U.S. Department of Transportation

Federal Aviation Administration

Advisory Circular

Subject: AIRWORTHINESS APPROVAL OF GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS) EQUIPMENT

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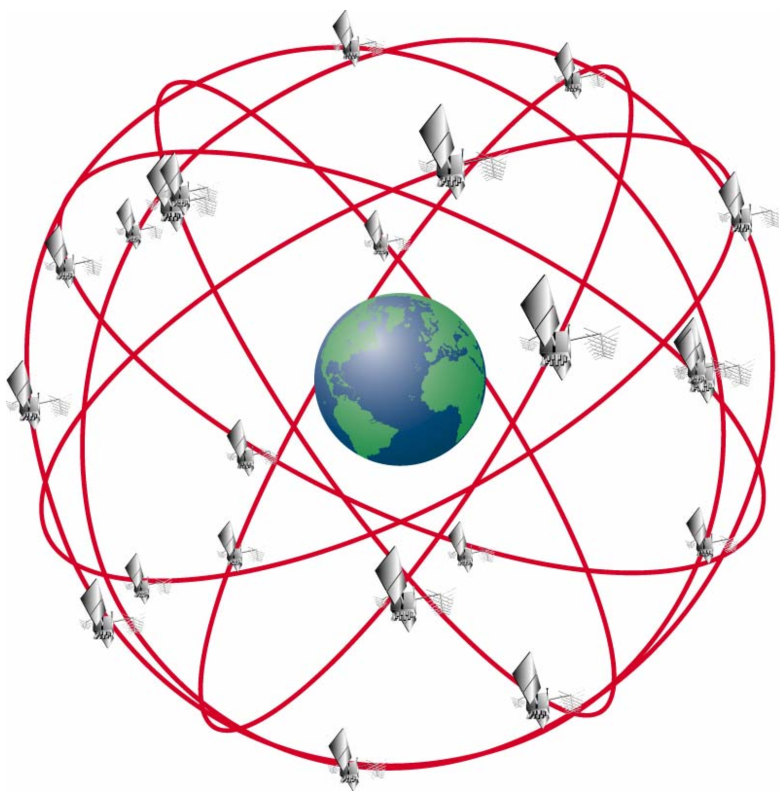
Change:



CONTENTS

1. PURPOSE. This advisory circular (AC) provides guidance material for the airworthiness approach of Global Navigation Satellite System (GNSS) equipment. Like all AC material, this AC is not mandatory and does not constitute a regulation. It is issued for guidance purposes and to outline a method of compliance with the rules. In lieu of following this method without deviation, the applicant may elect to follow an alternate method, provided the alternate method is also found by the Federal Aviation Administration (FAA) to be an acceptable means of complying with the requirements of the federal aviation regulations (Title 14 of the Code of Federal Regulations, 14 CFR). Because the method of compliance presented in this AC is not mandatory, the terms “shall” and “must” used herein apply only to an applicant who chooses to follow this particular method without deviation. This AC addresses the following equipment:

a. GNSS sensors, including those incorporating Wide Area Augmentation System (WAAS), Local Area Augmentation System (LAAS), or the Russian Global Navigation Satellite System (GLONASS).

b. GNSS stand-alone navigation equipment that provides deviations (steering commands) for en route, terminal, or approach operations (including Category I precision approach).

2. CANCELLATION.

a. AC 20-138, Airworthiness Approval of Global Positioning System (GPS) Navigation Equipment for Use as a VFR and IFR Supplemental Navigation System, dated May 25, 1994, is canceled.

3. RELATED FEDERAL AVIATION REGULATIONS. 14 CFR Parts 21, 23, 25, 27, 29, 43, 91, 121, and 135.

4. HOW TO USE THIS DOCUMENT. This document is organized into general categories of equipment and installations. Paragraph 8 summarizes the approval process and applies to all projects. Paragraph 9 applies to GNSS as an aid to visual flight rules (VFR) navigation, while paragraphs 10 through 25 address instrument flight rules (IFR) navigation. Guidance concerning the equipment performance and functions is provided in paragraphs 11 through 15, and installation guidance is provided in paragraphs 16 through 22. Paragraphs 23 through 25 provide additional information on the data submittal, ground test and flight test as they apply to an installation approval.

5. DEFINITIONS.

a. Ground-Based Augmentation System (GBAS). An augmentation system in which the user receives augmentation information directly from a ground-based transmitter.

b. GLONASS. GLONASS is a Russian satellite based radio navigation system, which provides a positioning service anywhere in the world. Until the FAA declares GLONASS fully operational for U.S. aviation, its use is limited to a supplement to GPS navigation. The FAA will declare GLONASS fully operational after the system management and maintenance are mature. The following capabilities are expected before the FAA will declare GLONASS operational for U.S. aviation:

(1) Mature maintenance practices;

(2) Commitment to maintain a complete constellation of satellites; and

(3) Issuance of international NOTAMs prior to any scheduled maintenance, and after the onset of any unscheduled outages.

c. Global Navigation Satellite System (GNSS). The GNSS is a generic term for satellite-based navigation, including GPS, SBAS, GBAS, GLONASS, and any other satellite navigation system.

d. GNSS Landing System (GLS). A satellite-based navigation system that provides precision approach (including SBAS/WAAS and GBAS/LAAS).

e. Global Positioning System (GPS). GPS is an U.S. satellite based radio navigation system that provides a precise positioning service anywhere in the world. The service provided by GPS for civil use is defined in the *GPS Standard Positioning System Signal Specification*.

f. Local Area Augmentation System (LAAS). LAAS is the GBAS provided by the FAA. This AC will be updated as LAAS develops.

g. Navigation. Navigation refers to any function used to plan or direct the course of an aircraft. A navigation system as addressed in this AC provides the functions of position estimation, path definition, path steering, and situation indications and alerting to the flight crew.

h. Required Navigation Performance (RNP). RNP is a statement of the navigation performance necessary for operation within a defined airspace. RNP RNAV is under development by the FAA, U.S. industry, and ICAO in order for RNP to achieve accurate, repeatable and predictable navigation performance (RTCA/DO-236A).

i. Satellite-Based Augmentation System (SBAS). A wide coverage augmentation system in which the user receives augmentation information from a satellite-based transmitter.

j. Special Category I (SCAT-I). In order to expedite the implementation of satellite-based navigation, the aeronautical industry and the FAA in 1993 developed RTCA/DO-217, *Minimum Aviation System Performance Standards (MASPS) DGNSS Instrument Approach System: Special Category I*. The FAA adopted this standard in Order 8400.11, *IFR Approval for Differential Global Positioning System Special Category I Instrument Approaches Using Private Ground Facilities*. The intent of SCAT-I is the same as LAAS, except it is limited to Category I precision approach and does not ensure interoperability between different vendors. SCAT-I allows private facilities to be fielded before all of the issues associated with a public system are resolved. With the adoption of ICAO standards for LAAS in 2001, the SCAT-I standards became obsolete and should no longer be used.

k. Stand-alone. Stand-alone as addressed in this AC refers to navigation equipment incorporating the GPS or GPS/WAAS position sensor and a navigation function, so that the equipment provides path deviations relative to a selected path.

l. Wide Area Augmentation System (WAAS). WAAS is the SBAS provided by the FAA.

6. RELATED READING MATERIALS.

a. FAA Orders and Technical Standard Orders (TSO). The following documents may be obtained from the Department of Transportation, FAA, Aircraft Certification Service, Aircraft Engineering Division, AIR-130, 800 Independence Avenue, SW., Washington, D.C. 20591, or on the FAA Internet at http://av-info.faa.gov/tso/.

(1) TSO-C115b, Airborne Area Navigation Equipment Using Multi-Sensor Inputs;

(2) TSO-C129a, Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS);

(3) TSO-C144, Airborne Global Positioning System Antenna;

(4) TSO-C145, Airborne Navigation Sensors Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS);

(5) TSO-C146, Stand-Alone Airborne Navigation Equipment Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS);

(6) Order 8400.11, IFR Approval of Differential GPS Special Category I Instrument Approaches Using Private Ground Facilities; and

(7) Order 8400.12A, Required Navigation Performance 10 (RNP-10) Operational Approval.

b. FAA Advisory Circulars. The following documents may be obtained from the Department of Transportation, Subsequent Distribution Office, SVC-121.23, Ardmore East Business Center, 3341 Q 75th Ave, Landover, MD 20785. The Advisory Circular Checklist (AC 00-2) is available at http://www2.airweb.faa.gov/Regulatory_and_Guidance_Library. The advisory circular checklist contains status and order information for the FAA advisory circulars.

(1) AC 20-115B, Radio Technical Commission for Aeronautics, Inc. Document RTCA/DO-178B;

(2) AC 20-129, Airworthiness Approval of Vertical Navigation (VNAV) Systems for Use in the U.S. National Airspace System (NAS) and Alaska;

(3) AC 20-130B, Airworthiness Approval of Navigation or Flight Management Systems Integrating Multiple Navigation Sensors;

(4) AC 21-40, Application Guide for Obtaining a Supplemental Type Certificate;

(5) AC 23-1309-1C, Equipment, Systems, and Installations in Part 23 Airplanes;

(6) AC 25-1309-1A, System Design and Analysis;

(7) AC 90-79, Recommended Practices and Procedures for the Use of Electronic Long-Range Navigation Equipment;

(8) AC 90-94, Guidelines for Using GPS Equipment for IFR En Route and Terminal Operations & for Nonprecision Instrument Approaches;

(9) AC 90-96, Approval of U.S. Operators and Aircraft to Operate under Instrument Flight Rules (IFR) in European Airspace Designated for Basic Area Navigation (BRNAV/RNP-5);

(10) AC 91-49, General Aviation Procedures for Flight in North Atlantic Minimum Navigation Performance Specification Airspace;

(11) AC 120-29, Criteria for Approving Category I and Category II Landing Minima for FAR 121 Operators. This AC supplements Appendix 2 of AC 120-29 with respect to the installation of GPS/WAAS Category I equipment; and

(12) AC 120-33, Operational Approval of Airborne Long-Range Navigation Systems for Flight within the North Atlantic Minimum Navigation Performance Specification Airspace.

c. RTCA, Inc. documents. The following documents may be purchased from RTCA, Inc., 1828 L Street, NW, Suite 805, Washington, DC 20036, or purchased on-line at http://www.rtca.org/.

