INTERNATIONAL STANDARDS
AND RECOMMENDED PRACTICES

AERONAUTICAL TELECOMMUNICATIONS

**ANNEX 10
TO THE CONVENTION ON INTERNATIONAL CIVIL AVIATION**

**VOLUME I
RADIO NAVIGATION AIDS**

SIXTH EDITION — JULY 2006

INTERNATIONAL CIVIL AVIATION ORGANIZATION

Checklist of Amendments to Annex 10, Volume I

	Effective date	*Date of applicability*
Sixth Edition (incorporates Amendments 1 to 81)	17 July 2006	23 November 2006
Amendment 82 (adopted by the Council on 26 February 2007)	16 July 2007	22 November 2007
Amendment 83 (adopted by the Council on 10 March 2008)	20 July 2008	20 November 2008
Amendment 84 (adopted by the Council on 6 March 2009)	20 July 2009	19 November 2009

Amendment 85
    (adopted by the Council on 26 February 2010)
    Replacement pages (iv), (xviii), (xix), 3-5, 3-6, 3-62, 3-63, 3-70,
    APP B-33, ATT C-13 to ATT C-16, ATT C-19 to ATT C-21,
    ATT D-1 to ATT D-4B and ATT D-7 to ATT D-9
	12 July 2010	18 November 2010

Transmittal note

Amendment 85

to the

International Standards and
Recommended Practices

AERONAUTICAL TELECOMMUNICATIONS

(Annex 10, Volume I, to the Convention on International Civil Aviation)

1.   Insert the following replacement pages in Annex 10, Volume I (Sixth Edition) to incorporate Amendment 85 which becomes applicable on 18 November 2010:

a)	Page (iv)	—	Table of Contents
b)	Pages (xviii) and (xix)	—	Foreword
c)	Pages 3-5, 3-6, 3-62, 3-63 and 3-70	—	Chapter 3
d)	Page APP B-33	—	Appendix B to Chapter 3
e)	Pages ATT C-13 to ATT C-16 and pages ATT C-19 to ATT C-21	—	Attachment C
f)	Pages ATT D-1 to ATT D-4B and pages ATT D-7 to ATT D-9	—	Attachment D

2.   Record the entry of this amendment on page (ii).

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ATTACHMENTS

Amendment	Source(s)	Subject(s)	*Adopted* *Effective* *Applicable*
70	ANC; Third Meeting of the Aeronautical Fixed Service Systems Planning for Data Interchange Panel; 34th Meeting of the European Air Navigation Planning Group	Restructuring of Annex 10 into five volumes; deletion of obsolete specifications and guidance material on manual Morse code procedures and teletypewriter systems; inclusion of material on common ICAO data interchange network (CIDIN).	20 March 1995 24 July 1995 9 November 1995
71	ANC; Special COM/OPS Divisional Meeting (1995); 12th, 13th and 14th Meetings of the All Weather Operations Panel; Secretariat proposals for deletion of obsolete material	Finalization of SARPs and guidance material for the microwave landing system (MLS), incorporation of a new strategy for introduction and application of non-visual aids to approach and landing in place of the ILS/MLS transition plan; relocation of material to Volumes III, IV and V, as appropriate; deletion of obsolete specifications for Consol and Loran-A systems and guidance material on the utilization of facilities, research, development and evaluation.	12 March 1996 15 July 1996 7 November 1996
72	—	No change.	—
73	Air Navigation Commission	Introduction of Human Factors-related material.	19 March 1998 20 July 1998 5 November 1998
74	Sixteenth Meeting of the All Weather Operations Panel; Air Navigation Commission	Introduction of: a) required navigation performance (RNP) for approach, landing and departure operation; b) updating of specifications for instrument landing system (ILS) and microwave landing system (MLS); and c) associated guidance material.	18 March 1999 19 July 1999 4 November 1999
75	—	No change.	—
76	Third meeting of the Global Navigation Satellite System Panel (GNSSP); proposal by the United Kingdom for continuity of service requirements for ILS and MLS	Global navigation satellite system (GNSS); continuity of service requirements for ILS localizers and MLS azimuth facilities used in support of Category IIIA operations; updating of references to the ITU Radio Regulations.	12 March 2001 16 July 2001 1 November 2001
77	Global Navigation Satellite System Panel (GNSSP)	Incorporation of GLONASS-related technical specifications in the satellite-based augmentation system (SBAS) and ground-based augmentation system (GBAS) sections of GNSS requirements; provision for use of GBAS positioning service in support of terminal area navigation (RNAV) operations; provision for use of new Message Type 28 to enhance performance of SBAS; and incorporation of additional guidance material and clarifications/editorial corrections to SARPs and guidance material.	27 February 2002 15 July 2002 28 November 2002
78	—	No change.	—

Amendment	Source(s)	Subject(s)	*Adopted* *Effective* *Applicable*
79	Fourth meeting of the Global Navigation Satellite System Panel	Changes to GNSS SARPs and related guidance material concerning performance specifications for approach with vertical guidance (APV); global positioning system (GPS) selective availability (SA) discontinuation and clarification of signal power level; specifications for modernized GLObal NAvigation Satellite System (GLONASS-M); frequency planning criteria for ground-based augmentation system (GBAS) and a number of other enhancements.	23 February 2004 12 July 2004 25 November 2004
80	Eleventh Air Navigation Conference	Updates to the strategy for introduction and application of non-visual aids to approach and landing.	25 February 2005 11 July 2005 24 November 2005
81	Navigation Systems Panel (NSP)	a) Introduction of ground-based regional augmentation system (GRAS) Standards and Recommended Practices (SARPs); b) Amendments to SARPs for instrument landing system (ILS), distance measuring equipment (DME) and microwave landing system (MLS).	24 February 2006 17 July 2006 23 November 2006
82	Aeronautical Communications Panel (ACP)	Identification of the universal access transceiver (UAT) operating frequency.	26 February 2007 16 July 2007 22 November 2007
83	Secretariat with the assistance of the Required Navigation Performance and Special Operations Requirements Study Group (RNPSORSG); Navigation Systems Panel (NSP)	a) Amendments to definitions and Standards to align required navigation performance (RNP) and area navigation (RNAV) terminology with the performance-based navigation (PBN) concept; and b) Amendments to resolve certain navigation systems implementation issues and to reflect the evolution of existing global navigation satellite systems (GNSS) and equipment.	10 March 2008 20 July 2008 20 November 2008
84	Navigation Systems Panel (NSP)	a) update and reorganize the material on general provisions for radio navigation aids; b) amend obsolete or ambiguous provisions for the instrument landing system (ILS); c) amend obsolete or ambiguous provisions material for the very high frequency (VHF) omnidirectional radio range (VOR); d) delete material on testing of non-directional beacons (NDB), which duplicates existing guidance contained in Doc 8071, *Manual on Testing of Radio Navigation Aids*; e) reflect the results of the review of the distance monitoring equipment (DME) issues identified in Recommendations 6/14 and 6/15 of the Eleventh Air Navigation Conference; f) update the accuracy Standard in light of actual avionics performance, and clarify and simplify existing material; and g) address potential safety issues identified in the course of microwave landing system (MLS) Category III certification.	6 March 2009 20 July 2009 19 November 2009

Amendment	Source(s)		Subject(s)	*Adopted* *Effective* *Applicable*
85	Navigation Systems Panel (NSP)	a)	improvement of the instrument landing system (ILS) localizer signal quality at aerodromes where building or terrain reflections cause interference of the reflected signal with the desired signal;	26 February 2010 12 July 2010 18 November 2010
		b)	extension of global navigation satellite system (GNSS) Category I approach operations; and	
		c)	evolution of the GLObal NAvigation Satellite System (GLONASS).	

* Did not affect any Standards or Recommended Practices.

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3.1.3.2.2   The emission from the localizer shall be horizontally polarized. The vertically polarized component of the radiation on the course line shall not exceed that which corresponds to a DDM error of 0.016 when an aircraft is positioned on the course line and is in a roll attitude of 20 degrees from the horizontal.

3.1.3.2.2.1   For Facility Performance Category II localizers, the vertically polarized component of the radiation on the course line shall not exceed that which corresponds to a DDM error of 0.008 when an aircraft is positioned on the course line and is in a roll attitude of 20 degrees from the horizontal.

3.1.3.2.2.2   For Facility Performance Category III localizers, the vertically polarized component of the radiation within a sector bounded by 0.02 DDM either side of the course line shall not exceed that which corresponds to a DDM error of 0.005 when an aircraft is in a roll attitude of 20 degrees from the horizontal.

3.1.3.2.3   For Facility Performance Category III localizers, signals emanating from the transmitter shall contain no components which result in an apparent course line fluctuation of more than 0.005 DDM peak to peak in the frequency band 0.01 Hz to 10 Hz.

3.1.3.3   *Coverage*

Note.— Guidance material on localizer coverage is given in Attachment C, 2.1.10 and Figures C-7A, C-7B, C-8A and C-8B.

3.1.3.3.1   The localizer shall provide signals sufficient to allow satisfactory operation of a typical aircraft installation within the localizer and glide path coverage sectors. The localizer coverage sector shall extend from the centre of the localizer antenna system to distances of:

46.3 km (25 NM) within plus or minus 10 degrees from the front course line;

31.5 km (17 NM) between 10 degrees and 35 degrees from the front course line;

18.5 km (10 NM) outside of plus or minus 35 degrees from the front course line if coverage is provided;

except that, where topographical features dictate or operational requirements permit, the limits may be reduced down to 33.3 km (18 NM) within the plus or minus 10-degree sector and 18.5 km (10 NM) within the remainder of the coverage when alternative navigational means provide satisfactory coverage within the intermediate approach area. The localizer signals shall be receivable at the distances specified at and above a height of 600 m (2 000 ft) above the elevation of the threshold, or 300 m (1 000 ft) above the elevation of the highest point within the intermediate and final approach areas, whichever is the higher, except that, where needed to protect ILS performance and if operational requirements permit, the lower limit of coverage at angles beyond 15 degrees from the front course line shall be raised linearly from its height at 15 degrees to as high as 1 350 m (4 500 ft) above the elevation of the threshold at 35 degrees from the front course line. Such signals shall be receivable, to the distances specified, up to a surface extending outward from the localizer antenna and inclined at 7 degrees above the horizontal.

Note.— Where intervening obstacles penetrate the lower surface, it is intended that guidance need not be provided at less than line-of-sight heights .

3.1.3.3.2   In all parts of the coverage volume specified in 3.1.3.3.1, other than as specified in 3.1.3.3.2.1, 3.1.3.3.2.2 and 3.1.3.3.2.3, the field strength shall be not less than 40 microvolts per metre (minus 114 dBW/m^2).

Note.— This minimum field strength is required to permit satisfactory operational usage of ILS localizer facilities.

