.
JAR	Joint Aviation Regulation (JAA)
LOC	Localizer
LTP/FTP	Landing Threshold Point/ Fictitious Threshold Point
MASPS	Minimum Aviation System Performance Specification
MASPS (RTCA)	Minimum Aviation System Performance Standard
MMR	Multi-Mode Receiver
MLS	Microwave Landing System
MOPS	Minimum Operational Performance Specification
MOPS (RTCA)	Minimum Operational Performance Standard
MTBO	Mean Time Between Outages
MTTR	Mean Time to Repair
NM	Nautical Mile
NSE	Navigation System Error
NTDP	Nominal Touch Down Point
PDF	Probability Density Function
PRC	Pseudo-Range Correction
RDP	Reference Datum Point
RNP	Required Navigation Performance
RSS	Root Sum Square
RTCA	Radio Technical Commission for Aeronautics
SARPs	Standards And Recommended Practices (ICAO)
SBAS	Space Based Augmentation System
SD	Standard Deviation
SIS	Signal-in-Space
TCH	Threshold Crossing Height
TSE	Total System Error
TTA	Time-to-Alert
VAL	Vertical Alert Limit
VDB	VHF Data Broadcast
VHF	Very High Frequency
WGS-84	World Geodetic System 1984

1.2.3

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CHAPTER 2

SYSTEM OVERVIEW

2.1 SYSTEM DESCRIPTION

The GNSS is a world-wide satellite based position, velocity and time determination system. It includes one or more satellite constellations and associated receivers. It also includes augmentation systems to enable, where necessary, the required performance for the desired operation.

The Ground Based Augmentation System (GBAS) is one such augmentation system and is intended primarily to support precision approach operations. It consists of a ground subsystem and an aircraft subsystem. One ground subsystem can support an unlimited number of aircraft subsystems within its service volume. The ground subsystem provides the aircraft with approach path definition data, as well as range corrections and integrity parameters for each satellite in view. The corrections and integrity parameters enable the aircraft to determine its position relative to the approach path with the required accuracy and integrity.

The GBAS Signal-in-Space is defined to be only the data broadcast from the ground to the aircraft subsystem. The Satellite Signals in Space are part of the basic GNSS satellite constellations. The phrase "Signals in Space" alone is used to describe all the transmissions together.