(1) RTCA/DO-160D, Environmental Conditions and Test Procedures for Airborne Equipment;

(2) RTCA/DO-178B, Software Considerations in Airborne Systems and Equipment Certification;

(3) RTCA/DO-200A, Standards for Processing Aeronautical Data;

(4) RTCA/DO-201A, Standards for Aeronautical Information;

(5) RTCA/DO-208, Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS);

(6) RTCA/DO-229C, Minimum Operational Performance Standards for Airborne GPS/WAAS Equipment; and

(7) RTCA/DO-236A, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation.

d. GPS Standard Positioning Service Performance Standard, October, 2001. Copies of this document and general information related to GPS may be requested at http://www.navcen.uscg.gov/.

e. Department of Defense Interface Control Document (ICD) ICD-GPS-200C, Navstar GPS Space Segment/Navigation User Interface. Copies of the this document may be requested from the GPS Joint Program Office, SSD/CZ, Los Angeles AFB, CA 90006. Alternatively, copies of this document may be requested at http://www.navcen.uscg.gov/.

f. National Imagery and Mapping Agency (NIMA) Technical Report NIMA TR 8350.2, World Geodetic System 1984, Its Definition and Relationships with Local Geodetic Systems. Copies of this document may be requested at http://www.nima.mil/.

g. FAA National Airspace System Architecture Version 4.0. An electronic version of this document and architecture updates is available at http://www.faa.gov/nasarchitecture/.

h. FAA Specification Wide Area Augmentation System (WAAS), FAA-E-2892B. This document is available on-line at http://faa.gps.gov/.

i. DOD/DOT 1999 Federal Radionavigation Plan (FRP). The FRP is published every two years in which copies may be ordered through the National Technical Information Service, Springfield, VA 22161; internet: http://www.ntis.gov/.

7. BACKGROUND.

a. Global Positioning System (GPS).

(1) System Description. The Global Positioning System is a satellite based radio navigation system, which broadcasts a signal that is used by receivers to determine precise position anywhere in the world. The receiver tracks multiple satellites and determines a pseudorange measurement that is then used to determine the user location. A minimum of four satellites are necessary to establish an accurate three-dimensional position. The Department of Defense (DOD) is responsible for operating the GPS satellite constellation and monitors the GPS satellites to ensure proper operation. Every satellite's orbital parameters (ephemeris data) are sent to each satellite for broadcast as part of the data message embedded in the GPS signal. The GPS coordinate system is the Cartesian earth-centered earth-fixed coordinates as specified in the World Geodetic System 1984 (WGS-84).

(2) System Availability and Reliability.

(i) The status of GPS satellites is broadcast as part of the data message transmitted by the GPS satellites. GPS status information is also available by means of the U.S. Coast Guard navigation information service: (703) 313-5907, Internet: http://www.navcen.uscg.mil/gpsnotices/. Additionally, satellite status is available through the Notice to Airmen (NOTAM) system.

(ii) The operational status of GNSS operations depends upon the type of equipment being used. For GPS-only equipment (TSO-C129), the operational status of nonprecision approach capability is provided through a prediction program that is embedded in the receiver or provided separately.

(3) Receiver Autonomous Integrity Monitoring (RAIM). When GNSS equipment is not using integrity information from WAAS, the GPS navigation receiver using RAIM provides GPS signal integrity monitoring. RAIM is necessary since delays of up to two hours can occur before an erroneous satellite transmission can be detected and corrected by the satellite control segment. The RAIM function is also referred to as fault detection. Another capability, fault exclusion, refers to the ability of the receiver to identify which satellite failed and exclude it from the position solution. Fault detection and exclusion (FDE) is provided in all primary means GPS equipment (Appendix 1, paragraph 2.b of this AC) and in all GPS/WAAS equipment.

(4) Selective Availability. Selective Availability (SA) is a method by which the accuracy of GPS is intentionally degraded. This feature is designed to deny an enemy the use of precise GPS positioning data. SA was discontinued on May 1, 2000.

(5) GPS Modernization. Initiatives to modernize the Global Positioning System include two new civilian signals. One of the new signals will be centered at 1176.45 MHz, and will provide an improved service that supports safety-of-life applications, including aeronautical applications. The other new signal will be centered at 1227.60 MHz, and will be available for general use in non-safety critical applications. Depending on the rate of GPS satellite launches, initial operating capability will be available between the years 2012 and 2015.

(6) System Performance. The GPS performance specifications contained in this AC are based upon unaugmented performance achieved with the Standard Positioning Service (SPS). GPS performance for a representative single-frequency receiver, as defined in the GPS SPS Performance Standard, is summarized in the following table.

Table 1. Summary of GPS Performance

Availability	Unspecified
Horizontal Navigation System Accuracy (95%)	33 m
Vertical Navigation System Accuracy (95%)	73 m
SIS Integrity	Unspecified
Service Volume	Global

(7) General Operational Limitations.

(i) TSO-C129() equipment: the requirements defined in TSO-C129() were developed for GPS to be used in addition to other navigation equipment.

(ii) GPS Primary Means equipment: the requirements specified in appendix 1 of this AC were developed for GPS to be used for limited operations (e.g. oceanic/remote operations as discussed in AC 90-94) without the need for other navigation equipment appropriate to the route to be flown.

(8) Equipment Classes. TSO-C129() defines different classes of equipment to support different equipment configurations. These classes are defined in paragraph (a)(2) of TSO-C129().

b. Satellite-Based Augmentation System (SBAS). To improve the accuracy, integrity and availability of GPS signals, ICAO has defined Standards and Recommended Practices (SARPs) for satellite-based augmentation systems (SBAS). The FAA developed the Wide Area Augmentation System (WAAS) to provide SBAS service throughout U.S. airspace. In addition, the FAA is working with civil aviation authorities in Europe and Japan to coordinate the development of their SBAS, (the European Geostationary Navigation Overlay System, or EGNOS, and the Japan Multifunctional Transport Satellite (MTSAT) Satellite-based Augmentation System, or MSAS).

(1) WAAS Description.

(i) The WAAS uses measurements from a wide area network of reference stations to determine satellite clock and ephemeris corrections and to model the propagation effects of the ionosphere. A monitoring system ensures that the SBAS is operating correctly and that the correction information is correct. This information is broadcast to users via a geostationary satellite, using a signal that is similar to the GPS signal. Since the SBAS satellite signal is similar to GPS, it also provides an additional pseudorange measurement to the receiver. The objectives of WAAS are:

(A) to improve the integrity of GPS through real-time monitoring;

(B) to improve the availability of GPS by providing an additional satellite signal; and

(C) to improve the accuracy of GPS by providing differential corrections.

(ii) WAAS provides a level of service that supports all phases of flight including LNAV/VNAV and LPV approaches. Both LNAV/VNAV and LPV approaches are approach procedures with vertical guidance as defined in ICAO Annex 6. These approaches provide vertical guidance, but do not meet the more stringent standards of a precision approach. In the long term, WAAS will provide Category I precision approach services in conjunction with modernized GPS. The FAA plans to decommission a significant percentage of its existing VOR and ILS infrastructure after WAAS services are available.

(2) WAAS Availability and Reliability. The FAA will provide notices to airmen (NOTAMs) to advise pilots of the status of the WAAS. This will also include NOTAMs advising if the operational capability of GPS/WAAS equipment is degraded. WAAS monitors both GPS and WAAS satellites and provides integrity.

(3) WAAS Performance Requirements (within Service Volume). WAAS performance defined in this AC is based on a single frequency user in the final configuration of WAAS, as defined in FAA-E2892B. The performance of WAAS is summarized in the following table.

Table 2. Summary of WAAS Performance

	En route through Nonprecision Approach	LPV
Availability	99.999%	99.9%
Horizontal Navigation System Accuracy (95%)	100 m	16 m
Vertical Navigation System Accuracy (95%)	Unspecified	20 m
SIS Integrity	Probability of misleading navigation in an hour = 10^{-7}	Probability of misleading navigation during an approach = 10^{-7}
Service volume	U.S. Airspace	Contiguous U.S., parts of Alaska

(4) WAAS General Operational Limitations. The requirements were developed for GPS/WAAS to be used within the SBAS coverage without the need for other radio navigation equipment appropriate to the route to be flown. Outside of the SBAS coverage, GPS/WAAS equipment reverts to GPS-only equipment and the general limitations of paragraph 6a(7) apply.

(5) WAAS Equipment Classes. RTCA/DO-229C, section 1.4, defines the different classes of GPS/WAAS equipment to support different equipment configurations.

c. Ground-Based Augmentation System (GBAS). To improve the accuracy, integrity and availability of GPS signals, ICAO has defined Standards and Recommended Practices (SARPs) for ground-based augmentation systems (GBAS). The FAA developed the Local Area Augmentation System (LAAS) to provide GBAS service at designated airports throughout the U.S.

(1) Local Area Augmentation System (LAAS).

(i) The LAAS is intended to support a level of navigation service that requires greater performance than that provided by WAAS. LAAS is being developed to ensure interoperability. Similar to the WAAS concept that incorporates the use of communication satellites to broadcast a correction message, the LAAS will broadcast its correction message via very high frequency (VHF) radio broadcast from a ground-based transmitter. The localized coverage area will support multiple operations to an airport. The LAAS will complement WAAS at locations where WAAS is unable to meet existing navigation and landing requirements. As the LAAS is further developed, it will provide a level of service sufficient to support CAT II/III precision approach and landing operations.

(ii) Since the LAAS is still in the development stage, guidance relating to the airworthiness approval of the LAAS airborne equipment has not been incorporated within this advisory circular.

8. APPROVAL PROCESS. This section describes the general approval process applicable to GNSS equipment. Unique approval issues associated with GPS for Oceanic/Remote Navigation and GLONASS are defined in appendices 1 and 2, respectively.

a. TSO Authorization (TSOA).

(1) Several TSO's have been written for GNSS-related equipment and components (reference paragraph 4.a of this AC). While the TSO process operates on the basis of self-certification by the applicant, it is beneficial to involve the ACO (both engineers and flight test pilots) in the evaluation of the equipment as early as possible for two primary reasons:

(i) Obtaining a TSOA does not ensure that the equipment will satisfy all of the applicable requirements when it is installed; and

(ii) The design of GNSS equipment has become increasingly more complex and workload intensive with no standardized interface with the pilot. The human factors evaluation of the equipment is subjective.

(2) It is recommended that the manufacturer elect to obtain an STC for their equipment concurrent with obtaining the TSOA. This has proven to be an effective means of involving the ACO and identifying issues associated with installing the article.

b. Airworthiness Approval.