3.1.3.3.2.1   For Facility Performance Category I localizers, the minimum field strength on the ILS glide path and within the localizer course sector from a distance of 18.5 km (10 NM) to a height of 60 m (200 ft) above the horizontal plane containing the threshold shall be not less than 90 microvolts per metre (minus 107 dBW/m^2).

3.1.3.3.2.2   For Facility Performance Category II localizers, the minimum field strength on the ILS glide path and within the localizer course sector shall be not less than 100 microvolts per metre (minus 106 dBW/m^2) at a distance of 18.5 km (10 NM) increasing to not less than 200 microvolts per metre (minus 100 dBW/m^2) at a height of 15 m (50 ft) above the horizontal plane containing the threshold.

3.1.3.3.2.3   For Facility Performance Category III localizers, the minimum field strength on the ILS glide path and within the localizer course sector shall be not less than 100 microvolts per metre (minus 106 dBW/m^2) at a distance of 18.5 km (10 NM), increasing to not less than 200 microvolts per metre (minus 100 dBW/m^2) at 6 m (20 ft) above the horizontal plane containing the threshold. From this point to a further point 4 m (12 ft) above the runway centre line, and 300 m (1 000 ft) from the threshold in the direction of the localizer, and thereafter at a height of 4 m (12 ft) along the length of the runway in the direction of the localizer, the field strength shall be not less than 100 microvolts per metre (minus 106 dBW/m^2).

Note.— The field strengths given in 3.1.3.3.2.2 and 3.1.3.3.2.3 are necessary to provide the signal-to-noise ratio required for improved integrity.

3.1.3.3.3   **Recommendation.—** *Above 7 degrees, the signals should be reduced to as low a value as practicable.*

Note 1.— The requirements in 3.1.3.3.1, 3.1.3.3.2.1, 3.1.3.3.2.2 and 3.1.3.3.2.3 are based on the assumption that the aircraft is heading directly toward the facility.

Note 2.— Guidance material on significant airborne receiver parameters is given in 2.2.2 and 2.2.4 of Attachment C.

3.1.3.3.4   When coverage is achieved by a localizer using two radio frequency carriers, one carrier providing a radiation field pattern in the front course sector and the other providing a radiation field pattern outside that sector, the ratio of the two carrier signal strengths in space within the front course sector to the coverage limits specified at 3.1.3.3.1 shall not be less than 10 dB.

Note.— Guidance material on localizers achieving coverage with two radio frequency carriers is given in the Note to 3.1.3.11.2 and in 2.7 of Attachment C.

3.1.3.3.5   **Recommendation.—** *For Facility Performance Category III localizers, the ratio of the two carrier signal strengths in space within the front course sector should not be less than 16 dB.*

3.1.3.4   *Course structure*

3.1.3.4.1   For Facility Performance Category I localizers, bends in the course line shall not have amplitudes which exceed the following:

Zone	*Amplitude (DDM)* *(95% probability)*
Outer limit of coverage to ILS Point "A"	0.031
ILS Point "A" to ILS Point "B"	0.031 at ILS Point "A" decreasing at a linear rate to 0.015 at ILS Point "B"
ILS Point "B" to ILS Point "C"	0.015

3.1.3.4.2   For Facility Performance Categories II and III localizers, bends in the course line shall not have amplitudes which exceed the following:

b)   range rate error of any satellite — 0.02 m (0.07 ft) per second;

c)   range acceleration error of any satellite — 0.007 m (0.02 ft) per second-squared; and

d)   root-mean-square range error over all satellites — 6 m (20 ft).

3.7.3.1.2   *Availability*. The GPS SPS availability shall be as follows:

≥99 per cent horizontal service availability, average location (36 m 95 per cent threshold)

≥99 per cent vertical service availability, average location (77 m 95 per cent threshold)

≥90 per cent horizontal service availability, worst-case location (36 m 95 per cent threshold)

≥90 per cent vertical service availability, worst-case location (77 m 95 per cent threshold)

3.7.3.1.3   *Reliability*. The GPS SPS reliability shall be within the following limits:

a)   frequency of a major service failure — not more than three per year for the constellation (global average);

b)   reliability — at least 99.94 per cent (global average); and

c)   reliability — at least 99.79 per cent (single point average).

3.7.3.1.4   *Coverage*. The GPS SPS shall cover the surface of the earth up to an altitude of 3 000 kilometres.

Note.— Guidance material on GPS accuracy, availability, reliability and coverage is given in Attachment D, 4.1.

3.7.3.1.5   *Radio frequency (RF) characteristics*

Note.— Detailed RF characteristics are specified in Appendix B, 3.1.1.1.

3.7.3.1.5.1   *Carrier frequency*. Each GPS satellite shall broadcast an SPS signal at the carrier frequency of 1 575.42 MHz (GPS L1) using code division multiple access (CDMA).

Note.— A new civil frequency will be added to the GPS satellites and will be offered by the United States for critical safety-of-life applications. SARPs for this signal may be developed at a later date.

3.7.3.1.5.2   *Signal spectrum*. The GPS SPS signal power shall be contained within a ±12 MHz band (1 563.42 – 1 587.42 MHz) centred on the L1 frequency.

3.7.3.1.5.3   *Polarization*. The transmitted RF signal shall be right-hand (clockwise) circularly polarized.

3.7.3.1.5.4   *Signal power level*. Each GPS satellite shall broadcast SPS navigation signals with sufficient power such that, at all unobstructed locations near the ground from which the satellite is observed at an elevation angle of 5 degrees or higher, the level of the received RF signal at the output of a 3 dBi linearly-polarized antenna is within the range of −158.5 dBW to −153 dBW for all antenna orientations orthogonal to the direction of propagation.

3.7.3.1.5.5   *Modulation*. The SPS L1 signal shall be bipolar phase shift key (BPSK) modulated with a pseudo random noise (PRN) 1.023 MHz coarse/acquisition (C/A) code. The C/A code sequence shall be repeated each millisecond. The transmitted PRN code sequence shall be the Modulo-2 addition of a 50 bits per second navigation message and the C/A code.

3.7.3.1.6   *GPS time*. GPS time shall be referenced to UTC (as maintained by the U.S. Naval Observatory).

3.7.3.1.7   *Coordinate system*. The GPS coordinate system shall be WGS-84.

3.7.3.1.8   *Navigation information*. The navigation data transmitted by the satellites shall include the necessary information to determine:

a)   satellite time of transmission;

b)   satellite position;

c)   satellite health;

d)   satellite clock correction;

e)   propagation delay effects;

f)   time transfer to UTC; and

g)   constellation status.

Note.— Structure and contents of data are specified in Appendix B, 3.1.1.2 and 3.1.1.3, respectively.

3.7.3.2   *GLONASS Channel of Standard Accuracy (CSA) (L1)*

Note.— In this section, the term GLONASS refers to all satellites in the constellation. Standards relating only to GLONASS-M satellites are qualified accordingly.

3.7.3.2.1   *Space and control segment accuracy*

Note.— The following accuracy Standards do not include atmospheric or receiver errors as described in Attachment D, 4.2.2.

3.7.3.2.1.1   *Positioning accuracy*. The GLONASS CSA position errors shall not exceed the following limits:

	Global average 95% of the time	Worst site 95% of the time
Horizontal position error	5 m (17 ft)	12 m (40 ft)
Vertical position error	9 m (29 ft)	25 m (97 ft)

3.7.3.2.1.2   *Time transfer accuracy*. The GLONASS CSA time transfer errors shall not exceed 700 nanoseconds 95 per cent of the time.

3.7.3.2.1.3   *Range domain accuracy*. The range domain error shall not exceed the following limits:

a)   range error of any satellite — 18 m (59.7 ft);

b)   range rate error of any satellite — 0.02 m (0.07 ft) per second;

c)   range acceleration error of any satellite — 0.007 m (0.023 ft) per second squared;

d)   root-mean-square range error over all satellites — 6 m (19.9 ft).

3.7.3.2.2   *Availability*. The GLONASS CSA availability shall be as follows:

a)   ≥99 per cent horizontal service availability, average location (12 m, 95 per cent threshold);

b)   ≥99 per cent vertical service availability, average location (25 m, 95 per cent threshold);

c)   ≥90 per cent horizontal service availability, worst-case location (12 m, 95 per cent threshold);

d)   ≥90 per cent vertical service availability, worst-case location (25 m, 95 per cent threshold).

3.7.3.2.3   *Reliability*. The GLONASS CSA reliability shall be within the following limits:

a)   frequency of a major service failure — not more than three per year for the constellation (global average); and

b)   reliability — at least 99.7 per cent (global average).

3.7.3.2.4   *Coverage*. The GLONASS CSA shall cover the surface of the earth up to an altitude of 2 000 km.

Note.— Guidance material on GLONASS accuracy, availability, reliability and coverage is given in Attachment D, 4.2.

3.7.3.2.5   *RF characteristics*

Note.— Detailed RF characteristics are specified in Appendix B, 3.2.1.1.

3.7.3.2.5.1   *Carrier frequency*. Each GLONASS satellite shall broadcast CSA navigation signal at its own carrier frequency in the L1 (1.6 GHz) frequency band using frequency division multiple access (FDMA).

Note 1.— GLONASS satellites may have the same carrier frequency but in this case they are located in antipodal slots of the same orbital plane.

Note 2.— GLONASS-M satellites will broadcast an additional ranging code at carrier frequencies in the L2 (1.2 GHz) frequency band using FDMA.

3.7.3.2.5.2   *Signal spectrum*. GLONASS CSA signal power shall be contained within a ±5.75 MHz band centred on each GLONASS carrier frequency.

3.7.3.2.5.3   *Polarization*. The transmitted RF signal shall be right-hand circularly polarized.

3.7.3.2.5.4   *Signal power level*. Each GLONASS satellite shall broadcast CSA navigation signals with sufficient power such that, at all unobstructed locations near the ground from which the satellite is observed at an elevation angle of 5 degrees or higher, the level of the received RF signal at the output of a 3 dBi linearly polarized antenna is within the range of −161 dBW to −155.2 dBW for all antenna orientations orthogonal to the direction of propagation.

Note 1.— The power limit of 155.2 dBW is based on the predetermined characteristics of a user antenna, atmospheric losses of 0.5 dB and an error of an angular position of a satellite that does not exceed one degree (in the direction causing the signal level to increase).

Note 2.— GLONASS-M satellites will also broadcast a ranging code on L2 with sufficient power such that, at all unobstructed locations near the ground from which the satellite is observed at an elevation angle of 5 degrees or higher, the level of the received RF signal at the output of a 3 dBi linearly polarized antenna is not less then −167 dBW for all antenna orientations orthogonal to the direction of propagation.

3.7.3.2.5.5   *Modulation*

3.7.3.2.5.5.1   Each GLONASS satellite shall transmit at its carrier frequency the navigation RF signal using a BPSK-modulated binary train. The phase shift keying of the carrier shall be performed at π-radians with the maximum error ±0.2 radian. The pseudo-random code sequence shall be repeated each millisecond.