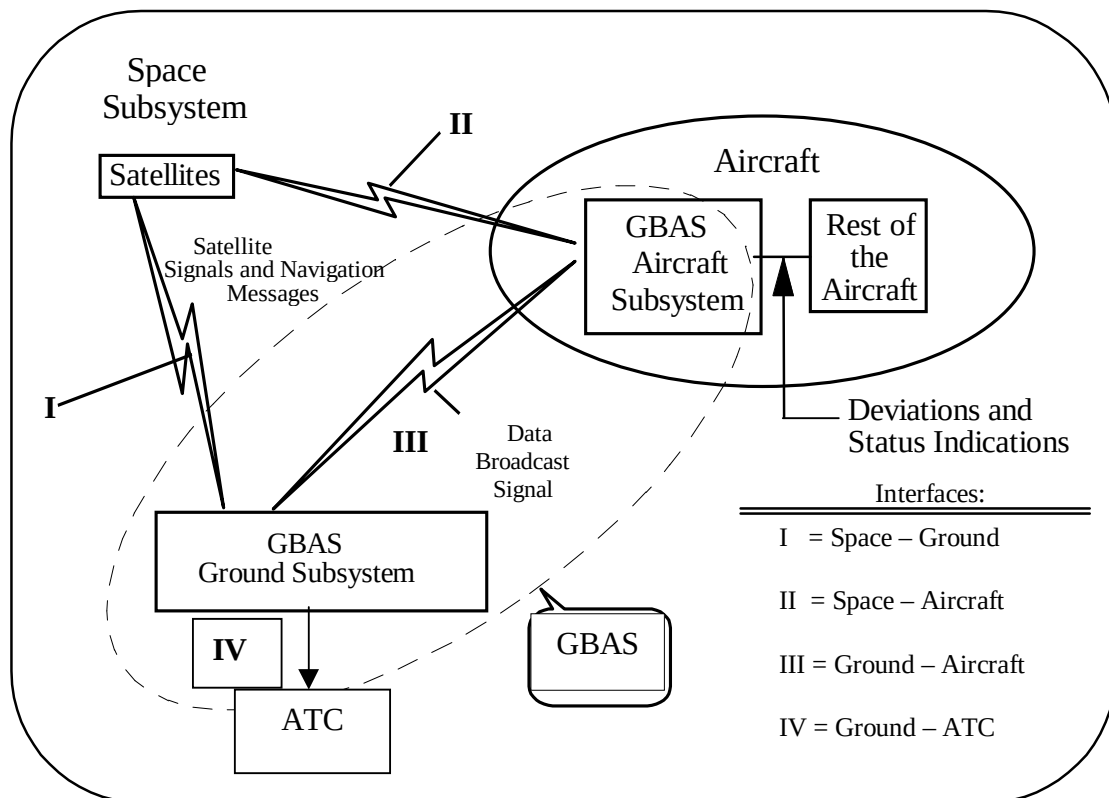


FIGURE 2-1 : HIGH-LEVEL REPRESENTATION OF GBAS

Current GBAS standards use GPS and GLONASS as ranging sources. Furthermore, the use of ranging signals from geostationary SBAS satellites is also possible. Appropriate standards will have to be developed for the use of ranging signals from additional constellations, such as Galileo. These standards will have to be compatible with, and build upon, the existing standards in ICAO Annex 10, ED-114 Ground Subsystem MOPS and ED-88(), RTCA/DO-253(), Airborne Subsystem MOPS.

The GBAS ground subsystem stores data, related to the serviced runway end(s), in the form of Final Approach Segment (FAS) path construction data blocks. It broadcasts this data continuously for reception by approaching aircraft.

The ground subsystem uses at least 2 reference receivers. They calculate pseudo-ranges for all satellites within view and the ground subsystem broadcasts differential corrections for them based on its own surveyed installation position in order that aircraft subsystems use it to correct their own measurement according to the differential principle. This principle requires that ground and aircraft subsystems use exactly the same ephemeris and satellite clock corrections. Moreover, since the differential principle removes all the ranging errors that are common to ground and aircraft subsystems, absolute tropospheric or SBAS corrections are not applied by the two subsystems.

The aircraft subsystem then corrects its own pseudo-range measurements for each satellite with the differential correction data received from the ground subsystem. The corrected pseudo-range measurements are then used to more accurately determine the aircraft's position relative to the selected Final Approach Path.

The GBAS integrity concept requires the aircraft subsystem to assess the integrity risk due to:

- a. fault-free, but rare measurement noise,
- b. faults of one of the ground subsystem reference receivers,

taking into account the geometry of the satellites used by the aircraft subsystem. In order to do that, the ground subsystem broadcasts specific integrity data to the aircraft subsystem for each pseudo-range correction. The aircraft subsystem uses specific integrity received data to limit the integrity risk.

For the cases where integrity is not a function of current satellite geometry at the aircraft subsystem, such as ranging source failures or ground subsystem faults, the integrity mechanisms are provided by the ground subsystem.

2.2 SUBSYSTEM INTERFACES

The input interfaces for both ground and aircraft subsystems include the GNSS signals in space (space subsystem), as illustrated in Figure 2-1.

2.2.1 Aircraft Subsystem Input and Output Signals

The aircraft subsystem receives the VHF Data Broadcast from the ground subsystem. Additionally, it has similar external interfaces to those of ILS. It receives inputs from the aircraft in the form of the channel number (tuning) and standard avionics interfaces.

The aircraft subsystem outputs guidance deviations, integrity and annunciation data to the aircraft; in a similar fashion to that of an ILS receiver.

2.2.2 Ground Subsystem Input and Output Signals

The ground subsystem is provided with the co-ordinates of its GNSS antennas, static parameters and the FAS data by the Air Navigation Service Provider.

Ground equipment status is output for remote display to the appropriate Air Navigation Service Provider (ATC and maintenance). Remote control inputs are available to the maintenance organization. It obtains a local power supply and has its own emergency power source.

2.3 GBAS CLASSIFICATION

GBAS requirements for accuracy, integrity, availability and continuity specified in this document are intended to support Category I, II, IIIA and IIIB operations.

In order to guarantee interoperability and enable efficient spectrum utilisation, the radio frequency and data broadcast characteristics, and frame and message structure, will be the same for GBAS supporting all categories of operations. Data formats for services using Galileo ranging signals and other services still need to be developed.

A service level concept relating ground facility capabilities to associated supportable operations given a specific level of aircraft equipage is under development at ICAO. This concept will need to be simple and transparent to both pilots and ATM.