(1) Persons seeking airworthiness (or installation) approval of GNSS equipment may obtain approval via a Type Certificate (TC), Supplemental Type Certificate (STC), or through field approval using FAA Form 337 (Major Repair and Alteration).

(2) Initial approvals. The initial certification of GNSS equipment requires the applicant to obtain installation approval via the TC or STC process involving extensive engineering and flight test evaluations as described in sections 11 through 14. Applicants are encouraged to obtain AC 21-40, an Application Guide for Obtaining a Supplemental Type Certificate.

(3) First-Time Stand-Alone Navigation Approvals. It is recommended that the ACO request a Special Certification Review (SCR) Team when evaluating a GNSS stand-alone navigation unit for the first time, typically as part of an STC. The SCR team should be coordinated through AIR-130. The team assists in applying a common standard, which will result in a more consistent evaluation than that from a single pilot.

(4) Follow-on approvals. For equipment that has already obtained installation approval, referencing the prior approval can facilitate airworthiness approval regardless of differences in the make/model aircraft. For these follow-on approvals, the following items should be considered:

(i) The installation should comply with the installation instructions and limitations, and any limitations should be copied from the installation instructions to the aircraft/rotorcraft flight manual or supplement (A/RFM)(S).

(ii) Limitations imposed on the GNSS equipment during the initial approval should be imposed for follow-on equipment approval.

(iii) The installed performance tests (sections 12 and 13) should be successfully completed.

(5) Field approvals. For follow-on approvals accomplished via a field approval on FAA Form 337 (Major Repair and Alteration), the approval for return to service must be signed by one of the entities noted in 14 CFR part 43 (i.e., repair station, manufacturer, holder of an inspection authorization). The following items should be considered prior to pursuing a field approval:

(i) The applicant and Aviation Safety Inspector (ASI) should be apprised that AFMS's that are sent to the ACO to support field approvals are generally reviewed for format only. Since the ACO flight test pilot is not performing the flight testing, it would be difficult to review for content and applicability.

(ii) An installation that intermixes GNSS equipment (reference paragraph 11.d.(2)(b)) should be completely re-evaluated when the installation is in a different make/model aircraft than the initial approval.

9. GNSS Equipment Limited to VFR Use. GNSS equipment may be installed on a no-hazard basis as a supplement to VFR navigation. Such installations need only to verify that the GNSS installation does not introduce a hazard to the aircraft (e.g., properly secured for crashworthiness, not combustible, etc). A readable placard stating "GPS limited to VFR use only" must be installed in clear view of the pilot, unless the equipment automatically displays this message on start-up and pilot action is required to clear the message.

10. TSO AUTHORIZATIONS. This section provides guidance on granting TSO Authorizations for GNSS-related equipment. Only issues that are unique to GNSS equipment are discussed.

a. Applicability of TSO-C129a.

(1) TSO-C129a defines an acceptable standard for GPS equipment intended to be used as a supplement to other navigation systems.

(2) There is no plan to withdraw TSO-C129a. Manufacturers of TSO-C129a equipment can continue to manufacture that equipment.

b. Multiple TSO Authorizations. Multiple TSO authorizations may be granted for equipment that accomplishes multiple functions. However, the number of TSO markings on GNSS equipment should be minimized to avoid confusion during installation and approval. The following combinations of TSO authorizations should not be granted, as the TSOs either contradict each other or are superfluous to a TSO with broader scope:

(1) TSO-C129() must not be combined with TSO-C145 or TSO-C146;

(2) TSO-C145 must not be combined with TSO-C146 Class 1, 2 or 3 equipment. The combination of TSO-C145 with TSO-C146 Class 4 equipment is permitted; and

(3) TSO-C146 must not be combined with TSO-C115().

(4) Any class of TSO-C129 may be combined with a LAAS TSO, and should be marked accordingly (e.g., TSO-C129 Class B1 and LAAS).

c. TSO-C145 and TSO-C146 Deviations.

(1) Under TSO-C129, many deviations have been granted to manufacturers due to the relative immaturity of the TSO, which significantly modified the industry standard (RTCA/DO-208). Applicants for TSO-C145 and TSO-C146 should not expect the same latitude when requesting deviations. These TSO's do not modify the industry standard (RTCA/DO-229C) which has been internationally harmonized and received a good deal of scrutiny since it was first published in January 1996.

(2) When requesting a deviation to these TSOs, the applicant must substantiate how their implementation is equivalent. A primary objective of RTCA/DO-229C is to standardize the interface and provide compatibility across equipment from different manufacturers. Therefore, the statement of equivalency for deviations to the pilot interface requirements must also include how the implementation is operationally compatible with other GPS/WAAS equipment.

(3) Deviations that are granted to these TSOs will be incorporated into the next revision of the TSO to ensure that all manufacturers have the same opportunity to deviate.

d. Technical Data. Paragraph 9.c of Order 8150.1A Technical Standard Order Procedures states that the ACO may elect to do a cursory review of the TSO submittal package. Due to the complexity of GPS/WAAS and GPS/LAAS equipment, the ACO should:

(1) Evaluate manufacturer supplied bench test data on the equipment and verify that the tests comply with Sections 2.4 and 2.5 of RTCA/DO-229C and RTCA/DO-253A and that the equipment has passed applicable tests.

(2) Verify compliance with the appropriate environmental qualification standards and tests in RTCA/DO-160D.

(3) Verify compliance to the design assurance levels consistent with the failure condition hazard classification. If the criteria in AC 23-1309-1C for different Classes of Part 23 aircraft is applied, the installation instructions must include a summary of the approval and a limitation. For example, TSO-C146 Class 3 equipment (GPS/WAAS precision approach stand-alone equipment) that has software developed to RTCA/DO-178B Level C would state the following:

> "This equipment complies with paragraph 3a of TSO-C146 for Class I, II, and III aircraft as defined in AC 23-1309-1C. This equipment is not eligible for installation in Part 25 or Part 23 Class IV aircraft."

(4) Verify compliance with the appropriate software qualification standards and tests in RTCA/DO-178B.

(5) Verify the approval of a data process capable of updating the navigation database for GNSS stand-alone navigation equipment (TSO-C129a Class A, TSO-C146). RTCA/DO-200A defines an acceptable means of ensuring that the aeronautical data process does not corrupt data, from the publication of data by a State to its application in the equipment. Any limitations or incompatibilities between the navigation function and the database must be identified in the installation manual.

(6) The ACO should review the installation and maintenance manuals. Special attention should be given to any installation limitations.

(7) For TSO-C146, the pilot's guide must be reviewed by a flight test pilot familiar with the equipment to ensure that it is complete, concise, and easy to understand.

(8) For TSO-C146, the quick reference guide must be evaluated by a flight test pilot familiar with the equipment. Recommended format and content for this guide can be found in appendix 3 of this AC.

(9) For TSO-C146, the training program must be reviewed by a flight test pilot familiar with the equipment. This training program may be a series of manuals, a videotape, interactive CD-ROM, etc. Due to the inherent complexity in area navigation operations, it is important that these training materials are useful and help pilots learn to operate the equipment.

e. <u>Major/Minor Design Changes.</u> The following changes are among those considered by the FAA to be major changes (per 14 CFR Part 21.611).

(1) changes to the navigation or integrity algorithms; and

(2) changes to navigational display formats and navigation/function operating procedures.

11. <u>EQUIPMENT PERFORMANCE – GPS ANTENNA</u>. This section provides guidance related to the basic functions and performance of the GNSS antenna. The antenna does not have to be installed in an aircraft to comply with the means defined in this section. Typically, this guidance will be applicable to the manufacturer who is seeking a TSO Authorization (TSOA). If the manufacturer does not obtain a TSOA, this section would apply as part of the airworthiness approval.

a. TSO-C144, *Airborne Global Positioning System Antenna*, defines an acceptable means of compliance for a GNSS antenna.

b. <u>Antennas authorized under TSO-C129.</u> A number of antennas were authorized under TSO-C129, before TSO-C144 became available. This paragraph addresses the installation of these antennas.

(1) Antennas authorized as part of GPS receiver TSOA. Antennas authorized in conjunction with a GPS receiver under TSO-C129 may continue to be installed along with the associated receiver. These antennas must not be installed with a different receiver.

(2) Antennas authorized independently from a GPS receiver. TSO-C129 does not provide an adequate standard to ensure interoperability between GPS antennas, and must not be applied to antennas without reference to a specific GPS receiver. Unfortunately, some antennas have been approved under an authorization to TSO-C129 without reference to a specific GPS receiver. These antennas must not be installed with any new receivers (i.e., one for which a previous TC/STC does not exist). Manufacturers should obtain TSO-C144 for their antennas as quickly as practical to ensure compatibility with receiver equipment and to facilitate installation.

c. <u>Lightning Qualification.</u> The RTCA/DO-160D category for lightning induced transient susceptibility that best represents the transient induced in the antenna cable during the Direct Effects of Lightning test (Section 23 of RTCA/DO-160D) should be identified for comparison to the receiver susceptibility at time of installation.

d. <u>Signal Power/Loss.</u> The following issues should be addressed in the installation instructions.

(1) <u>Passive antennas authorized under TSO-C144.</u> Passive antennas are those without a preamplifier (reference RTCA/DO-228, Section 2.2.2). The maximum (and minimum, if applicable) signal loss between the antenna output port and receiver input port must be defined, to yield the maximum and minimum receiver sensitivities defined in paragraph 2.1.1.10 of RTCA/DO-229C. This information should be described as a function of the type and lengths of interconnecting cable and type and number of connectors.

(2) Active antennas authorized under TSO-C144. An active antenna is defined as one that includes a low noise power amplifier as part of the antenna assembly (reference RTCA/DO-228, Section 2.2.2). The installation instructions must identify the maximum and minimum output signal power and amplifier noise figure. These guidelines can be compared to the minimum and maximum signal levels defined in the GNSS receiver installation instructions. Guidelines on the loss associated with recommended cables and connectors should be provided so that the installer can determine the maximum and minimum signal power at the receiver port. This range will be compared to the range specified by the GNSS receiver manufacturer at time of installation.

(3) Antennas authorized with a specific receiver (TSO-C145, TSO-C146, TSO-CPAN). The installation instructions must identify the maximum (and minimum, if applicable) signal loss between the antenna output port and receiver input port to yield the maximum and minimum receiver sensitivities defined for the receiver. This information should be described as a function of the type and lengths of interconnecting cable and type and number of connectors.

e. Differential Group Delay. The differential group delay is defined within section 2.1.4.5 of RTCA/DO-229C and section 2.3.6.4.1of RTCA/DO-253A. The differential group delay of the antenna must be documented in the installation instructions for those antennas intended to support LPV and GLS approach operations. Antennas have filters that could affect the delay.