3.7.3.2.5.5.2   The modulating navigation signal shall be generated by the Modulo-2 addition of the following three binary signals:

a)   ranging code transmitted at 511 kbits/s;

b)   navigation message transmitted at 50 bits/s; and

c)   100 Hz auxiliary meander sequence.

3.7.3.2.6   *GLONASS time.* GLONASS time shall be referenced to UTC(SU) (as maintained by the National Time Service of Russia).

3.7.3.2.7   *Coordinate system*. The GLONASS coordinate system shall be PZ-90.

Note.— Conversion from the PZ-90 coordinate system used by GLONASS to the WGS-84 coordinates is defined in Appendix B, 3.2.5.2.

3.7.3.2.8   *Navigation information.* The navigation data transmitted by the satellite shall include the necessary information to determine:

a)   satellite time of transmission;

b)   satellite position;

c)   satellite health;

d)   satellite clock correction;

e)   time transfer to UTC; and

f)   constellation status.

Note.— Structure and contents of data are specified in Appendix B, 3.2.1.2 and 3.2.1.3, respectively.

3.7.3.3   *Aircraft-based augmentation system (ABAS)*

3.7.3.3.1   *Performance*. The ABAS function combined with one or more of the other GNSS elements and both a fault-free GNSS receiver and fault-free aircraft system used for the ABAS function shall meet the requirements for accuracy, integrity, continuity and availability as stated in 3.7.2.4.

3.7.3.4   *Satellite-based augmentation system (SBAS)*

3.7.3.4.1   *Performance*. SBAS combined with one or more of the other GNSS elements and a fault-free receiver shall meet the requirements for system accuracy, integrity, continuity and availability for the intended operation as stated in 3.7.2.4.

3.7.3.5.4.5 *Power transmitted in adjacent channel*s. The amount of power during transmission under all operating conditions when measured over a 25 kHz bandwidth centred on the ith adjacent channel shall not exceed the values shown in Table 3.7.3.5-1 (located at the end of section 3.7).

3.7.3.5.4.6 *Unwanted emissions.* Unwanted emissions, including spurious and out-of-band emissions, shall be compliant with the levels shown in Table 3.7.3.5-2 (located at the end of section 3.7). The total power in any VDB harmonic or discrete signal shall not be greater than –53 dBm.

3.7.3.5.5 *Navigation information.* The navigation data transmitted by GBAS shall include the following information:

a) pseudo-range corrections, reference time and integrity data;

b) GBAS-related data;

c) final approach segment data when supporting precision approach; and

d) predicted ranging source availability data.

Note.— Structure and contents of data are specified in Appendix B, 3.6.3.

3.7.3.6 *Aircraft GNSS receiver*

3.7.3.6.1 The aircraft GNSS receiver shall process the signals of those GNSS elements that it intends to use as specified in Appendix B, 3.1 (for GPS), Appendix B, 3.2 (for GLONASS), Appendix B, 3.3 (for combined GPS and GLONASS), Appendix B, 3.5 (for SBAS) and Appendix B, 3.6 (for GBAS and GRAS).

3.7.4   Resistance to interference

3.7.4.1 GNSS shall comply with performance requirements defined in 3.7.2.4 and Appendix B, 3.7 in the presence of the interference environment defined in Appendix B, 3.7.

Note.— GPS and GLONASS operating in the frequency band 1 559 – 1 610 MHz are classified by the ITU as providing a radio navigation satellite service (RNSS) and aeronautical radio navigation service (ARNS) and are afforded special spectrum protection status for RNSS. In order to achieve the performance objectives for precision approach guidance to be supported by the GNSS and its augmentations, RNSS/ARNS is intended to remain the only global allocation in the 1 559 – 1 610 MHz band and emissions from systems in this and adjacent frequency bands are intended to be tightly controlled by national and/or international regulation.

3.7.5   Database

Note.— SARPs applicable to aeronautical data are provided in Annex 4, Annex 11, Annex 14 and Annex 15.

3.7.5.1 Aircraft GNSS equipment that uses a database shall provide a means to:

a) update the electronic navigation database; and

b) determine the Aeronautical Information Regulation and Control (AIRAC) effective dates of the aeronautical database.

Note.— Guidance material on the need for a current navigation database in aircraft GNSS equipment is provided in Attachment D, 11.

Table 3.7.2.4-1   Signal-in-space performance requirements

Typical operation	Accuracy horizontal 95% (Notes 1 and 3)	Accuracy vertical 95% (Notes 1 and 3)	Integrity (Note 2)	Time-to-alert (Note 3)	Continuity (Note 4)	Availability (Note 5)
En-route	3.7 km (2.0 NM)	N/A	$1 - 1 \times 10^{-7}$/h	5 min	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
En-route, Terminal	0.74 km (0.4 NM)	N/A	$1 - 1 \times 10^{-7}$/h	15 s	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
Initial approach, Intermediate approach, Non-precision approach (NPA), Departure	220 m (720 ft)	N/A	$1 - 1 \times 10^{-7}$/h	10 s	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
Approach operations with vertical guidance (APV-I)	16.0 m (52 ft)	20 m (66 ft)	$1 - 2 \times 10^{-7}$ in any approach	10 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999
Approach operations with vertical guidance (APV-II)	16.0 m (52 ft)	8.0 m (26 ft)	$1 - 2 \times 10^{-7}$ in any approach	6 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999
Category I precision approach (Note 7)	16.0 m (52 ft)	6.0 m to 4.0 m (20 ft to 13 ft) (Note 6)	$1 - 2 \times 10^{-7}$ in any approach	6 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999

NOTES.—

1. The 95th percentile values for GNSS position errors are those required for the intended operation at the lowest height above threshold (HAT), if applicable. Detailed requirements are specified in Appendix B and guidance material is given in Attachment D, 3.2.

2. The definition of the integrity requirement includes an alert limit against which the requirement can be assessed. For Category I precision approach, a vertical alert limit (VAL) greater than 10 m for a specific system design may only be used if a system-specific safety analysis has been completed. Further guidance on the alert limits is provided in Attachment D, 3.3.6 to 3.3.10. These alert limits are:

Typical operation	Horizontal alert limit	Vertical alert limit
En-route (oceanic/continental low density)	7.4 km (4 NM)	N/A
En-route (continental)	3.7 km (2 NM)	N/A
En-route, Terminal	1.85 km (1 NM)	N/A
NPA	556 m (0.3 NM)	N/A
APV-I	40 m (130 ft)	50 m (164 ft)
APV- II	40 m (130 ft)	20.0 m (66 ft)
Category I precision approach	40 m (130 ft)	35.0 m to 10.0 m (115 ft to 33 ft)

3. The accuracy and time-to-alert requirements include the nominal performance of a fault-free receiver.

4. Ranges of values are given for the continuity requirement for en-route, terminal, initial approach, NPA and departure operations, as this requirement is dependent upon several factors including the intended operation, traffic density, complexity of airspace and availability of alternative navigation aids. The lower value given is the minimum requirement for areas with low traffic density and airspace complexity. The higher value given is appropriate for areas with high traffic density and airspace complexity (see Attachment D, 3.4.2). Continuity requirements for APV and Category I operations apply to the average risk (over time) of loss of service, normalized to a 15-second exposure time (see Attachment D, 3.4.3).

3.2.5.2   *Conversion between PZ-90 and WGS-84.* The following conversion parameters shall be used to obtain position coordinates in WGS-84 from position coordinates in PZ-90 (Version 2):

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{WGS-84} = \begin{bmatrix} -0.36 \\ +0.08 \\ +0.18 \end{bmatrix} + \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{PZ-90}$$

Note.— X, Y and Z are expressed in metres.

3.2.5.2.1   The conversion error shall not exceed 0.1 metres (1 sigma) along each coordinate axis.

3.3   Combined use of GPS and GLONASS

3.3.1   AIRCRAFT ELEMENTS

3.3.1.1   *Combined GNSS receiver.* The combined GNSS receiver shall process signals from GPS and GLONASS in accordance with the requirements specified in 3.1.3.1, GPS (GNSS) receiver, and 3.2.3.1, GLONASS (GNSS) receiver.

3.3.1.1.1   *Resistance to interference.* The combined GNSS receiver shall meet the individual requirements for GPS and GLONASS as specified in 3.7.

3.3.1.2   *Antenna(e).* GPS and GLONASS signals shall be received through one or more antennae.

Note.— Performance characteristics of GNSS receiver antennae are defined in 3.8.

3.3.1.3   *Conversion between coordinate systems.* Position information provided by a combined GPS and GLONASS receiver shall be expressed in WGS-84 earth coordinates. The GLONASS satellite position, obtained in PZ-90 coordinate frame, shall be converted to account for the differences between WGS-84 and PZ-90, as defined in 3.2.5.2.

3.3.1.4   *GPS/GLONASS time.* When combining measurements from GLONASS and GPS, the difference between GLONASS time and GPS time shall be taken into account.

3.4   Aircraft-based augmentation system (ABAS)

Note.— Guidance on ABAS is given in Attachment D, section 5.

3.5   Satellite-based augmentation system (SBAS)

3.5.1   GENERAL

Note.— Parameters in this section are defined in WGS-84.

3.5.2   RF CHARACTERISTICS

3.5.2.1   *Carrier frequency stability*. The short-term stability of the carrier frequency (square root of the Allan Variance) at the output of the satellite transmit antenna shall be better than 5×10^{-11} over 1 to 10 seconds.

3.5.2.2   *Carrier phase noise*. The phase noise spectral density of the unmodulated carrier shall be such that a phase locked loop of 10 Hz one-sided noise bandwidth is able to track the carrier to an accuracy of 0.1 radian (1 sigma).

3.5.2.3   *Spurious emissions*. Spurious emissions shall be at least 40 dB below the unmodulated carrier power over all frequencies.

3.5.2.4   *Code/carrier frequency coherence*. The short-term (less than 10 seconds) fractional frequency difference between the code phase rate and the carrier frequency shall be less than 5×10^{-11} (standard deviation). Over the long term (less than 100 seconds), the difference between the change in the broadcast code phase, converted to carrier cycles by multiplying the number of code chips by 1 540, and the change in the broadcast carrier phase, in cycles, shall be within one carrier cycle (standard deviation).

Note.— This applies to the output of the satellite transmit antenna and does not include code/carrier divergence due to ionospheric refraction in the downlink propagation path.

3.5.2.5   *Correlation loss*. The loss in the recovered signal power due to imperfections in the signal modulation and waveform distortion shall not exceed 1 dB.

Note.— The loss in signal power is the difference between the broadcast power in a 2.046 MHz bandwidth and the signal power recovered by a noise-free, loss-free receiver with 1-chip correlator spacing and a 2.046 MHz bandwidth.