CHAPTER 3

SYSTEM FUNCTIONAL PERFORMANCE

These requirements include the concept of a fault-free aircraft subsystem as a means of combining the signals in space broadcast by the space subsystem and the ground subsystem. This aircraft subsystem is defined to have nominal accuracy performance and, because it is assumed to have no failure, it does not contribute to the Signal-in-Space integrity and continuity performance.

Thus, concerning the outputs of the aircraft subsystem:

- a. accuracy is related to the total system (using an onboard receiver with nominal accuracy performances).
- b. integrity and continuity are only related to the Signal-in-Space.

These requirements are intended to be generic and to apply to any GNSS GBAS architecture. It is expected that any future Category II/III architecture will be based on the use of two or more GNSS signals on different frequencies but that one frequency from one constellation might provide adequate performance with reduced availability.

3.1 SIGNALS FROM THE GNSS SPACE SUBSYSTEM

Normal GBAS performance is dependent on the correct operation of the GNSS space subsystem, GPS, GLONASS and Galileo. The GBAS must use the GNSS signals correctly both within the ground subsystem and within the aircraft subsystem. GBAS will detect operationally relevant failures in the space subsystem.

SBAS satellites can be used as supplementary ranging sources by GBAS. In this case, the differential corrections transmitted by SBAS shall not be used by GBAS.

GPS, GLONASS and Galileo sensors shall be designed to operate with a Signal-in-Space that meets the requirements of the relevant GNSS SARPs.

GPS, GLONASS and Galileo ionospheric and tropospheric correction models shall not be used by GBAS.

For combined GPS/GLONASS/Galileo configurations, the reference co-ordinate system shall be WGS-84 and reference time shall be GPS time. GLONASS and Galileo satellite co-ordinates processed from ephemeris data shall be converted into WGS-84.

3.2 ACCURACY

The GBAS Accuracy requirements are based upon ILS specifications to minimise the validation and aircraft certification impact. In addition the Category III requirements have also been validated against aircraft certification requirements for runway touchdown performance. See Appendix A for a rationale on the accuracy requirements and measurement methodology.

3.2.1 System Lateral Accuracy

Lateral accuracy is defined in terms of lateral Navigation System Error (NSE).

The lateral NSE is the difference between the indicated and the true lateral displacement from the final approach path.

The probability that the lateral NSE value is within the limits shown below shall be at least 95% per approach. See Appendix A.

The lateral accuracy limits are given as a function of the horizontal distance (D) of aircraft position from the Landing Threshold Point / Fictitious Threshold Point (LTP/FTP) as depicted in Figure 3-1. LTP/FTP and the other Final Approach Segment points are defined in ICAO Annex 10.

3.2.1.1 Category I

Between 291 m and 873 m from LTP/FTP, a constant value of 16 m.

Between 873 m and 7500 m from LTP/FTP, a value linearly varying from 16 m to 27.7 m.

Over 7500 m from LTP/FTP, within the limit of coverage a constant value of 27.7 m.

3.2.1.2 Category II

Between LTP/FTP and 291 m from LTP/FTP, a constant value of 6.1 m.

Between 291 m and 7500 m from LTP/FTP, a value linearly varying from 6.1 m to 27.7 m.

Over 7500 m from LTP/FTP, within the limit of coverage a constant value of 27.7 m.

3.2.1.3 Category III

Along the runway, a constant value of 3.6 m.

Between LTP/FTP and 7500 m from LTP/FTP, a value linearly varying from 3.6 m to 27.7 m.

Over 7500 m from LTP/FTP, within the limit of coverage a constant value of 27.7 m.

NOTE: The accuracy requirement must be satisfied for the worst-case geometry under which the system is declared available.