12. EQUIPMENT PERFORMANCE – GNSS SENSOR. This section provides guidance related to the basic functions and performance of the GPS sensor, including those sensors that integrate WAAS or LAAS. Appendix 3 provides unique guidance material for GPS sensors that integrate GLONASS. The sensor does not have to be installed in an aircraft to comply with the means defined in this section. Typically, this guidance will be applicable to the manufacturer who is seeking a TSO Authorization (TSOA) for TSO-C129a, TSO-C145a, TSO-C146a, TSO-CPAN, or TSO-CVDB. If the manufacturer does not obtain a TSOA, this section would apply as part of the airworthiness approval.

a. Acceptable Means.

(1) GPS. TSO-C129() defines an acceptable means of compliance for GPS equipment that is intended to supplement other navigation equipment on the aircraft. With one exception, GPS equipment that complies with this standard has a limitation that the aircraft must be equipped with other means of navigation appropriate to the route to be flown. The exception is the use of this equipment for oceanic and remote operation, if several additional features are provided as described in Appendix 1 of this AC.

(2) GPS/WAAS. RTCA/DO-229C, Section 2.1, defines an acceptable means of compliance for the GPS sensors capable of using WAAS. RTCA/DO-229C is a complete set of standards for GPS and GPS/WAAS and should not be used in conjunction with TSO-C129(). GPS equipment that complies with the standards in DO-229C does not have a limitation that the aircraft must be equipped with other means appropriate to the route to be flown.

(3) GPS/WAAS/LAAS sensor. TSO-C145a defines an acceptable means of compliance for this equipment when operating in the GPS/WAAS mode. When operating in the GPS/LAAS mode, the equipment must comply with the requirements of Section 2 of RTCA/DO-253A.

(4) GPS/LAAS. TSO-C129() defines an acceptable means of compliance for this equipment when operating in GPS mode (i.e., outside the coverage of a selected LAAS ground facility). When operating in the GPS/LAAS mode and conducting a GLS approach, the equipment must comply with the requirements of Section 2 of RTCA/DO-253A. When operating in GPS/LAAS mode and not conducting a GLS approach, the equipment must comply with the sensor requirements of RTCA/DO-253A (for PVT) and the navigation requirements of TSO-C129. For Class B1 and B2 equipment, the requirements in paragraph (a)(4)(vii) do not apply when a LAAS-correction position is being used. For Class C1 and C2 equipment, the requirements in paragraph (a)(5)(vii) do not apply when a LAAS-corrected position is being used. GPS/LAAS equipment carries the basic GPS limitation that the aircraft must be equipped with other means of navigation appropriate to the route to be flown.

b. Non-Standard Mask Angle. All equipment has a mask angle, the elevation angle above the horizon at which the GNSS receiver considers satellites for use in the solution. The accuracy and reliability of GPS signals is affected by a number of factors, including shadowing of the signal (by a portion of the aircraft or local terrain), the GPS antenna gain and atmospheric effects (ionosphere and troposphere). A 5 degree mask angle is standard. Receivers may track a satellite below 5 degrees, but must not incorporate it in the navigation position solution unless all of the following issues are addressed:

(1) The actual antenna characteristics below 5 degrees must be used when demonstrating compliance to the performance characteristics defined in TSO-C129a, RTCA/DO-229C or RTCA/DO-253A. Since the antenna standards in TSO-C144 are written against a 5 degree mask angle, use of a mask angle below 5 degrees requires that a specific antenna be included as part of the TSOA for the sensor.

(2) When testing the susceptibility of the receiver to interference, the signal level of the GPS signals must be adjusted based on the minimum antenna gain relative to a -4.5dBic for a standard antenna. The interference power cannot be adjusted down as the location of the interference emitter is unknown. This will result in a lower signal-to-noise ratio as the signal power has to be reduced based on antenna gain but the interference power would not be reduced.

(3) Accuracy must be demonstrated for satellites at the design mask angle. The sensor may use a weighted position solution, which deweights satellites at low elevation angles based on the accuracy demonstrated for those elevation angles.

(i) For equipment that assumes that GPS selective availability is active, the ionospheric, tropospheric, and airframe multipath errors can be considered negligible down to 2 degrees. The use of a mask angle below 2 degrees requires validation of the error models for these effects.

(ii) For GPS equipment that takes advantage of the discontinuance of selective availability, the aviation community has validated error models down to a 5 degree mask angle (see RTCA/DO-229C, Appendices A and J). The use of a mask angle below 5 degrees requires validation of the error models for these effects.

(4) Prediction programs and availability assessments intended to support flight planning functions must use the equipment mask angle except as follows:

(i) For en route, terminal and nonprecision approach operations, the predicted mask angle must be at or above 2 degrees.

(ii) For precision approach, the predicted mask angle must be at or above 5 degrees.

c. Interference Testing. The GPS and WAAS signal acquisition and track performance, WAAS message loss rate, integrity and accuracy requirements will be verified during minimum signal conditions and interference. These tests must be conducted in accordance with the test conditions and procedures specified in RTCA/DO-229C.

d. Prediction Programs. Unlike conventional ground-based navigation aids which have a direct correlation between a facility outage (VOR fails) and the loss of an operational capability (VOR approach is unavailable), GPS satellite failures have a non-intuitive impact on operational capability. The operator is responsible for considering the effects of satellite outages during flight planning. Prediction programs and availability assessments are essential to enabling the operator to fulfill this responsibility.

(1) The FAA plans to provide NOTAM service for all approach operations using TSO-C145 or TSO-C146 equipment, and for GLS precision approach operations using LAAS equipment.

(2) For oceanic/remote operation based on GPS, a prediction program must be provided to determine if GPS satellite outages have an operational impact on oceanic/remote operations.

(3) For basic RNAV operations in Europe, a prediction program should be provided (see AC 90-96 for additional information).

(4) For non-precision approach operations using TSO-C129 equipment, manufacturers must provide a prediction availability based upon RAIM. For non-precision approach operations using GPS/WAAS equipment, this capability should be provided to support GPS operations outside of the WAAS coverage area.

(5) Prediction Program Requirements. The following guidelines apply to any prediction program that is intended to assess the operational impact of satellite outages.

(i) This prediction program can be provided on any processing platform (in the GPS equipment or not).

(ii) The prediction program software should be developed in accordance with at least RTCA DO 178B/EUROCAE 12B, level D guidelines.

(iii) The program should use either a RAIM algorithm identical to that used in the airborne equipment, or an algorithm based on assumptions for RAIM prediction that give a more conservative result.

(iv) The program should calculate RAIM availability based on the same satellite mask angle used in the equipment, but not less than 2 degrees for en route and terminal operations or 5 degrees for precision approach operations.

(v) The program should have the capability to manually designate GPS satellites which are expected to be out-of-service for the intended flight.

(vi) For en route predictions, the program should allow the user to select the intended route (including declared alternates) and the time and duration of the flight. The maximum outage of RAIM (and FDE, if applicable) should be provided, and any predicted outages of navigation capability must be identified. Note that for oceanic/remote operations, the maximum duration of an FDE outage cannot exceed 34 minutes for RNP-10 operation (see Order 8400.12a) and 51 minutes for MNPS operation (see AC 90-94). For B-RNAV operations, the maximum acceptable duration of a RAIM outage is 5 minutes (see AC 90-96).

(vii) For approach predictions, the program should allow the user to select the destination and expected time of arrival, and provide a RAIM availability prediction over an interval of at least ±15 minutes computed in intervals of 5 minutes or less about the ETA.

13. EQUIPMENT PERFORMANCE – SENSOR INTERFACE TO OTHER SYSTEMS.

a. Interface to multi-Sensor navigation systems. Equipment requirements applicable to the integration of a GNSS sensor with a multi-sensor navigation system is in TSO-C129 (Class B and C equipment) and TSO-C115b.

b. Interface to non-navigation systems. GNSS sensors may provide input to a variety of applications, including terrain awareness and warning systems (TAWS), automatic dependent surveillance (ADS), and moving map displays for situational awareness. The guidance material in this AC for sensors applies to all of these integrations, and should be used with the guidance material for the application. For specific information relating to TAWS equipment, see TSO-C151a. GPS, GPS/WAAS, or GPS/LAAS position information may be used as the horizontal position determination as addressed in Appendix 1, Section 5 of TSO-C151a.

14. <u>EQUIPMENT PERFORMANCE – STAND-ALONE NAVIGATION EQUIPMENT.</u> In addition to the guidance in this section, stand-alone navigation equipment incorporates an antenna and a sensor and should comply with the guidance in paragraphs 11 and 12 of this AC.

a. <u>Acceptable Means</u>.

(1) <u>GPS</u>. TSO-C129() defines an acceptable means of compliance for GPS equipment.

(2) <u>GPS/WAAS</u>. TSO-C146a defines an acceptable means of compliance for GPS/WAAS equipment. RTCA/DO-229C is a complete set of standards and should not be used in conjunction with TSO-C129().

Note: In addition to the sensor improvements, there are a number of differences between TSO-C129() and TSO-C146, most notably the compatibility of TSO-C146 equipment with RNP RNAV operations as described in Appendix 5, more explicit pilot interface requirements (see RTCA/DO-229C, Section 2.2.1.1), and a Vector-to-Final capability (see RTCA/DO-229C, Section 1.8.2.4).

(3) <u>GPS/WAAS/LAAS</u>. TSO-C146a defines an acceptable means of compliance for this equipment when operating in the GPS/WAAS mode. When operating in the GPS/LAAS mode and conducting a GLS approach, the equipment must comply with the requirements of Section 2 of RTCA/DO-253A. When operating in the GPS/LAAS mode and not conducting a GLS approach, the equipment must comply with the sensor requirements of Section 2 of RTCA/DO-253A (for PVT) and the navigation requirements of RTCA/DO-229C (Section 2.2).

(4) <u>GPS/LAAS</u>. TSO-C129() defines an acceptable means of compliance for this equipment when operating in GPS mode (i.e., outside the coverage of a selected LAAS ground facility). When operating in the GPS/LAAS mode and conducting a GLS approach, the equipment must comply with the requirements of Section 2 of RTCA/DO-253A. When operating in GPS/LAAS mode and not conducting a GLS approach, the equipment must comply with the sensor requirements of Section 2 of RTCA/DO-253A and the navigation requirements of TSO-C129a, Class A1 or A2 (except the RAIM requirements of paragraph (a)(3)(xv)).

b. <u>Evaluation of Human Factors.</u>

(1) The applicant is encouraged to involve the ACO as early as possible in the evaluation of the pilot interface.