3.5.2.6   *Maximum code phase deviation*. The maximum uncorrected code phase of the broadcast signal shall not deviate from the equivalent SBAS network time (SNT) by more than $\pm 2^{-20}$ seconds.

3.5.2.7   *Code/data coherence*. Each 2-millisecond symbol shall be synchronous with every other code epoch.

3.5.2.8   *Message synchronization*. The leading edge of the first symbol that depends on the first bit of the current message shall be broadcast from the SBAS satellite synchronous with a 1-second epoch of SNT.

3.5.2.9   *Convolutional encoding*. A 250-bit-per-second data stream shall be encoded at a rate of 2 symbols per bit using a convolutional code with a constraint length of 7 to yield 500 symbols per second. The convolutional encoder logic arrangement shall be as illustrated in Figure B-11 with the G3 output selected for the first half of each 4-millisecond data bit period.

3.5.2.10   *Pseudo-random noise (PRN) codes*. Each PRN code shall be a 1 023-bit Gold code which is itself the Modulo-2 addition of two 1 023-bit linear patterns, G1 and $G2_i$. The $G2_i$ sequence shall be formed by delaying the G2 sequence by the associated integer number of chips as illustrated in Table B-23. Each of the G1 and G2 sequences shall be defined as the output of stage 10 of a 10-stage shift register, where the input to the shift register is the Modulo-2 addition of the following stages of the shift register:

a)   G1: stages 3 and 10; and

b)   G2: stages 2, 3, 6, 8, 9 and 10.

The initial state for the G1 and G2 shift registers shall be "1111111111".

b) localizer course bends due to static objects equals plus or minus 4μ*A*. Limit plus or minus 5μ*A*. Therefore allowance for moving objects to define localizer sensitive area is

$$\sqrt{5^2 - 4^2} = 3\mu A$$

In case b) the sensitive area would be larger, thus keeping interfering objects further away from the runway so that they produce 3μ*A* or less distortion of the localizer beam. The same principle is applied to the glide path sensitive area.

2.1.10   *Reducing localizer bends and areas with insufficient difference in depth of modulation (DDM)*

2.1.10.1   *Introduction.* Owing to site effects at certain locations, it is not always possible to produce, with simple standard ILS installations, localizer courses that are sufficiently free from troublesome bends or irregularities. If this is the case, it is highly preferable to use two radio frequency carriers to provide the standard coverage and signal characteristics. Additional guidance on two radio frequency carrier coverage is provided in 2.7. If standard coverage requirements still cannot be met, reducing radiation in the direction of objects and accepting an increase of the lower vertical coverage boundaries as permitted in Chapter 3, 3.1.3.3.1 may be employed.

2.1.10.2   *Reducing standard localizer coverage.* When using the coverage reduction option defined in Chapter 3, 3.1.3.3.1, care needs to be taken to ensure that the reduced coverage volume is consistent with the minimum altitudes published for the instrument approach procedure. Additionally, normal vectoring operations should not be terminated and a clearance to intercept the localizer should not be issued until within the promulgated coverage area. This is sometimes referred to as the operational service volume.

2.1.10.2.1   *Operational considerations from an air traffic management perspective.* Instrument approach procedures must be designed to take into account any reduction in localizer coverage permitted by the Standard in Chapter 3, 3.1.3.3.1. This can be done either by ensuring that the procedure remains within localizer coverage or by providing alternative means to navigate. Consequently, a significant portion (3.7 km (2 NM) minimum) of the initial segment must be within localizer coverage. Localizer coverage needs to be available sufficiently in advance of the area where controllers usually give the approach or intercept clearance to permit pilots to verify the Morse code identification (IDENT).

2.1.10.2.2   *Operational considerations from a pilot/aircraft perspective.* For aircraft equipped with automatic flight control systems (AFCS), localizer coverage needs to be available prior to the activation of the AFCS intercept mode (manual or automatic flight) and sufficiently in advance of the area where controllers usually give the approach or intercept clearance to permit checking the IDENT signal. When flying manually or when using an AFCS, pilots normally check the IDENT of the ILS facility and then wait to arm the mode enabling localizer intercept turn initiation and capture until after receiving the approach or intercept clearance. Ideally, additional aids (if included in the approach procedure) should permit a determination of the relationship between the aircraft position and the localizer front course line by the pilot.

2.2   ILS airborne receiving equipment

2.2.1   To ensure that the required operational objectives are achieved, it is necessary for the airborne receiving equipment to meet defined performance standards.

Note.— The relevant minimum operational performance standards for ILS receivers are detailed in RTCA DO-195 (1986) and EUROCAE ED-46B (including Amendments Nos. 1 and 2) for the localizer, in RTCA DO-143 (1970) and EUROCAE 1/WG 7/70 for the marker beacon, and in RTCA DO-192 (1986) and EUROCAE ED-47B (including Amendment No. 1) for the glide path receivers.

2.2.2   *Immunity performance of ILS localizer receiving systems to interference from VHF FM broadcast signals*

2.2.2.1   With reference to Note 2 of 3.1.4.2, Chapter 3, the immunity performance defined there must be measured against an agreed measure of degradation of the receiving system's normal performance, and in the presence of, and under standard conditions for the input wanted signal. This is necessary to ensure that the testing of receiving equipment on the bench can be performed to a repeatable set of conditions and results and to facilitate their subsequent approval. Tests have shown that FM interference signals may affect both course guidance and flag current, and their effects vary depending on the DDM of the wanted signal which is applied. Additional information can be found in ITU Recommendation ITU-R SM.1140, *Test procedures for measuring receiver characteristics used for determining compatibility between the sound-broadcasting service in the band of about 87–108 MHz and the aeronautical services in the band 108–118 MHz.*

Note.— ITU Recommendation ITU-R SM.1140 can be found in the Manual on Testing of Radio Navigation Aids *(Doc 8071), Volume I.*

2.2.2.2   Commonly agreed methodology and formulae should be used to assess potential incompatibilities to receivers meeting the general interference immunity criteria specified in Chapter 3, 3.1.4. The formulae provide clarification of immunity interference performance of spurious emission (type A1) interference, out-of-band channel (type A2) interference, two-signal and three-signal third order (type B1) interference, and overload/desensitization (type B2) interference. Additional information can be found in ITU Recommendation 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.*

Note.— ITU Recommendation ITU-R SM.1009-1 can be found in Doc 8071, Volume I.

2.2.3   *Localizer and glide path antenna polarization*

2.2.3.1   Over the localizer and glide path frequency bands, respectively, the reception of vertically polarized signals from the forward direction with respect to the localizer and glide path antenna should be at least 10 dB below the reception of horizontally polarized signals from the same direction.

2.3   Alarm conditions for ILS airborne equipment

2.3.1   Ideally, a receiver alarm system such as a visual flag should warn a pilot of any unacceptable malfunctioning conditions which might arise within either the ground or airborne equipments. The extent to which such an ideal may be satisfied is specified below.

2.3.2   The alarm system is actuated by the sum of two modulation depths and, therefore, the removal of the ILS course modulation components from the radiated carrier should result in the actuation of the alarm.

2.3.3   The alarm system should indicate to the pilot and to any other airborne system which may be utilizing the localizer and glide path data, the existence of any of the following conditions:

a)   the absence of any RF signal as well as the absence of simultaneous 90 Hz and 150 Hz modulation;

b)   the percentage modulation of either the 90 Hz or 150 Hz signal reduction to zero with the other maintained at its normal 20 per cent and 40 per cent modulation respectively for the localizer and glide path;

Note.— It is expected that the localizer alarm occur when either the 90 Hz or 150 Hz modulation is reduced to 10 per cent with the other maintained at its normal 20 per cent. It is expected that the glide path alarm occur when either the 90 Hz or 150 Hz modulation is reduced to 20 per cent with the other maintained at its normal 40 per cent.

2.3.3.1   The alarm indication should be easily discernible and visible under all normal flight deck conditions. If a flag is used, it should be as large as practicable commensurate with the display.

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2.4   Guidance for the siting, elevation, adjustment
and coverage of glide path equipment

</div>

2.4.1   *Lateral placement.* The lateral placement of the glide path antenna system with respect to the runway centre line is normally not less than 120 m (400 ft). In deciding the lateral placement of the glide path antenna, account should be taken of the appropriate provisions of Annex 14 with regard to obstacle clearance surfaces and objects on strips for runways.

2.4.2   *ILS glide path curvature.* In many cases, the ILS glide path is formed as a conic surface originating at the glide path aerial system. Owing to the lateral placement of the origin of this conic surface from the runway centre line, the locus of the glide path in the vertical plane along the runway centre line is a hyperbola. Curvature of the glide path occurs in the threshold region and progressively increases until touchdown. To limit the amount of curvature, the glide path antenna should not be located at an excessive lateral distance from the runway centre line.

2.4.3   *Procedure design.* Chapter 3, 3.1.5.1 provides Standards and Recommended Practices for the glide path angle and the height of the ILS reference datum. The longitudinal position of the glide path antenna with respect to the runway threshold is established in order to provide the selected glide path angle and desired ILS reference datum height for the precision approach procedure designed for that runway. The precision approach procedure design may be modified to meet obstacle clearance requirements or to account for technical siting constraints for the glide path antenna (for example, crossing runways or taxiways). The procedure designer will take into account the acceptable glide path angle, threshold crossing height and runway length available as they relate to the type of aircraft expected to use the precision approach procedure.

2.4.4   *Longitudinal placement.* Assuming that the reflecting surface in the beam forming area can be approximated by a planar surface with appropriate lateral and longitudinal slopes, the required longitudinal position of the glide path antenna is then a function of the ILS reference datum above the runway threshold and of the projection of the glide path reflection plane along the runway centre line . This situation is described pictorially in Figure C-5. In this figure, the line OP is defined by the intersection between the glide path reflection plane and the vertical plane along the runway centre line, and point O is at the same longitudinal distance from the threshold as the glide path antenna. Depending on the height and orientation of the reflection plane, point O may be above or below the runway surface.

For a planar reflecting surface, the longitudinal position of the glide path antenna is then calculated as follows:

$$D = \frac{H + Y}{\tan(\theta) + \tan(\alpha)}$$

where

     D =   the horizontal distance between O and P (equivalent to the longitudinal distance from the glide path antenna to the runway threshold);

     H =   the nominal height of the ILS reference datum above the runway threshold;

     Y =   the vertical height of the runway threshold above P';

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2.5   Diagrams (Figures C-6 to C-12 illustrate certain of the Standards contained in Chapter 3)

The accompanying graphs illustrate a method that can be used to measure the relative phase relationship between the 90 Hz and 150 Hz tones. The upper portion of each graph shows the individual waveforms and their relationship at the limit of phase differences allowed by Chapter 3, 3.1.3.5.3.3 and 3.1.5.5.3. The lower portion shows the combined waveforms as would be seen on an oscilloscope. By taking the ratio of P_1 and P_2, which gives a value equal to or less than unity, it is possible to determine if the phasing is within tolerance. For Categories I and II ILS the ratio should be greater than 0.903 and for Category III the ratio should be greater than 0.951.