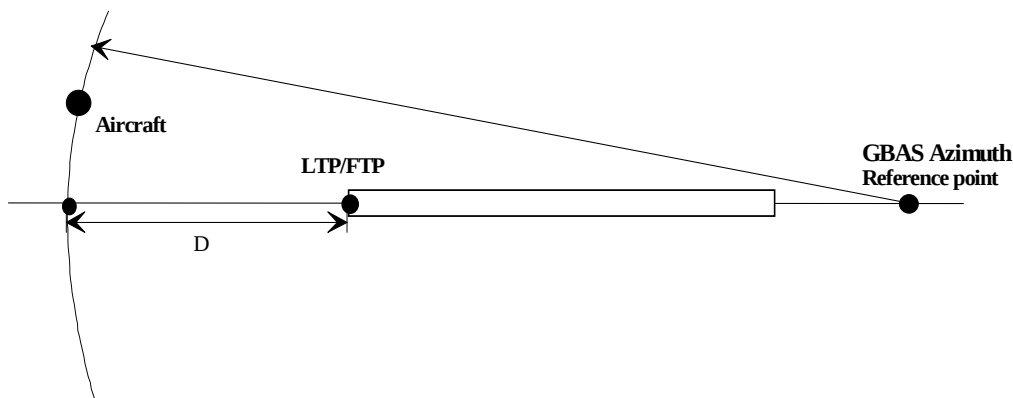


FIGURE 3-1 : PRECISION APPROACH - PLAN VIEW

3.2.2 System Vertical Accuracy

The GBAS vertical accuracy is defined in terms of vertical Navigation System Error (NSE).

The vertical NSE is the difference between the measured and true vertical displacement from the final approach path.

The probability that the vertical NSE value is within the limits shown below shall be at least 95% per approach. See Appendix A.

The vertical accuracy limits are given as a function of the height (H) above Landing Threshold Point / Fictitious Threshold Point (LTP/FTP) of aircraft position as depicted in Figure 3-2.

3.2.2.1 Category I

Between 100 ft HAT and 200 ft HAT, a constant value of 4 m.

Between 200 ft and 1340 ft HAT, a value linearly varying from 4 m to 17.3 m.

Above 1340 ft HAT, in the limit of coverage, a constant value of 17.3 m.

3.2.2.2 Category II

Between 50 ft HAT and 100 ft HAT, a constant value of 1.4 m.

Between 100 ft and 1340 ft HAT, a value linearly varying from 1.4 m to 17.3 m.

Above 1340 ft HAT, in the limit of coverage, a constant value of 17.3 m.

3.2.2.3 Category III

Between 50 ft HAT and 100 ft HAT, a value linearly varying from 1.0 m to 1.4 m

Between 100 ft and 1340 ft HAT, a value linearly varying from 1.4 m to 17.3 m.

Above 1340 ft HAT, in the limit of coverage, a constant value of 17.3 m.

NOTE 1: The accuracy requirement must be satisfied for the worst-case geometry under which the system is declared available.

NOTE 2: The accuracy requirements above are given for a system supporting 200ft Decision Height CAT I operations, 100ft Decision Height CAT II operations, and automatic landing and rollout CAT III operations.

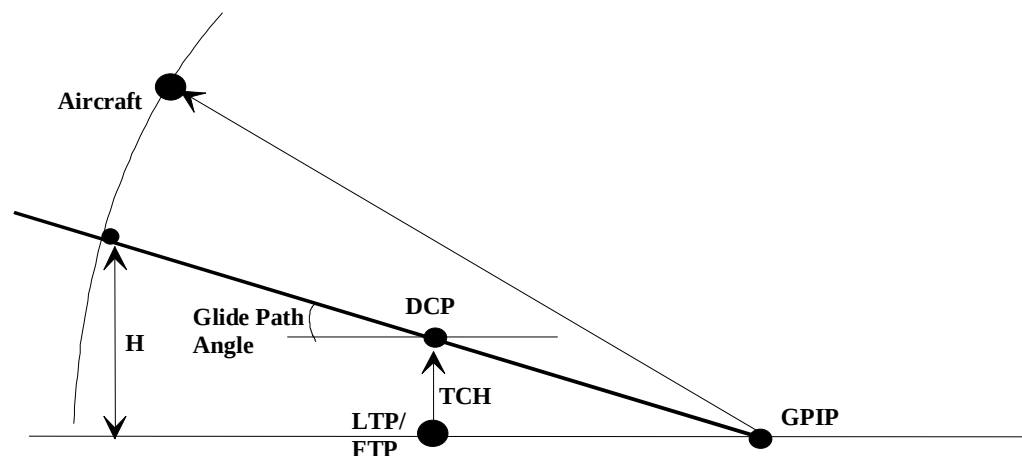


FIGURE 3-2 : PRECISION APPROACH - PROFILE VIEW

3.2.3 Spectral Content

The spectral content of the GBAS error is assumed to be bias-like. This assumption will be validated as part of the lower-level requirements development.

3.3 CONTINUITY OF SERVICE

3.3.1 System level

The GBAS Continuity of Service risk is defined as the probability, that within any defined period, an approach and landing cannot be continued due to an unscheduled loss of lateral or vertical guidance or warning annunciation onboard the aircraft assuming the system was available at the start of the defined period.

The total GBAS system Continuity of Service shall be such that aircraft complies with Airworthiness and Operational requirements.