(2) Controls.

(i) Appropriate feedback must be supplied during data entry, with confirmation of input action prior to activation based upon that input. Any equipment prompts must be easily understood. A suitable interface should be provided to allow data input, data output, and control of equipment operation.

(ii) Particular attention should be placed on the controls required to perform operations that occur with a high frequency or that must be conducted under potentially stressful or busy conditions such as terminal area operations and missed approaches. The workload associated with accessing the Direct-To function, entering a Hold mode, executing a missed approach, and initiating an approach to a different runway at the same airport (or to the alternate airport) following a missed approach should be minimized.

(iii) Controls intended for use in flight should be designed to minimize errors and, when operated in all possible combinations and sequences, should result in a condition whose presence or continuation would not be detrimental to the continued performance of the equipment. Controls should be designed to maximize operational suitability and minimize pilot workload. The amount of force required to activate knobs/buttons should be acceptable, feedback to the pilot should be adequate, and risk of inadvertent activation or deactivation should be minimized. Knob shape and size should not interfere with equipment use and should help distinguish controls. Reliance on pilot memory for operational procedures should be minimized. For those procedures that require pilot memory items, the memory item steps should be minimal and as intuitive as possible. The control/display should be operable with the use of only one hand.

(iv) Controls that are normally adjusted in flight should be readily accessible and properly labeled as to their function. Controls that are not normally adjusted in flight should not be readily accessible to the flight crew. Labels should be horizontally oriented, unobstructed by use of controls, descriptive of control function, and consistent across the equipment. The use of abbreviations should be minimized. When abbreviations are used, they should conform to Section 2.2.1.1.5 of RTCA/DO-229C.

(v) Controls should be arranged logically according to functional groups, sequence of use, and frequency of use. All displays and controls must be arranged to facilitate equipment usage.

(3) Messages.

(i) Standard pilot terminology should be used and their meaning should be readily understood.

(ii) Messages should indicate what action should be considered or taken and should employ the minimum number of words required to convey its meaning. Messages or annunciation of messages not relevant to the execution of an approach, landing, rollout, or missed approach should be suppressed during the approach. Messages not requiring pilot action during flight should not be shown during flight. Messages should be operationally relevant to current or upcoming phases of flight. Pilot recall of messages from the message storage queue should bring up the most important messages first. The hierarchy of messages should be determined by the impact of the message on the safety of the flight for the current and upcoming phases of flight. Presentation of messages should not obscure safety-critical portions of guidance displays. Messages requiring prompt pilot action should stay up until action is taken or the pilot cancels the message. Safety-critical messages should be accompanied by an aural alert if that alert is not already provided by another aircraft system. Messages of operational significance to the flight should not time out.

(4) Prompts. Where possible, prompts should specifically indicate what programming action should be done next (e.g., "enter next waypoint"). Where possible, prompts should indicate the specific control that should be used next, rather than relying on pilot memory. Multiple prompts requiring different actions should be presented sequentially rather than concurrently.

(5) Cross-Track Deviation Display. Minimum discernible movement, accuracy of the centered display, resolution of the electrical output, linearity of the display and/or electrical output, and display latency should be as specified in Section 2 of RTCA/DO-229C for applicable navigation modes. Deviation display designs with display ranges and resolutions outside the bounds of the required values should be substantiated by demonstration, by reference to appropriate empirical data, or by similarity to previous certified range/resolution displays.

(6) For TSO-C146a equipment, the flight crew workload requirements in paragraph 2.2.1.1.3 of RTCA/DO-229C are particularly important and compliance to the requirements should be verified. The manufacturer must also have specific and detailed rationale for deviating from any of the recommendations defined in Table 2-4 of RTCA/DO-229C.

(7) For TSO-C146a equipment, the manufacturer must identify any acronyms that do not comply with the recommendation in RTCA/DO-229C, paragraph 2.2.1.1.7. A specific and detailed rationale for deviating must be documented.

(8) For TSO-C146a equipment, compliance to the requirements should be demonstrated under the test procedures specified in paragraph 2.2.5.11 of RTCA/DO-229C. Someone not familiar with the development of the equipment should conduct these tests to properly evaluate the pilot interface, documentation, and training information. This person should have not had time to become familiar with its operation, other than the opportunity to review the documentation and training materials to be supplied with the equipment.

c. Navigation Database. For area navigation equipment, the navigation database is an essential component of the ability of the equipment to perform its intended function. Guidelines pertaining to the navigation database can be found in RTCA/DO-200A, Requirements on the Aeronautical Data Process. Particular attention should be paid to the specification of the format of data loaded into the navigation database, as described in RTCA/DO-200A, Appendix 3.

(1) Database Process. The equipment manufacturer is usually the last link in the aeronautical data processing chain, as the format for the data loaded in the final database is typically proprietary. The applicant for a TSOA must identify an aeronautical data process which will be accessible to the equipment users. RTCA/DO-200A provides an acceptable means of compliance for this aeronautical data process. Note that the approval of the database process is included as part of the TSOA for GNSS equipment.

(2) Installation Instructions. The installation instructions must contain a limitation identifying the requirements for the navigation database. This limitation will also be included in the A/RFM(S). The limitation should state: "Database xxxxxxx-yyy must be installed and contain current data", where "xxxxxxxx" is the primary identification of the database, "yyy" is the secondary identification tied to any changes in the database (content or format) that impact the operational capability of the navigation system, considered to be a major change under a TSOA. Minor changes may be indicated with a subsequent version level by amending "-zzz" to the part number. Applicability dates should also be accessible.

(3) Reference System. The installation instructions should explain that GNSS navigation is referenced to the WGS-84 coordinate system. The following text is recommended: "Navigation information is referenced to WGS-84 reference system, and should only be used where the Aeronautical Information Publication (including electronic data and aeronautical charts) conform to WGS-84 or equivalent." This explanation should also be included in the general section of the A/RFM(S).

(4) Government Provided Electronic Database. Electronic databases sponsored by a government organization must follow the same database assurance processes as described above and in RTCA/DO-200A. GNSS equipment compatibility with government-provided electronic databases must be verified during the TSO and/or installation approval process.

15. EQUIPMENT PERFORMANCE – LAAS VDB RECEIVER.

a. Section 2 of RTCA/DO-253A defines an acceptable means of compliance for LAAS VHF data broadcast receivers.

b. The receiver should be tested using the test procedures specified in Section 2.5.2 of RTCA/DO-253A.

c. FM Immunity. FM immunity is required for VDB receivers. The test procedure specified in RTCA/DO-253A, Section 2.5.2.2.9.2 can be used, with the exception that the undesired FM signal should be tuned to 107.9 MHz.

16. INSTALLATION ISSUES – GENERAL. The following issues apply to the installation of all GNSS equipment intended for IFR use.

a. Failure Classification.

(1) From en route and terminal operations, the loss of navigation information is typically considered to be a major failure condition for the aircraft (see AC 25.1309-1; AC 23.1309-1; AC 27-1; or AC 29-2 as applicable to the aircraft). GNSS navigation data is considered to be misleading when unannunciated position errors exist. For en route, terminal, and non-precision approach (NPA) and LNAV/VNAV approaches, presenting misleading information to the flight crew is also considered to be a major failure condition for the aircraft. For LPV and GLS approaches, presenting misleading information to the flight crew is considered to be a hazardous failure condition. These failure classifications are summarized in the following table.

Table 3. Typical Hazard Classifications

	En route/ Terminal Area/ NPA (LNAV)	NPA with Vertical Guidance (LNAV/VNAV)	LPV Approach	GLS Precision Approach (Cat. I)
Loss of Navigation	Major	Minor	Minor	Minor
Misleading Information	Major	Major	Hazardous	Hazardous

(2) The applicant must conduct a safety assessment of the GNSS equipment installation to verify that design errors and failure modes meet the probability requirements for that failure class. AC 25.1309-1, AC 23.1309-1, AC 27-1, or AC 29-2, per the latest revision levels as applicable, provide an acceptable means for showing that the hardware complies with pertinent airworthiness requirements.

b. Software Considerations. AC 20-115, current edition, defines an acceptable means of qualifying software. The applicant is encouraged to submit the Plan for Software Aspects of Certification (PSAC) early in the software development process. Early submittal will allow timely resolution of issues such as partitioning and determination of software levels.

c. Installation Instructions.

(1) The equipment must be installed in accordance with the instructions and limitations provided by the manufacturer of the equipment.

(2) Equipment should be installed with separation between wires of redundant systems. Wire separation will reduce the possibility of loss of navigation due to a single event. When wire separation cannot be achieved, the following questions must be evaluated and the potential for common failure modes minimized:

(i) Is it possible for a cable harness to be exposed to wire chafing in a manner that both GPS channels fail simultaneously?

(ii) Is the cable harness located near flight control cables, high electrical capacity lines or fuel lines?

(iii) Is the cable harness located in a protected area of the aircraft (isolated from engine rotor burst)?

(iv) Is any electromagnetic interference (EMI) between GNSS systems caused by cable routing?

d. Environmental Considerations.

(1) Most equipment will have been tested by the manufacturer to the environmental categories described in RTCA/DO-160D, with results described in an environmental qualification form. For this equipment, the environmental categories (or criteria) to which the equipment has been tested must be compatible with the aircraft environment in which the GNSS system is installed.

(2) For equipment which has not been tested to the environmental categories described in RTCA/DO-160D, comparable testing must be conducted and a thorough definition of the aircraft environment must be developed through testing of the normal and abnormal environments. At a minimum, the environmental performance requirements identified in section 2.4 of RTCA/DO-229C must be met for all components in the airborne GNSS system.

17. INSTALLATION ISSUES – GPS ANTENNA.

a. Antenna Placement.

(1) The antenna must be separated as much as possible from transmitting antennas (e.g., VHF, TCAS, SATCOM, and HF). For small aircraft, the antenna should also be separated as much as possible from the windscreen to prevent case-to-antenna coupling.

(2) The antenna installation should minimize the potential for signal blockage by any portion of the aircraft during aircraft maneuvering. Shadowing by aircraft structure can adversely affect the operation of the GNSS equipment. Typically, a GNSS antenna is located forward or aft of the wings on the top of the fuselage.

(3) For installations on rotorcraft, the effects of the rotor blades on antenna performance must be considered. Reference paragraph 13a(2)(b) ground test, to verify compatibility.