Figure C-6.   ILS wave forms illustrating relative audio phasing of the 90 Hz and 150 Hz tones

When topographical features dictate or operational requirements and alternative navigation facilities permit, the following coverage may be provided:

Note.— If coverage as prescribed in Chapter 3, 3.1.3.3.1 is required outside the plus or minus 35-degree sector, this is provided to 18.5 km (10 NM), as indicated by the broken arc above.
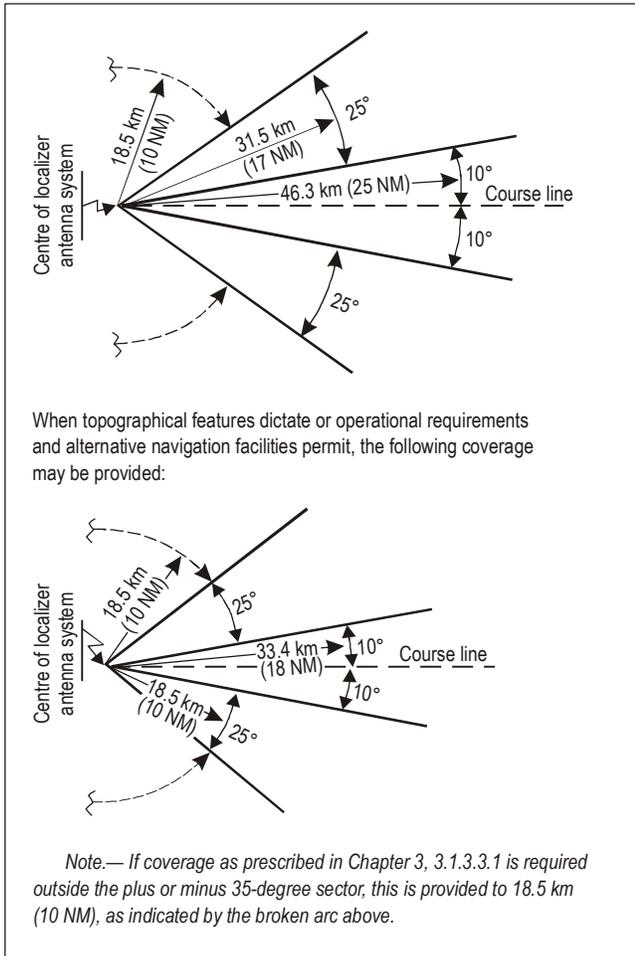
Figure C-7A.   Localizer coverage with respect to azimuth
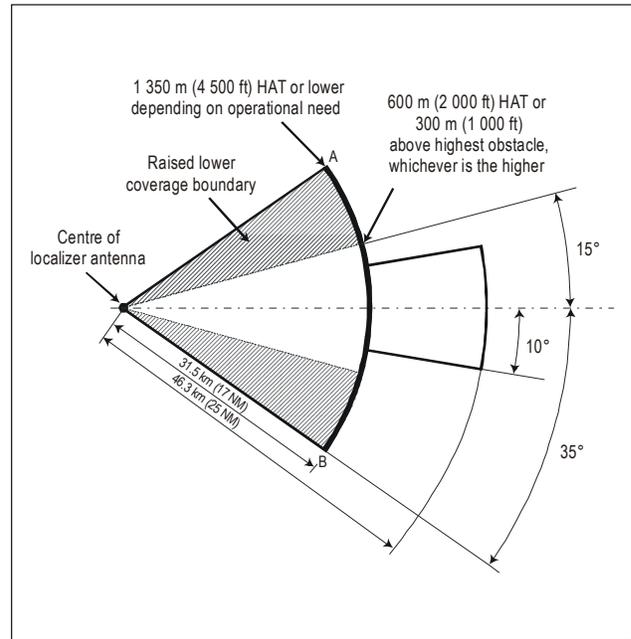
Figure C-7B.   Reduced localizer coverage with respect to azimuth

D = Distances and azimuths specified in 3.1.3.3.1

Note.— The point P is either 600 m (2 000 ft) above the elevation of the threshold, or 300 m (1 000 ft) above the elevation of the highest point within the intermediate and final approach areas, whichever is the higher.
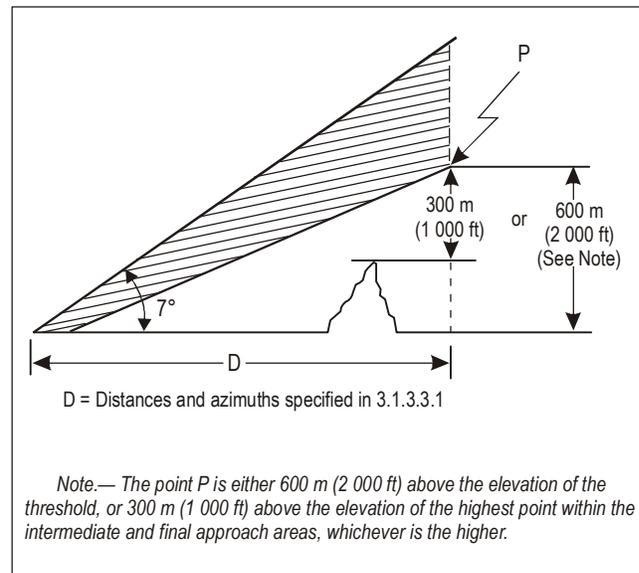
Figure C-8A.   Localizer coverage with respect to elevation
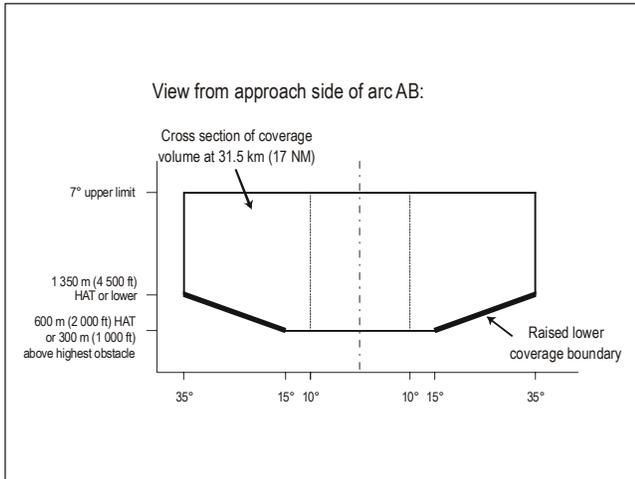
**Figure C-8B.   Reduced localizer coverage
with respect to elevation**

(a) Azimuthal cover

(b) Elevation cover

R = Point at which the downward-extended straight portion
of the ILS glide path intersects the runway centre line.

θ = (ILS) glide path angle.
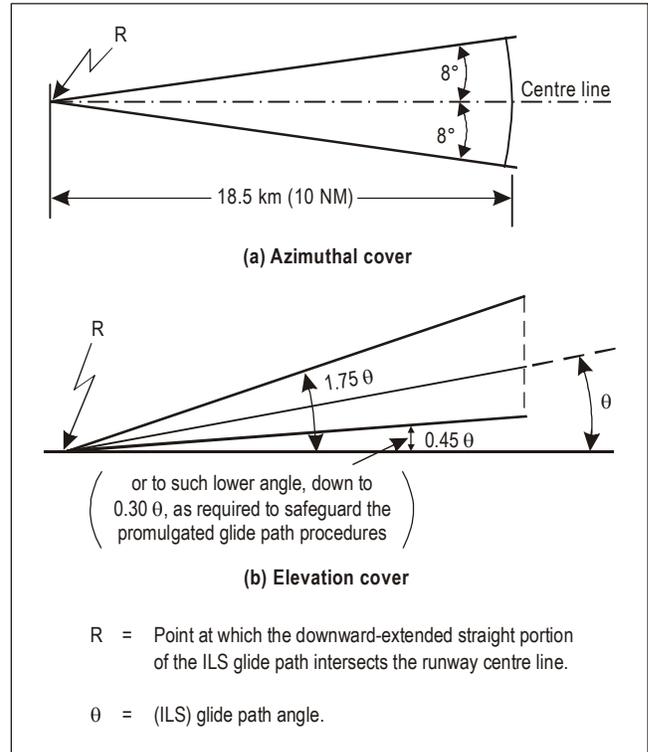
Figure 10.   Glide path coverage