NOTE 1: *Airworthiness requirements require that system loss of function occurrence rate is less than a level depending upon the severity of the effects at the aircraft level of the malfunction. It is up to the certification applicant to determine what are the effects with respect to the aircraft and systems definition as well as aircraft operations.*

NOTE 2: *The total Continuity of Service of GBAS is not quantified, because, in order to ease certification issues, airborne requirements are adopted from existing airworthiness requirements and cannot be easily compared to ILS Signal-in-Space Continuity of Service requirements.*

NOTE 3: *The objective for a system to support landings in CAT IIIB conditions is to be fail-operational.*

3.3.2 Signal-in-Space Continuity of Service

The Signal-in-Space Continuity of Service Risk is defined as the probability, that within any specific period, an approach cannot be continued due to an unscheduled loss of lateral or vertical guidance or warning annunciation onboard the aircraft. So, the Signal-in-Space Continuity of Service is defined by the probability that a fault-free aircraft subsystem provides valid outputs during any defined period of an approach, assuming that outputs were valid at the start of the period. Outputs are considered as valid if the NSE is lower than the corresponding alert limit and if there is no warning.

For CAT I operations, the Signal-in-Space Continuity of Service shall be greater than or equal to $1 - 8 \times 10^{-6}$ during any 15 s period.

NOTE: *ICAO is in the process of relaxing the CAT-I continuity requirement to an average continuity. These changes have not been incorporated due to the state of advancement of this document.*

For CAT II and CAT IIIA operations, the Signal-in-Space Continuity of Service shall be greater than or equal to $1 - 4 \times 10^{-6}$ during any 15 s period.

For CAT IIIB operations, the Signal-in-Space Continuity of Service shall be greater than or equal to $1 - 2 \times 10^{-6}$ during any 15 s period for vertical and greater than or equal to $1 - 2 \times 10^{-6}$ during any 30 s period for lateral guidance.

See Appendix B for GBAS Continuity of Service requirement derivation.

3.4 AVAILABILITY

Availability is the portion of time during which the service can be used for CAT I, CAT II or CAT III operations with reliable navigation information presented to the crew, autopilot, and other system managing the flight of the aircraft.

GBAS service is defined to be available when all the conditions needed to initiate a CAT I, CAT II or CAT III operation i.e. Accuracy, Integrity and Continuity of Service performances better than required, are met throughout the coverage service volume.

For GBAS, the availability is given by a combination of the space subsystem availability and ground and aircraft subsystems availability. The ground and aircraft subsystems loss of availability results from constraints due to Accuracy, Integrity and Continuity of Service requirements. No additional requirement is made on these subsystems related to availability. Availability can be predicted from considerations on statistical performance of the system, considering the effect of system failures.

In order to provide the same level of performance as an equivalent ILS system (see Appendix D for details on the Availability requirement derivation), the availability for the different operations supported by the GBAS system shall meet the requirements defined in following table.

Operation	Availability
CAT I	0.9975
CAT II	0.999
CAT III	0.999

Table 3-1 : GBAS availability requirements

3.5 INTEGRITY

3.5.1 System Level

The total GBAS system integrity shall be such that the aircraft complies with Airworthiness requirements.

NOTE 1: *Airworthiness requirements require that system malfunction occurrence rate is less than a level depending upon the severity of the effects of the malfunction at the aircraft level. It is up to the certification applicant to determine what are the effects with respect to the aircraft and system definition as well as aircraft operations. Generally, for CAT I operations, the effects of landing system malfunctions are considered as hazardous, while for CAT II/III, the same effects are considered as Catastrophic.*

NOTE 2: *The total integrity of GBAS is not quantified, because, in order to ease certification issues, aircraft requirements are adopted from existing airworthiness requirements and cannot be easily compared to ILS Signal-in-Space integrity requirements.*

3.5.2 Signal-in-Space Integrity

The GBAS Signal-in-Space (SIS) integrity risk is defined as the probability that the GBAS ground subsystem provides information, which when processed by a fault-free receiver, using any data that could be used by the aircraft, results in the position error exceeding the alert limit for a period longer than the maximum SIS Time-to-Alert without annunciation (section 3.7).

3.5.2.1 Category I requirements

For operations in CAT I conditions, the SIS integrity risk value is required to be less than 2×10^{-7} in any one operation.

3.5.2.2 Category II/III requirements

For operations in CAT II/III conditions, the SIS integrity risk value is required to be less than 1×10^{-9} in any one operation.