(4) The installer must ensure that a 5 degree mask angle (or lower if the receiver installation instructions identify a lower mask angle) is provided by the installation. This includes consideration of antenna location and blockage, with the aircraft at typical cruising attitude and during typical maneuvers.

b. Anti-Ice Protection. If the aircraft is approved for flight into known icing conditions, the antenna must not be susceptible to ice buildup (i.e., is installed in a non-icing location on the aircraft, or is of a sufficiently low profile that ice does not accumulate on the antenna). Alternatively, the equipment can be shown to operate satisfactorily when the antenna is subject to icing if there are no harmful effects of the ice build-up, such as possible ingestion into the engine of accumulated ice or degradation in aerodynamic performance. The effects of ice accumulation on the antenna, if any, can be found in the manufacturer's installation instructions. See AC 23.1419-2A and AC 25-1419-1 for additional guidance.

c. Antenna Cables. Double shielded cables should be used to prevent interference coupling into the cable.

d. Structure. Any modifications to the aircraft to install a new antenna need to be evaluated for their impact on aircraft structure. For specific guidance relating to modifications in the fuselage structure for Part 23 aircraft, see AC 23-5, Cutouts in a Modified Fuselage of Small Airplanes.

18. INSTALLATION ISSUES – GNSS SENSOR.

a. Antenna/Sensor Compatibility.

(1) Using the guidelines in the installation instructions, verify the antenna installation is compatible with the GNSS equipment. This may be accomplished by one of the following:

(i) The antenna (part number) is identified in the GNSS equipment installation instructions as compatible;

(ii) The GNSS equipment installation instructions state that the equipment is compatible with any standard, passive TSO-C144 antenna. In this case the antenna should have authorization to TSO-C144. Compare the RTCA/DO-160D category for lightning-induced transients specified in the antenna installation instructions with the category defined in the receiver installation instructions; or

(iii) The GNSS equipment installation instructions state that the equipment is compatible with any standard, active TSO-C144 antenna. A signal power budget must be defined that takes the output power at the low-noise amplifier of the antenna (as defined in the antenna installation instructions) and matches that to the receiver dynamic range and sensitivity (as defined in the GNSS equipment installation instructions). Compare the RTCA/DO-160D category for lightning-induced transients specified in the antenna installation instructions with the category defined in the receiver installation instructions.

(2) Use the guidelines in the installation instructions when determining what cables and connectors to use to connect the antenna to the receiver, including cable lengths that result in acceptable loss of signal power.

(3) Ensure antenna and GNSS equipment compatibility for aircraft equipped with SATCOM. Some equipment may have been qualified to less stringent interference levels for aircraft installations without SATCOM.

b. Interference - Electromagnetic Compatibility (EMC).

(1) The equipment must not be the source of objectionable conducted or radiated interference or be adversely affected by conducted or radiated interference from other equipment or systems installed in the aircraft.

(2) Proper grounding of GNSS and other equipment is essential to ensuring EMC.

(3) When possible, do not install the sensor near a VHF radio.

(4) The following paragraphs identify potential sources of interference and means of mitigating that interference:

(i) SATCOM. Out-of-band SATCOM emissions and in-band intermodulation between multiple channel SATCOM installations can affect GNSS. GNSS equipment must not be installed in aircraft with multiple SATCOM channels unless the simultaneous use of interfering frequencies can either be prevented or demonstrated not to interfere with the operation of the GNSS equipment. Note that some equipment is not compatible with SATCOM installations at all, as noted in the installation instructions.

(ii) VHF Communications. Harmonic, spurious, and local oscillator harmonics from VHF equipment can cause interference to GNSS. Interference can be mitigated by:

(A) Installing filters at the output of the VHF transmitter to prevent antenna-to-antenna interference. Such filters should have an insertion loss of 2 dB or less to preclude the need for reevaluation of installed VHF transceiver performance.

(B) Installing the GNSS equipment as far away as feasible from any VHF transmitter equipment (to prevent case-to-case interference).

(C) Replacing the VHF equipment.

(iii) ELT. An ELT can re-radiate DME signals that can interfere with GPS. Replacing the ELT can eliminate this problem.

(iv) DME. DME has been known to cause interference to GPS. Replacing the DME transceiver can eliminate the problem.

c. Interface Requirements. Ensure sensor compatibility for aircraft systems utilizing the position output (e.g. flight management system, automatic dependent surveillance system). Systems should use the same bus standard (e.g., ARINC 429 with ARINC-743 data, RS-232 with RTCA/DO-229 Appendix L data).

(1) Operation of the GNSS equipment must not adversely affect the performance of other aircraft equipment. Likewise, operation of the GNSS equipment must not interfere with the operation of other equipment installed in the aircraft.

(2) Additional information on interfacing a GNSS sensor with a multi-sensor system can be found in AC 20-130A.

d. GPS Equipment (with or without LAAS). Equipment that uses TSO-C129 as the basis for the GPS functions has a limited ability to meet navigation requirements. This limitation should be documented in the A/RFM(S) as follows: "The aircraft must have other approved navigation equipment installed and operating appropriate to the route of flight".

19. INSTALLATION ISSUES – SENSOR INTERFACE TO OTHER SYSTEMS.

a. Interface to multi-Sensor navigation systems. Guidance material applicable to the integration of a GNSS sensor with a multi-sensor navigation system is in AC 20-130A.

b. Interface to non-navigation systems. GNSS sensors may provide input to a variety of applications, including terrain awareness and warning systems (TAWS), automatic dependent surveillance (ADS), and moving map displays for situational awareness. The guidance material in this AC for sensors applies to all of these installations, and should be used with the guidance material for the application. For specific information relating to TAWS equipment, see AC 25-23, *Airworthiness Criteria for the Installation Approval of a Terrain Awareness and Warning System for Part 25 Airplanes*. GPS, GPS/WAAS, or GPS/LAAS position information may be used as the horizontal position determination as addressed in paragraph 11 of AC 25-23.

20. INSTALLATION ISSUES – STAND-ALONE NAVIGATION EQUIPMENT. In addition to the guidance in this section, stand-alone navigation equipment incorporates an antenna and a sensor and should comply with the guidance in paragraphs 16 and 17 of this AC.

a. GNSS Configuration Strapping. Often, GNSS equipment uses software configuration straps. These software configuration straps disable/enable functionality, configure the input/output formats, determine the displayed units of measure, and more. The software configuration programming documentation must become a part of the installation package and should be included in the Master Drawing List.

b. General Human Factors Considerations.

(1) Control Accessibility. Controls installed for in-flight operation should be readily accessible from the pilot's seated position. Only single-hand operation should be required, the controls should be readily identifiable, and the use of controls should not obscure pertinent displays.

(2) Inadvertent Turnoff. System controls should be arranged to provide adequate protection against inadvertent system turnoff.

(3) Control/Display Visibility.

(i) The appropriate flight crew member(s) should have an unobstructed view of displayed data when in the seated position.

(ii) Compliance with limitations in the installation instructions for display readability should be verified.

(iii) All displays, controls, and annunciators must be easily readable under all normal cockpit conditions and expected ambient light conditions (total darkness to bright, reflected sunlight).

(4) Annunciations.

(i) Visual annunciations must be consistent with the criticality of the annunciation and must be readable under all normal cockpit illumination conditions. Visual annunciations must not be so bright or startling as to reduce pilot dark adaptation.

(ii) Audible alarms should be sufficiently loud and of appropriate pitch quality, duration and pattern. Alarms should be easily deactivated (but not easily deactivated inadvertently).

c. Source Selection. For installations where GNSS outputs can drive a display that is shared with other navigation equipment (e.g., VOR/DME, ILS, MLS), the pilot must be able to select the source of guidance, and the selected source must be clearly annunciated to the flightcrew. GNSS-based navigation (GPS, GPS/WAAS, GPS/LAAS) need not be differentiated. Annunciation of the selected source should be driven by the same switch to preclude erroneous information in case of switch failure. Autopilot operation should be inhibited if the displayed source is not the same as the source driving the autopilot (this must be the case for approach operation).

d. Navigation Display.

(1) The horizontal (and vertical) deviation(s) display(s) and failure annunciation shall be located within the pilot's primary field of view, as shall any indication requiring immediate aircrew action. For the purpose of this AC, the primary field of view is within 15 degrees of the pilot's primary line of sight.

(2) Displays used for loss of integrity monitoring, waypoint sequencing, start of a turn, turn anticipation, active waypoint, distance to active waypoint, desired track and actual track (track angle error), TO/FROM indication, approach mode annunciation, and automatic mode switching shall be located within the pilot's normal field of view. If the box is located in the center radio stack, the lateral normal field of view is from the center of the airspeed indicator to and including the box. If the box is installed to the left of the airspeed indicator, the lateral normal field of view is the center of the altimeter to and including the box. The vertical normal field of view includes the basic "T" instrument and the box.

e. Failure Indications.

(1) It is important to install the equipment such that all failure conditions result in appropriate displays.

(2) For installations not incorporating an external navigation display (CDI, HSI, etc.), complete blanking of the Control Display Unit (CDU) display is acceptable.

(3) Presentation of a failure/status annunciation (flag or integrity annunciation) does not require removal of navigation information from the navigation display.

(4) A unique annunciation of the loss of integrity monitoring should be provided.

f. Dual GNSS Installations.

(1) Synchronization. Dual installations should be synchronized whenever possible to reduce crew workload and prevent confusion over which system/flight plan is driving the navigation data. If the Failure Hazard Assessment requires dual GNSS or is operationally required, then synchronization is required. If the navigation equipment are not synchronized, then the following issues should be evaluated:

(i) The pilot and co-pilot should be able to view and enter data in the offside unit. This must not interfere with throttle levers, flap handle, etc.

(ii) The workload associated with manually updating both units to maintain consistency between them should be evaluated.

(iii) There should be no possible confusion as to the unit that is in command (either driving autopilot or the display for the pilot flying.

(iv) Displays and annunciations should be evaluated for possible inconsistencies that result from differences in the two units (e.g., different flight plans could result in one unit going into approach mode while the other unit does not). These inconsistencies must not cause a misleading situation. These are of particular concern when the cockpit architecture allows for cross coupling (e.g. GNSS-2 switched to drive side 1 displays).

(2) Intermixing of RNAV equipment. Installation of area navigation equipment with different crew interfaces can be very confusing and lead to problems since they may have conflicting methods of operation and conflicting display formats. There can be problems even when intermixing different versions of the same equipment. For approach operation, intermixing of RNAV equipment is not allowed. At a minimum, considerations should be given to the following potential incompatibilities, especially when the cockpit architecture allows for cross coupling (i.e. GNSS-2 switched to drive side 1 displays).