A — Course sector ≤ 6 degrees
B — Displacement sensitivity = 0.00145 DDM/metre (0.00044 DDM/foot)
   at the ILS reference datum
C — DDM increases linearly from zero to value of 0.180, and then
   ≥ 0.180
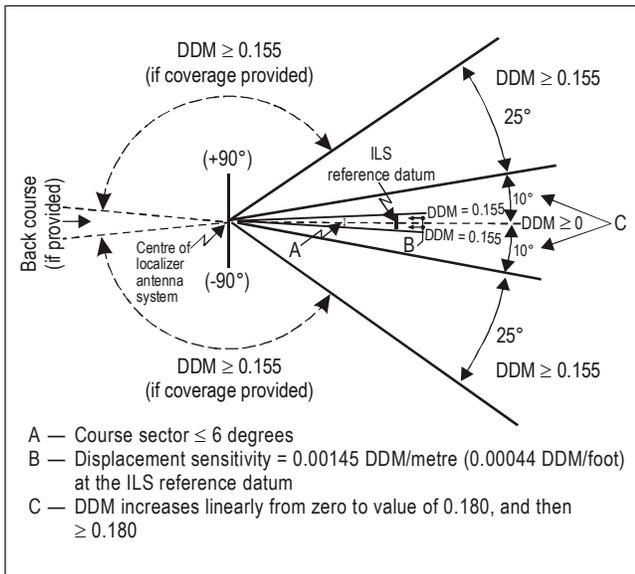
**Figure 9.   Difference in depth of modulation and
displacement sensitivity**
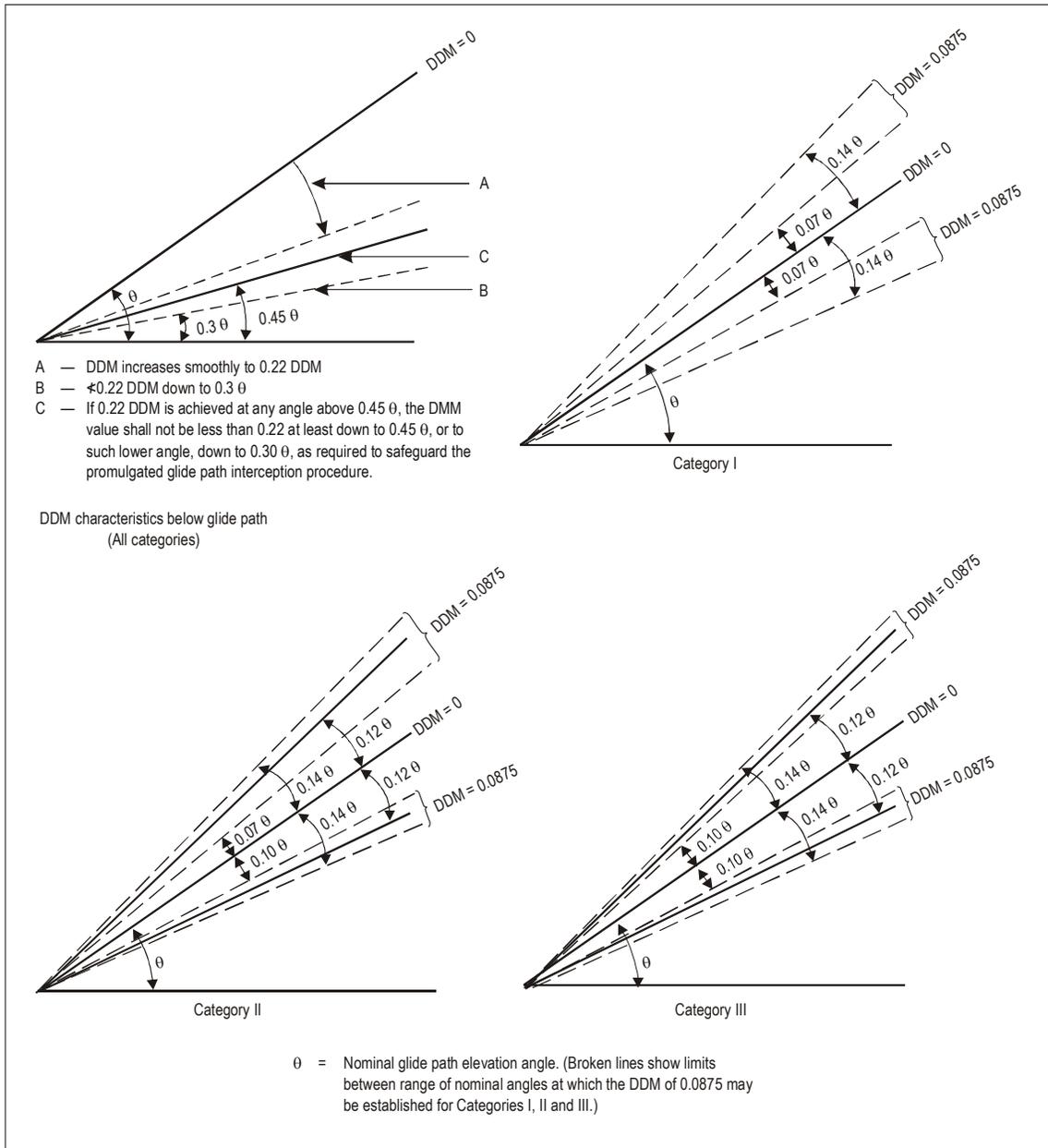
Figure C-11.   Glide path — difference in depth of modulation

ATTACHMENT D.   INFORMATION AND MATERIAL FOR GUIDANCE IN THE APPLICATION OF THE GNSS STANDARDS AND RECOMMENDED PRACTICES

1.   Definitions

Bi-binary. Bi-binary is known as "Manchester Encoding". It is sometimes referred to as "Differential Manchester Encoding". Using this system, it is the transition of the edge that determines the bit.

Chip. A single digital bit of the output of a pseudo-random bit sequence.

Gold code. A class of unique codes used by GPS, which exhibit bounded cross-correlation and off-peak auto-correlation values.

Selective availability (SA). A set of techniques for denying the full accuracy and selecting the level of positioning, velocity and time accuracy of GPS available to users of the standard positioning service signal.

Note.— GPS SA was discontinued at midnight on 1 May 2000.

2.   General

Standards and Recommended Practices for GNSS contain provisions for the elements identified in Chapter 3, 3.7.2.2. Additional implementation guidance is provided in the *Global Navigation Satellite System (GNSS) Manual* (Doc 9849).

Note.— Except where specifically annotated, GBAS guidance material applies to GRAS.

3.   Navigation system performance requirements

3.1   Introduction

3.1.1   Navigation system performance requirements are defined in the *Performance-based Navigation (PBN) Manual* (Doc 9613) for a single aircraft and for the total system which includes the signal-in-space, the airborne equipment and the ability of the aircraft to fly the desired trajectory. These total system requirements were used as a starting point to derive GNSS signal-in-space performance requirements. In the case of GNSS, degraded configurations which may affect multiple aircraft are to be considered. Therefore, certain signal-in-space performance requirements are more stringent to take into account multiple aircraft use of the system.

3.1.2   Two types of approach and landing operations with vertical guidance (APV), APV-I and APV-II, use vertical guidance relative to a glide path, but the facility or navigation system may not satisfy all of the requirements associated with precision approach. These operations combine the lateral performance equal to that of an ILS Category I localizer with different levels of vertical guidance. Both APV-I and APV-II provide access benefits relative to a non-precision approach, and the service that is provided depends on the operational requirements and the SBAS infrastructure. APV-I and APV-II exceed the requirements (lateral and vertical) for current RNAV approaches using barometric altimetry, and the relevant on-board equipment will therefore be suitable for the conduct of barometric VNAV APV and RNAV non-precision approaches.

3.2   Accuracy

3.2.1   GNSS position error is the difference between the estimated position and the actual position. For an estimated position at a specific location, the probability should be at least 95 per cent that the position error is within the accuracy requirement.

3.2.2   Stationary, ground-based systems such as VOR and ILS have relatively repeatable error characteristics, so that performance can be measured for a short period of time (e.g. during flight inspection) and it is assumed that the system accuracy does not change after the test. However, GNSS errors change over time. The orbiting of satellites and the error characteristics of GNSS result in position errors that can change over a period of hours. In addition, the accuracy itself (the error bound with 95 per cent probability) changes due to different satellite geometries. Since it is not possible to continually measure system accuracy, the implementation of GNSS demands increased reliance on analysis and characterization of errors. Assessment based on measurements within a sliding time window is not suitable for GNSS.

3.2.3   The error for many GNSS architectures changes slowly over time, due to filtering in the augmentation systems and in the user receiver. This results in a small number of independent samples in periods of several minutes. This issue is very important for precision approach applications, because it implies that there is a 5 per cent probability that the position error can exceed the required accuracy for an entire approach. However, due to the changing accuracy described in 3.2.2, this probability is usually much lower.

3.2.4   The 95 per cent accuracy requirement is defined to ensure pilot acceptance, since it represents the errors that will typically be experienced. The GNSS accuracy requirement is to be met for the worst-case geometry under which the system is declared to be available. Statistical or probabilistic credit is not taken for the underlying probability of particular ranging signal geometry.

3.2.5   Therefore, GNSS accuracy is specified as a probability for each and every sample, rather than as a percentage of samples in a particular measurement interval. For a large set of independent samples, at least 95 per cent of the samples should be within the accuracy requirements in Chapter 3, Table 3.7.2.4-1. Data is scaled to the worst-case geometry in order to eliminate the variability in system accuracy that is caused by the geometry of the orbiting satellites.

3.2.6   An example of how this concept can be applied is the use of GPS to support performance required for non-precision approach operations. Assume that the system is intended to support non-precision approaches when the horizontal dilution of precision (HDOP) is less than or equal to 6. To demonstrate this performance, samples should be taken over a long period of time (e.g. 24 hours). The measured position error g for each sample i is denoted g_i. This error is scaled to the worst-case geometry as $6 \times g_i$/HDOP. Ninety-five per cent of the scaled errors must be less than 220 m for the system to comply with the non-precision accuracy requirement under worst-case geometry conditions. The total number of samples collected must be sufficient for the result to be statistically representative, taking into account the decorrelation time of the errors.

3.2.7   A range of vertical accuracy values is specified for Category I precision approach operations which bounds the different values that may support an equivalent operation to ILS. A number of values have been derived by different groups, using different interpretations of the ILS standards. The lowest value from these derivations was adopted as a conservative value for GNSS; this is the minimum value given for the range. Because this value is conservative, and because GNSS error characteristics are different from ILS, it may be possible to achieve Category I operations using larger values of accuracy within the range. The larger values would result in increased availability for the operation. The maximum value in the range has been proposed as a suitable value, subject to validation.

3.2.8   The GPS SPS position error (Chapter 3, 3.7.3.1.1.1) accounts for the contribution of the space and control segment to position errors (satellite clock and ephemeris errors) only; it does not include the contributions of ionospheric and tropospheric delay model errors, errors due to multipath effects, and receiver measurement noise errors (Attachment D, 4.1.2). These errors are addressed in the receiver standards. The user positioning error at the output of ABAS-capable equipment is mainly driven by the GNSS receiver used.

3.2.8.1   For Basic GNSS receivers, the receiver qualification standards require demonstration of user positioning accuracy in the presence of interference and a model of selective availability (SA) to be less than 100 m (95 per cent of time) horizontally and 156 m (95 per cent of time) vertically. The receiver standards do not require that a Basic GNSS receiver applies the ionospheric correction described in Appendix B, 3.1.2.4.

Note.— The term "Basic GNSS receiver" designates the GNSS avionics that at least meet the requirements for a GPS receiver as outlined in Annex 10, Volume I and the specifications of RTCA/DO-208 as amended by United States Federal Aviation Administration (FAA) TSO-C129A, or EUROCAE ED-72A (or equivalent).

3.2.8.2   Since the discontinuation of SA, the representative user positioning accuracy of GPS has been conservatively estimated to be as shown in Table D-0. The numbers provided assume that the worst two satellites of a nominal 24 GPS satellite constellation are out of service. In addition, a 7 m (1 σ) ionospheric delay model error, a 0.25 m (1 σ) residual tropospheric delay error, and a 0.80 m (1 σ) receiver noise error are assumed. After discontinuation of SA (Attachment D, 1.), the dominant pseudo-range error for users of the GPS Standard Positioning Service is the ionospheric error that remains after application of the ionospheric corrections. This error is also highly variable and depends on conditions such as user geomagnetic latitude, level of solar activity (i.e. point of the solar cycle that applies), level of ionospheric activity (i.e. whether there is a magnetic storm, or not), elevation angle of the pseudo-range measurement, season of the year, and time of day. The ionospheric delay model error assumption reflected in Table D-0 is generally conservative; however, conditions can be found under which the assumed 7 m (1 σ) error during solar maximum would be inadequate.

Table D-0.   GPS user positioning accuracy

	GPS user positioning accuracy 95% of time, global average
Horizontal position error	33 m (108 ft)
Vertical position error	73 m (240 ft)

3.2.9   SBAS and GBAS receivers will be more accurate, and their accuracy will be characterized in real time by the receiver using standard error models, as described in Chapter 3, 3.5, for SBAS and Chapter 3, 3.6, for GBAS.