(i) Data entry: The two units must have consistent methods of data entry, and similar pilot procedures for accomplishing common tasks. RTCA/DO-229C Section 2.2.1.1.3 identifies a minimum set of common tasks that should be considered. Any differences should be evaluated for pilot workload. If the wrong procedures are used (the procedures for data entry on the offside are used), there must be no misleading information and it should be easy to identify and recover from the mistake.

(ii) CDI scaling: Sensitivity must be consistent or annunciated. Stand-alone navigation equipment that complies with RTCA/DO-229C will have consistent scaling provided the flight plans between the units are identical (see synchronization issues above).

(iii) Display symbology and mode annunciations: There should be no conflicting symbols or annunciations (e.g., a common symbol used for two different purposes), and differences should be specifically evaluated to evaluate the potential confusion they may cause.

(iv) Mode logic: The modes internal to the equipment and interfaced to the rest of the aircraft should be consistent.

(v) Equipment failure: The effect of failure of one unit must not result in misleading information.

(vi) Displayed data: The display of primary navigation parameters (reference RTCA/DO-229C sections 2.2.1.4, 2.2.2.4, 2.2.3.4, and 2.2.4.4) must use consistent units and a consistent notation. Any inconsistency in the display of the primary information should not be approved.

(vii) Database differences: Differences in the area navigation database must not be allowed. A means of ensuring compatible updates between the units must be defined and documented in the A/RFM(S).

g. Interface to Flight Guidance System (FGS).

NOTE: When used in this section, the word "consistent" means that the installed GNSS equipment does not alter the cockpit design philosophy or intended function of an FGS mode, switch or annunciation.

(1) Connection to the autopilot must be consistent with the autopilot installation instructions and the GNSS installation instructions.

(2) The GNSS steering commands must be magnitude and rate limited within the FGS. For GNSS steering modes, protection must exist in the GNSS or the FGS to keep the aircraft within the approved operational envelope (e.g. roll, pitch, speed, and altitude). Many FGS systems rely upon the interfacing equipment to provide the protection mechanisms for the external engaged mode (e.g. LNAV/VNAV). For example, with VNAV steering, the FGS provided speed protection (e.g. alpha floor) might not be provided for when engaged in VNAV (or during the WAAS PA phase). VNAV in this case, may be controlling to path (without reference to speed), in which case for an improperly constructed descent or glide path, could result in the aircraft exceeding the speed margins. During precision approach operations, most GNSS equipment will output lateral and vertical deviations (similar to ILS) to the FGS (rather than steering commands). If ILS look-alike deviations are not provided, then FGS limit protections must be provided (either in the GNSS or FGS). AC 20-129 provides guidance for airworthiness approval of vertical navigation (VNAV) systems for use in the U.S. National Airspace System (NAS) and Alaska.

(3) A positive, continuous and unambiguous indication must be provided of the modes actually in operation, as well as those that are armed for engagement. In addition, where engagement of a mode is automatic, clear indication must be given when the mode has been armed by either action of a member of the flight crew, or automatically by the system.

(4) The GNSS equipment must be compatible with the FGS modes of operation. For example the arm, engage and disengage sequence of the GNSS equipment must be consistent in the annunciation and engage/disengage timing of the FGS. This is particularly important during WAAS approach, which include different levels of service (reference section 2.2.4.7.4 of RTCA/DO-229C). Failure of a GNSS mode to engage when selected or when disengaged (manual or automatic) must result in similar annunciation schema as if an FGS mode failed to engage or disengaged.

(5) If the GNSS equipment is connected to a reduced bank selector, the GNSS bank angle, like the FGS, must not be limited by this switch selection during approach. Consistency in the operation must be maintained.

(6) Some aircraft operate in areas of the operational flight envelope where buffet onset can occur when normal maneuvering load factors are present (e.g. at higher altitudes). This is a concern, since the GNSS equipment can automatically sequence waypoints and initiate turn maneuvers which may or may not have the pilots attention. If buffet protection is not provided for in the GNSS or FGS (e.g. bank angle limiting, or limiting of cruise altitude based upon buffet margin), an A/RFM(S) limitation should be added to the performance section, prohibiting cruise operation at weight/altitude combinations that result in buffet margins less than 1.4g.

(7) For those aircraft that have incorporated bank angle limiting, consideration should be given to whether the GNSS equipment is defining a path that cannot be flown. This becomes particularly important for RNP RNAV routes where containment is an issue (reference appendix 7 of this AC).

h. Interface to Magnetic/True Switch.

(1) If a MAG/TRUE heading reference switch is installed in the aircraft, the GNSS equipment must be compatible with its operation. The GNSS equipment must maintain consistency in the displays and operation for both manual and automatic heading reference changes.

(2) If a MAG/TRUE heading reference switch is not installed in the aircraft (that is the RMI or HSI can only be referenced to magnetic headings), the GNSS must not be allowed to be configured for true headings (limitation in the A/RFM(S) and/or configuration programming). This requirement may not be necessary if other means are established to ensure display compatibility.

i. Interface to Barometric Altimeter.

(1) If there is an air data source select switch, when the pilot de-selects an air data source the de-selected source must no longer be used by the GNSS equipment. This becomes important for barometric-aided FDE, since erroneous altitude inputs to the FDE algorithm could lead to improper satellite detection and exclusion.

(2) If the GNSS equipment requires barometric corrected (or pressure) altitude data for certain operations (identified in the GNSS installation instructions), the installation should provide an automatic altitude input from the air data system to the GNSS such that additional pilot actions are not required.

(3) If an automatic input of the barometric corrected altitude is not available, an alert for the pilot during approach must be provided indicating the need to enter the barometric pressure setting in the GNSS. If the system requires multiple entries to enter the correction, the workload should be evaluated during an approach.

21. INSTALLATION ISSUES – LPV AND GLS APPROACHES. GNSS equipment intended for LPV or precision approach operation must provide for the following:

a. Update Rate. For sensors that support an LPV or precision approach capability (Class 3 equipment of TSO-C145A, LAAS equipment), the position used for precision approach must be output at 5 Hz.

NOTE: TSO-C145A only requires a 1 Hz output, which can only be considered for use in applications with inertial aiding.

b. Differential Group Delay. When installing GNSS equipment that provides precision approach capability, verify that the differential group delay of the antenna is less than or equal to the requirement for the receiver (as specified in RTCA/DO-229C, section 2.1.4.5). The differential group delay of the antenna will be documented in the installation instructions, and the requirement for differential group delay will be documented in the receiver installation instructions. Antennas have filters that could affect the delay. If the antenna instructions do not document the differential group delay, then the data should be obtained and found to be within the limits specified in the receiver installation instructions before approval can be given for approach operations.

c. Performance Monitoring. Sufficient information must be provided in the flight deck to allow the pilots to monitor the progress and safety of the approach operation. This in flight performance monitoring must include:

(1) Unambiguous identification of the intended path for the approach, (e.g. WAAS approach, identifier/frequency, and selected navigation source), and

(2) Indication of the position of the aircraft with respect to the intended path (e.g. cross track and vertical deviation information).

d. System Status. The flight crew must have a means to evaluate the capability of the aircraft elements to accomplish the low visibility operation prior to and after departure. The flight crew must be advised of failed aircraft system elements affecting the decision to continue to the destination or divert to an alternate.

e. Annunciations. For installations containing more than one approach navigation source, the navigation source (e.g. ILS, GLS) selected for the approach must be positively indicated in the primary field of view at each pilot station.

f. Accessibility.

(1) Single systems must be accessible and usable by either pilot located at a pilot or copilot crew station.

(2) Dual (or more) systems must have a convenient and expedient way to “crossload” and be kept updated.

22. INSTALLATION ISSUES – LAAS VDB RECEIVER.

a. Interference – EMC. The VDB receiver may be susceptible to interference from VHF communications equipment on the aircraft.

(1) For horizontally polarized VDB antenna operating in the presence of a +40 dBm (EIRP) vertically polarized VHF communications transmission, at least 53 dBc of isolation is required to protect the VDB receiver from desensitization. This isolation maybe achieved through a combination of 15 dBc of cross-polarization rejection and -38 dBc of antenna coupling.

(2) For aircraft using a vertically polarized VDB antenna, the full 53 dBc must be achieved through antenna coupling. It is not feasible to accomplish this isolation simply due to free space path loss: special considerations will be required.

b. Compatibility with other systems. The VDB receiver may use the localizer or VOR antenna. In this case, the performance of the localizer or VOR receivers must be re-assessed due to the degradation in signal strength resulting from the splitter. AC 23-8A, AC 25-7A, AC 27-1B, and AC 29-2A provide guidance material on these installations.

c. VDB aircraft implementation loss. The aircraft implementation loss should be less than 6 dB (gain) and greater than –15 dB (loss) for horizontally polarized antenna, or less than 6 dB (gain) and greater than –11 dB (loss) for vertical polarized antenna. The total implementation loss is the algebraic sum (in decibels) of the antenna gain (referenced to an isotropic radiator) and the attenuation (as a negative number) between the antenna and the VDB receiver. The attenuation includes line dissipation and VSWR mismatch losses. The implementation loss should be verified over the frequency range 108.000 to 117.95 MHz.

d. The VDB antenna should be installed so that the maximum received power from any on-board transmitter does not exceed the desensitization levels of the VDB receiver specified in Section 2.2.9.1 of RTCA/DO-253A.

23. INSTALLED PERFORMANCE - DATA SUBMITTAL.

a. General. This section identifies documentation typically required by the aircraft certification authorities to support installation approval. For equipment that has not obtained a TSOA, the equipment issues described in section 10 of this AC must also be addressed as part of the installation. For equipment that has a TSO marking, the items under section 10 should be evaluated during the first installation approval in any make/model aircraft.

(1) Aircraft Certification Plan. Provide a plan that establishes the certification basis, how the program will be administered, method of compliance, and schedule. When establishing the certification basis, the plan should identify how the product will meet the applicable airworthiness requirements and any special conditions. AC 21-40, Application Guide for Obtaining a Supplemental Type Certificate, provides guidance on the content of a certification plan.

(2) Design Data.

(i) Provide the installation instruction manual from the original equipment manufacturer.

(ii) Provide installation drawings depicting all interface connections, switching, wire diagrams, external annunciations, configuration programming and cockpit layout.