Note 1.— The term "SBAS receiver" designates the GNSS avionics that at least meet the requirements for an SBAS receiver as outlined in Annex 10, Volume I and the specifications of RTCA/DO-229C, as amended by United States FAA TSO-C145A/TSO-C146A (or equivalent).

Note 2.— The term "GBAS receiver" designates the GNSS avionics that at least meet the requirements for a GBAS receiver as outlined in Annex 10, Volume I and the specifications of RTCA/DO-253A, as amended by United States FAA TSO-C161 and TSO-C162 (or equivalent).

3.3   Integrity and time-to-alert

3.3.1   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 a system to provide timely and valid warnings to the user (alerts) when the system must not be used for the intended operation (or phase of flight).

3.3.2   To ensure that the position error is acceptable, an alert limit is defined that represents the largest position error allowable for a safe operation. The position error cannot exceed this alert limit without annunciation. This is analogous to ILS in that the system can degrade so that the error is larger than the 95th percentile but within the monitor limit.

3.3.3   The integrity requirement of the navigation system for a single aircraft to support en-route, terminal, initial approach, non-precision approach and departure is assumed to be $1 - 1 \times 10^{-5}$ per hour.

3.3.4   For satellite-based navigation systems, the signal-in-space in the en-route environment simultaneously serves a large number of aircraft over a large area, and the impact of a system integrity failure on the air traffic management system will be greater than with traditional navigation aids. The performance requirements in Chapter 3, Table 3.7.2.4-1, are therefore more demanding.

3.3.5   For APV and precision approach operations, integrity requirements for GNSS signal-in-space requirements of Chapter 3, Table 3.7.2.4-1, were selected to be consistent with ILS requirements.

3.3.6   Alert limits for typical operations are provided in Note 2 to Table 3.7.2.4-1. A range of alert limits is specified for precision approach operations, reflecting potential differences in system design that may affect the operation. In ILS, monitor thresholds for key signal parameters are standardized, and the monitors themselves have very low measurement noise on the parameter that is being monitored. With differential GNSS, some system monitors have comparably large measurement noise uncertainty whose impact must be considered on the intended operation. In all cases, the effect of the alert limit is to restrict the satellite-user geometry to one where the monitor performance (typically in the pseudorange domain) is acceptable when translated into the position domain.

3.3.7   The smallest precision approach vertical alert limit (VAL) value (10 m (33 ft)) was derived based on the monitor performance of ILS as it could affect the glide slope at a nominal decision altitude of 60 m (200 ft) above the runway threshold. By applying this alert limit, the GNSS error, under faulted conditions, can be directly compared to an ILS error under faulted conditions, such that the GNSS errors are less than or equal to the ILS errors. For those faulted conditions with comparably large measurement noise in GNSS, this results in monitor thresholds are more stringent than ILS.

3.3.8   The largest precision approach VAL value (35 m (115 ft)) was derived to ensure obstacle clearance equivalent to ILS for those error conditions which can be modelled as a bias during the final approach, taking into account that the aircraft decision altitude is independently derived from barometric pressure. An assessment has been conducted of the worst-case effect of a latent bias error equal to the alert limit of 35 m (115 ft), concluding that adequate obstacle clearance protection is provided on the approach and missed approach (considering the decision altitude would be reached early or late, using an independent barometric altimeter). It is important to recognize that this assessment only addressed obstacle clearance and is limited to those error conditions which can be modelled as bias errors. Analysis has shown 35 m (115 ft) bias high and low conditions can be tolerated up to the approach speed category (Categories A through D) glide path angle limits in the *Procedures for Air Navigation Services — Aircraft Operations* (PANS-OPS, Doc 8168) without impinging on the ILS obstacle clearance surfaces.

3.3.9   Since the analysis of a 35 m (115 ft) VAL is limited in scope, a system-level safety analysis should be completed before using any value greater than 10 m (33 ft) for a specific system design. The safety analysis should consider obstacle clearance criteria and risk of collision due to navigation error, and the risk of unsafe landing due to navigation error, given the system design characteristics and operational environment (such as the type of aircraft conducting the approach and the supporting airport infrastructure). With respect to the collision risk, it is sufficient to confirm that the assumptions identified in 3.3.8 are valid for the use of a 35 m (115 ft) VAL. With respect to an unsafe landing, the principal mitigation for a navigation error is pilot intervention during the visual segment. Limited operational trials, in conjunction with operational expertise, have indicated that navigation errors of less than 15 m (50 ft) consistently result in acceptable touchdown performance. For errors larger than 15 m (50 ft), there can be a significant increase in the flight crew workload and potentially a significant reduction in the safety margin, particularly for errors that shift the point where the aircraft reaches the decision altitude closer to the runway threshold where the flight crew may attempt to land with an unusually high rate of descent. The hazard severity of this event is major (see the *Safety Management Manual (SMM)* (Doc 9859)). One acceptable means to manage the risks in the visual segment is for the system to comply with the following criteria:

a)   the fault-free accuracy is equivalent to ILS. This includes system 95 per cent vertical navigation system error (NSE) less than 4 m (13 ft), and a fault-free system vertical NSE exceeding 10 m (33 ft) with a probability less than 10^{-7} for

each location where the operation is to be approved. This assessment is performed over all environmental and operational conditions under which the service is declared available;

b) under system failure conditions, the system design is such that the probability of an error greater than 15 m (50 ft) is lower than 10^{-5}, so that the likelihood of occurrence is remote. The fault conditions to be taken into account are those affecting either the core constellations or the GNSS augmentation under consideration. This probability is to be understood as the combination of the occurrence probability of a given failure with the probability of detection for applicable monitor(s). Typically, the probability of a single fault is large enough that a monitor is required to satisfy this condition.

3.3.10   For GBAS, a technical provision has been made to broadcast the alert limit to aircraft. GBAS standards require the alert limit of 10 m (33 ft). For SBAS, technical provisions have been made to specify the alert limit through an updatable database (see Attachment C).

3.3.11   The approach integrity requirements apply in any one landing and require a fail-safe design. If the specific risk on a given approach is known to exceed this requirement, the operation should not be conducted. One of the objectives of the design process is to identify specific risks that could cause misleading information and to mitigate those risks through redundancy or monitoring to achieve a fail-safe design. For example, the ground system may need redundant correction processors and to be capable of shutting down automatically if that redundancy is not available due to a processor fault.

3.3.12   A unique aspect of GNSS is the time-varying performance caused by changes in the core satellite geometry. A means to account for this variation is included in the SBAS and GBAS protocols through the protection level equations, which provide a means to inhibit use of the system if the specific integrity risk is too high.

3.3.13   GNSS performance can also vary across the service volume as a result of the geometry of visible core constellation satellites. Spatial variations in system performance can further be accentuated when the ground system operates in a degraded mode following the failure of system components such as monitoring stations or communication links. The risk due to spatial variations in system performance should be reflected in the protection level equations, i.e. the broadcast corrections.

3.3.14   GNSS augmentations are also subject to several atmospheric effects, particularly due to the ionosphere. Spatial and temporal variations in the ionosphere can cause local or regional ionospheric delay errors that cannot be corrected within the SBAS or GBAS architectures due to the definition of the message protocols. Such events are rare and their likelihood varies by region, but they are not expected to be negligible. The resulting errors can be of sufficient magnitude to cause misleading information and should be mitigated in the system design through accounting for their effects in the broadcast parameters (e.g. σ_{iono_vert} in GBAS), and monitoring for excessive conditions where the broadcast parameters are not adequate. The likelihood of encountering such events should be considered when developing any system monitor.

3.3.15   Another environmental effect that should be accounted for in the ground system design is the errors due to multipath at the ground reference receivers, which depend on the physical environment of monitoring station antennas as well as on satellite elevations and times in track.

3.4   Continuity of service

3.4.1   Continuity of service of a system is the capability of the system to perform its function without unscheduled interruptions during the intended operation.

3.4.2   *En-route*

3.4.2.1   For en-route operations, continuity of service relates to the capability of the navigation system to provide a navigation output with the specified accuracy and integrity throughout the intended operation, assuming that it was available

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3.5.5.2   When developing operating procedures for GNSS approach systems, the duration of an outage and its impact on the alternate airport should be considered. Although GNSS outages can occur which affect many approaches, the approach service can be restored without any maintenance because of the orbiting of the satellites.

3.5.6   *Determining GNSS availability*

The availability of GNSS is complicated by the movement of satellites relative to a coverage area under consideration and the potentially long time needed to restore a satellite in the event of a failure. Accurately measuring the availability would require many years to allow for a measurement period longer than the MTBF and repair times. The availability of GNSS should be determined through design, analysis and modelling, rather than measurement. The availability model should account for the ionospheric, tropospheric and receiver error models used by the receiver to verify integrity (e.g. HPL, LPL and VPL calculations). The availability specified in Chapter 3, 3.7.2.4, applies to the design availability.

   Note.— Additional guidance material pertaining to reliability and availability of radio communications and navigation aids is contained in Attachment F.

4.   GNSS core elements

4.1   GPS

   Note.— Additional information concerning GPS can be found in the Global Positioning System Standard Positioning Service — Performance Standard*, October 2001, and Interface Control Document (ICD)-GPS-200C.*

   4.1.1   The performance standard is based upon the assumption that a representative standard positioning service (SPS) receiver is used. A representative receiver has the following characteristics: designed in accordance with ICD-GPS-200C; uses a 5-degree masking angle; accomplishes satellite position and geometric range computations in the most current realization of the World Geodetic System 1984 (WGS-84) Earth-Centred, Earth-Fixed (ECEF) coordinate system; generates a position and time solution from data broadcast by all satellites in view; compensates for dynamic Doppler shift effects on nominal SPS ranging signal carrier phase and C/A code measurements; excludes GPS unhealthy satellites from the position solution; uses up-to-date and internally consistent ephemeris and clock data for all satellites it is using in its position solution; and loses track in the event that a GPS satellite stops transmitting C/A code. The time transfer accuracy applies to a stationary receiver operating at a surveyed location. A 12-channel receiver will meet performance requirements specified in Chapter 3, 3.7.3.1.1.1 and 3.7.3.1.2. A receiver that is able to track four satellites only (Appendix B, 3.1.3.1.2) will not get the full accuracy and availability performance.

   4.1.2   *Accuracy*. The accuracy is measured with a representative receiver and a measurement interval of 24 hours for any point within the coverage area. The positioning and timing accuracy are for the signal-in-space (SIS) only and do not include such error sources as: ionosphere, troposphere, interference, receiver noise or multipath. The accuracy is derived based on the worst two of 24 satellites being removed from the constellation and a 6-metre constellation RMS SIS user range error (URE).

   4.1.3   *Range domain accuracy*. Range domain accuracy is conditioned by the satellite indicating a healthy status and transmitting C/A code and does not account for satellite failures outside of the normal operating characteristics. Range domain accuracy limits can be exceeded during satellite failures or anomalies while uploading data to the satellite. Exceedance of the range error limit constitutes a major service failure as described in 4.1.6. The range rate error limit is the maximum for any satellite measured over any 3-second interval for any point within the coverage area. The range acceleration error limit is the maximum for any satellite measured over any 3-second interval for any point within the coverage area. The root-mean-square range error accuracy is the average of the RMS URE of all satellites over any 24-hour interval for any point within the coverage area. Under nominal conditions, all satellites are maintained to the same standards, so it is appropriate for availability modelling purposes to assume that all satellites have a 6-metre RMS SIS URE. The standards are restricted to range domain errors allocated to space and control segments.

4.1.4   *Availability*. Availability is the percentage of time over any 24-hour interval that the predicted 95 per cent positioning error (due to space and control segment errors) is less than its threshold, for any point within the coverage area. It is based on a 36-metre horizontal 95 per cent threshold; a 77-metre vertical 95 per cent threshold; using a representative receiver; and operating within the coverage area over any 24-hour interval. The service availability assumes the worst combination of two satellites out of service.

4.1.4.1   *Relationship to augmentation availability.* The availability of ABAS, GBAS and SBAS does not directly relate to the GPS availability defined in Chapter 3, 3.7.3.1.2. States and operators must evaluate the availability of the augmented system by comparing the augmented performance to the requirements. Availability analysis is based on an assumed satellite constellation and the probability of having a given number of satellites. Twenty-four operational satellites are available on orbit with 0.95 probability (averaged over any day), where a satellite is defined to be operational if it is capable of, but is not necessarily transmitting, a usable ranging signal. At least 21 satellites in the 24 nominal plane/slot positions must be set healthy and must be transmitting a navigation signal with 0.98 probability (yearly averaged).

4.1.5   *Reliability*. Reliability is the percentage of time over a specified time interval that the instantaneous SPS SIS URE is maintained within the range error limit, at any given point within the coverage area, for all healthy GPS satellites. The reliability standard is based on a measurement interval of one year and the average of daily values within the coverage area. The single point average reliability assumes that the total service failure time of 18 hours will be over that particular point (3 failures each lasting 6 hours).

4.1.6   *Major service failure.* A major service failure is defined to be a condition over a time interval during which a healthy GPS satellite's ranging signal error (excluding atmospheric and receiver errors) exceeds the range error limit. As defined in Chapter 3, 3.7.3.1.1.3 a), the range error limit is the larger of:

a)   30 m; or

b)   4.42 times the URA, not to exceed 150 m.

4.1.7   *Coverage*. The SPS supports the terrestrial coverage area, which is from the surface of the earth up to an altitude of 3 000 km.

4.2   GLONASS

Note.— Additional information concerning GLONASS can be found in the GLONASS Interface Control Document *published by Scientific Coordination Information Center, Russian Federation Ministry of Defence, Moscow.*

4.2.1   *Assumptions.* The performance standard is based upon the assumption that a representative channel of standard accuracy (CSA) receiver is used. A representative receiver has the following characteristics: designed in accordance with GLONASS ICD; uses a 5-degree masking angle; accomplishes satellite position and geometric range computations in the most current realization of the PZ-90 and uses PZ-90 – WGS-84 transformation parameters as indicated in Appendix B, 3.2.5.2; generates a position and time solution from data broadcast by all satellites in view; compensates for dynamic Doppler shift effects on nominal CSA ranging signal carrier phase and standard accuracy signal measurements; excludes GLONASS unhealthy satellites from the position solution; uses up-to-date and internally consistent ephemeris and clock data for all satellites it is using in its position solution; and loses track in the event that a GLONASS satellite stops transmitting standard accuracy code. The time transfer accuracy applies to a stationary receiver operating at a surveyed location.

4.2.2   *Accuracy*. Accuracy is measured with a representative receiver and a measurement interval of 24 hours for any point within the coverage area. The positioning and timing accuracy are for the signal-in-space (SIS) only and do not include such error sources as: ionosphere, troposphere, interference, receiver noise or multipath. The accuracy is derived based on the worst two of 24 satellites being removed from the constellation and a 6-metre constellation RMS SIS user range error (URE).

4.2.3   *Range domain accuracy*. Range domain accuracy is conditioned by the satellite indicating a healthy status and transmitting standard accuracy code and does not account for satellite failures outside of the normal operating characteristics.

Range domain accuracy limits can be exceeded during satellite failures or anomalies while uploading data to the satellite. Exceeding the range error limit constitutes a major service failure as described in 4.2.6. The range rate error limit is the maximum for any satellite measured over any 3-second interval for any point within the coverage area. The range acceleration error limit is the maximum for any satellite measured over any 3-second interval for any point within the coverage area. The root-mean-square range error accuracy is the average of the RMS URE of all satellites over any 24-hour interval for any point within the coverage area. Under nominal conditions, all satellites are maintained to the same standards, so it is appropriate for availability modelling purposes to assume that all satellites have a 6-metre RMS SIS URE. The standards are restricted to range domain errors allocated to space and control segments.

4.2.4   *Availability.* Availability is the percentage of time over any 24-hour interval that the predicted 95 per cent positioning error (due to space and control segment errors) is less than its threshold, for any point within the coverage area. It is based on a 12-metre (40-foot) horizontal 95 per cent threshold and a 25-metre (80-foot) vertical 95 per cent threshold, using a representative receiver and operating within the coverage area over any 24-hour interval. The service availability assumes the worst combination of two satellites out of service.

4.2.4.1   *Relationship to augmentation availability.* The availability of ABAS, GBAS and SBAS does not directly relate to the GLONASS availability defined in Chapter 3, 3.7.3.2.2. Availability analysis is based on an assumed satellite constellation and the probability of having a given number of satellites. Twenty-four operational satellites are available in orbit with 0.95 probability (averaged over any day), where a satellite is defined to be operational if it is capable of, but is not necessarily transmitting, a usable ranging signal. At least 21 satellites in the 24 nominal plane/slot positions must be set healthy and must be transmitting a navigation signal with 0.98 probability (yearly averaged).

4.2.5   *Reliability.* Reliability is the percentage of time over a specified time interval that the instantaneous CSA SIS URE is maintained within the range error limit, at any given point within the coverage area, for all healthy GLONASS satellites. The reliability standard is based on a measurement interval of one year and the average of daily values within the coverage area. The single point average reliability assumes that the total service failure time of 18 hours will be over that particular point (3 failures each lasting 6 hours).

4.2.6   *Major service failure.* A major service failure is defined as a condition over a time interval during which a healthy GLONASS satellite's ranging signal error (excluding atmospheric and receiver errors) exceeds the range error limit of 18 m (60 ft) (as defined in Chapter 3, 3.7.3.2.1.3 a)) and/or failures in radio frequency characteristics of the CSA ranging signal, navigation message structure or navigation message contents that deteriorate the CSA receiver's ranging signal reception or processing capabilities.

4.2.7   *Coverage.* The GLONASS CSA supports the terrestrial coverage area, which is from the surface of the earth up to an altitude of 2 000 km.

4.2.8   *GLONASS time.* GLONASS time is generated based on GLONASS Central Synchronizer time. Daily instability of the Central Synchronizer hydrogen clock is not worse than 5×10^{-14}. The difference between GLONASS time and UTC(SU) is within 1 millisecond. The navigation message contains the requisite data to relate GLONASS time to UTC(SU) within 0.7 microsecond.

4.2.8.1   *Transformation of GLONASS-M current data information into common form.* A satellite navigation message contains current data information in N_T parameter. It could be transformed into the common form by the following algorithm:

a)   Current year number J in the four-year interval is calculated:

      If $1 \leq N_T \leq 366$;   J = 1;
      If $367 \leq N_T \leq 731$;   J = 2;
      If $732 \leq N_T \leq 1096$;   J = 3;
      If $1097 \leq N_T \leq 1461$;   J = 4.

b)   Current year in common form is calculated by the following formula:

Y = 1996 + 4 (N$_4$ – 1) + (J – 1).

c)   Current day and month (dd/mm) are extracted from the reference table stored in user equipment ROM. The table interrelates N$_T$ parameter and common form dates.

4.2.9   *GLONASS coordinate system*. The GLONASS coordinate system is PZ-90 as described in *Parameters of Earth, 1990 (PZ-90)*, published by the Topographic Service, Russian Federation Ministry of Defence, Moscow.

4.2.9.1   PZ-90 parameters include fundamental geodetic constants, dimensions of the common terrestrial ellipsoid, the characteristics of the gravitational field of the earth, and the elements of the Krasovsky ellipsoid (coordinate system 1942) orientation relative to the common terrestrial ellipsoid.

4.2.9.2   By definition, the coordinate system PZ-90 is a geocentric Cartesian space system whose origin is located at the centre of the earth's body. The Z-axis is directed to the Conventional Terrestrial Pole as recommended by the International Earth Rotation Service. The X-axis is directed to the point of intersection of the earth's equatorial plane and zero meridian established by the Bureau International de l'Heure. The Y-axis completes the right-handed coordinate system.

4.3   Dilution of precision

Dilution of precision (DOP) factors express how ranging accuracy is scaled by a geometry effect to yield position accuracy. The optimal geometry (i.e. the lowest DOP values) for four satellites is achieved when three satellites are equally spaced on the horizon, at minimum elevation angle, and one satellite is directly overhead. The geometry can be said to "dilute" the range domain accuracy by the DOP factor.

4.4   GNSS receiver

4.4.1   The failures caused by the receiver can have two consequences on navigation system performance which are the interruption of the information provided to the user or the output of misleading information. Neither of these events are accounted for in the signal-in-space requirement.

4.4.2   The nominal error of the GNSS aircraft element is determined by receiver noise, interference, and multipath and tropospheric model residual errors. Specific receiver noise requirements for both the SBAS airborne receiver and the GBAS airborne receiver include the effect of any interference below the protection mask specified in Appendix B, 3.7. The required performance has been demonstrated by receivers that apply narrow correlator spacing or code smoothing techniques.

5.   Aircraft-based augmentation system (ABAS)

5.1   ABAS augments and/or integrates the information obtained from GNSS elements with information available on board the aircraft in order to ensure operation according to the values specified in Chapter 3, 3.7.2.4.

5.2   ABAS includes processing schemes that provide:

a)   integrity monitoring for the position solution using redundant information (e.g. multiple range measurements). The monitoring scheme generally consists of two functions: fault detection and fault exclusion. The goal of fault detection is to detect the presence of a positioning failure. Upon detection, proper fault exclusion determines and excludes the source of the failure (without necessarily identifying the individual source causing the problem), thereby allowing GNSS navigation to continue without interruption. 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 uses information from additional on-board sensors (e.g. barometric altimeter, clock and inertial navigation system (INS));