(iii) Provide reliability data to establish that all probable failures affecting the navigation function are detected.

(iv) Provide a system safety assessment to confirm that all failure conditions have been identified, classified and described in functional and operational terms. Hardware and software design assurance levels must be substantiated.

(3) Structural Analysis. The installation of the GNSS equipment, including antenna, must be sufficient to meet all structural mounting, dynamic, and emergency landing loads appropriate to the aircraft. The installer must verify whether antenna installations penetrating the pressure vessel require a damage tolerance assessment of the installation.

(4) Power Supply. Provide an electrical load analysis to verify that the total electrical load requirements are within the capabilities of the aircraft's electrical generating system. Verify that the supplied electrical power is consistent with applicable equipment reliability requirements.

(5) Equipment Compatibility. Provide a data flow diagram to identify which equipment interfaces with the newly installed GNSS equipment. The typical interfaces are to a barometric altimeter (paragraph 11d(6) of this AC), flight management system (see AC 20-130B), and Flight Guidance System (paragraph 11d(4) of this AC). If the data flow diagram indicates that there are additional interfaces, the applicant and FAA should develop ground and flight tests to ensure proper functioning of these interfaces.

(6) Environment. Provide qualification data substantiating that the aircraft environment in which the GNSS equipment is to be installed is appropriate to the environmental categories (or criteria) in RTCA/DO-160D to which the equipment has been tested.

b. Stand-Alone Navigation Equipment Installation.

(1) Pilot's Guide. An operations manual (pilot's guide) describing the equipment, functions and procedures must be provided with the GNSS equipment. It is essential that the pilot's guide be complete, concise, and easy to understand. The pilot's guide should be reviewed by a flight test pilot familiar with the equipment.

(2) Quick Reference Guide. A quick reference guide must be provided with the GNSS equipment as a training aid for the operation of the GNSS equipment. The guide should be evaluated by a flight test pilot familiar with the equipment. Recommended format and content for this guide is in Appendix 5 of this AC.

(3) A/RFM(S). An A/RFM(S) containing the limitations and operating procedures applicable to the equipment installed must be provided for each installation of GNSS navigation equipment for IFR approval. Standard wording for the general and limitations sections are provided in Appendix 4.

(4) Ground and Flight Test Plans (functional and EMI/EMC testing). The applicant must submit the proposed ground and flight test plans to demonstrate the equipment performance (as described in sections 13 and 14) and EMI/EMC testing.

24. INSTALLED PERFORMANCE - GROUND TEST.

a. General

(1) Power Supply. Assess all switching and transfer functions, including electrical bus switching, pertaining to the GNSS installation.

(2) Accuracy. The accuracy of GNSS equipment is not a function of the installation, and should not be evaluated for each installation. The accuracy of the equipment will be demonstrated under the evaluation of the sensor, typically as part of a TSO Authorization.

(3) Interference.

(i) The lack of interference from VHF radio should be demonstrated on the completed GNSS installation by tuning each VHF transmitter to the frequencies listed below and transmitting for a period of 30 seconds while observing the signal status of each satellite being received. Degradation of individually received satellite signals below a point where navigation is no longer possible is not acceptable and will require that additional isolation measures be taken. Reevaluation of installed VHF transceiver performance is not necessary if the filter insertion loss is 2 dB or less. Evaluate the following VHF frequencies:

121.150 MHz 131.250 MHz
121.175 MHz 131.275 MHz
121.200 MHz 131.300 MHz

(ii) For installations on rotorcraft, ensure that the rotorblades do not interfere with the GPS/WAAS received signals. This problem has been experienced in some rotorcraft and varies with the rotation rate.

(4) Antenna to Aircraft Navigation Reference Offset. If applicable, for GNSS equipment supporting precision approach capability, confirm that the antenna to aircraft center of navigation offset is appropriate to the installation (reference RTCA/DO-229C section 2.2.4.3.3).

b. Sensor Installation. No ground tests are recommended for the sensor. Guidance relating to the interface between the sensor and the navigation system can be found in AC 20-130B.

c. Stand-Alone Navigation Equipment Installation.

(1) Visibility of the controls, displays, and annunciators relating to the GNSS installation should be evaluated during day and night lighting conditions. No distracting cockpit glare or reflections may be introduced and all controls must be illuminated for identification and ease of use. Night lighting should be consistent with other cockpit lighting.

(2) Layout of the installed equipment should be evaluated with emphasis on equipment controls, applicable circuit breakers (labels and accessibility), switching arrangement, and related indicators, displays, annunciators, etc.

(3) Navigation parameters displayed on cockpit instruments such as HSI, CDI, distance display, electronic flight instruments system (EFIS), moving maps, flight management systems, etc. should be evaluated.

(4) Failure modes and associated annunciations, such as loss of electrical power, loss of signal reception, GNSS equipment failure, autopilot/flight director response to flags, etc. should be reviewed.

(5) Manual approach selection or manual tuning of the approach should override any automatic selection. Once an approach has been selected, appropriate feedback to the pilot (e.g. display of approach name (including runway), airport and reference path identifier) must be given to indicate the approach has been correctly selected.

25. INSTALLED PERFORMANCE - FLIGHT TEST.

a. Sensor Installation. Conduct a functional flight test. Verify continuity of navigation data during normal aircraft maneuvering for the navigation modes to be validated (e.g. bank angles of up to 30 degrees and pitch angles associated with approaches, missed approaches and departures). AC 20-130B has guidance on the interface between the sensor and the navigation system.

b. Stand-Alone Navigation Equipment Installation.

(1) Continuity of Navigation. Verify continuity of navigation data during normal aircraft maneuvering for the navigation modes to be validated (e.g. bank angles of up to 30 degrees and pitch angles associated with approaches, missed approaches and departures).

(2) Equipment Operation. Verify the overall operation of the GNSS equipment to include at least the following: the ability to create and modify a flight plan, hold at a designated waypoint, intercept and track to or from a waypoint on a selected course (Course to a Fix leg, CF), turn anticipation, waypoint sequencing, selection of an approach and the general presentation of navigational data (depiction of the "TO" waypoint, distance to waypoint, estimated time of arrival, estimated time en route, ground speed, etc.).

(3) Flight Technical Error. Verify that flight technical error (FTE) can be maintained at less than 1.0 NM for en route and approach transition operating modes, and less than 0.25 NM for non-precision approach, both with and without autopilot and/or flight director use, as applicable. This test may not be necessary if the FTE has been previously established for the aircraft. One acceptable way of assessing FTE is to monitor the measured cross-track deviation using the navigation display provided.

(4) Interface to Flight Guidance System (FGS).

(i) Evaluate steering response while flight director and/or autopilot is coupled to the GNSS equipment during a variety of different track and mode changes. This evaluation should include, as applicable, transition from en route to approach transition to approach to missed approach modes and vice-versa. Additionally, evaluate all available display sensitivities.

(ii) Execute several fly-by turns with varying wind conditions for flight director and autopilot. Verify the equipment accomplishes the turn as a fly-by waypoint and discourages overshoot. Fly-by turns are turns where the equipment initiates the turning maneuver before sequencing the waypoint by an amount equal to the turn anticipation distance.

(iii) Verify that the lateral maneuver anticipation supplied by the GNSS equipment is appropriate for the aircraft type. Verify that if the GNSS equipment is coupled to an autopilot or on approach, an appropriate annunciation of impending waypoint crossing is provided.

(iv) Verify that execution of the Direct-To function with a resultant aircraft heading change does not overshoot and cause "S" turns.

(v) Evaluate the autopilot response to a GNSS fault by pulling the circuit breaker for the GNSS equipment. This test should be done in each of the GNSS modes, if applicable.

(vi) Precision Approach

(A) For installations where the autopilot has not been modified and the GNSS equipment provides ILS-like deviations, conduct several approaches while flying raw data, flight director and coupled to the autopilot, as applicable. The objective of this test is to ensure that the GNSS equipment interface is compatible with the aircraft; the objective is not to verify approach performance.

(B) For installations where the autopilot has been modified, the autopilot lateral/vertical control channel performance has not been assessed, or non-standard deviations are provided (not ILS-like), then the approach performance will need to be evaluated per AC 23.1329-2, 25.1329-1, or equivalent means.

(C) For manual control to the approach flight path, the appropriate flight display(s) must provide sufficient information to maintain the approach path and make alignment with the runway or go-around without excessive reference to other cockpit displays.

(5) Interface to Barometric Altimeter. If the equipment uses barometric input, verify that the equipment properly interprets the barometer reading. Manual entry should be accomplished during an approach to evaluate the crew workload.

(6) Switching and Transfer Functions. Verify/assess all switching and transfer functions, including electrical bus switching, pertaining to the GNSS installation. Evaluate the aircraft system response during switches to all alternate navigation sources.

(7) Failure Modes/Annunciations. Review and verify where appropriate various failure modes and associated annunciations, such as loss of electrical power, loss of signal reception, GNSS equipment failure, FGS response to GNSS flags, etc. Verify that a warning associated with loss of navigation is accompanied by a visible indication within the pilot's primary field of view.

(8) Crew Workload. An analysis of crew workload when operating the GNSS equipment in association with other piloting requirements should be conducted during all phases of flight, including those non-normal procedures that can be evaluated in flight.

c. LAAS Precision Approach Navigator Installation

(1) Continuity of Navigation. Verify continuity of navigation data during normal aircraft maneuvering for the navigation modes to be validated (e.g. bank angles of up to 30 degrees and pitch angles associated with approaches, missed approaches and departures).

(2) Interface to Flight Guidance System (FGS).

(i) Evaluate steering response while flight director and/or autopilot is coupled to the PAN equipment during a variety of different mode changes and approach intercepts. Additionally, all available display sensitivities should be evaluated.

(ii) Evaluate the autopilot response to a GNSS fault by pulling the circuit breaker for the GNSS equipment. This test should be done in each of the GNSS modes, if applicable.

(iii) Conduct several approaches while flying raw data, flight director only and coupled to the autopilot, as applicable. The objective of the test is to ensure that the GNSS equipment interface is compatible with the aircraft and is not a verification of approach performance. This objective is valid only for installations with existing and proven performance (e.g. GNSS providing ILS like deviations to replace or supplement an existing ILS). For installations where the autopilot has been modified or the autopilot lateral/vertical control channel performance has not been assessed, then the approach performance will need to be evaluated per AC 23.1329-2(), 25.1329-1(), or equivalent means.

(iv) For manual control to the approach flight path, the appropriate flight display(s) must provide sufficient information without excessive reference to other cockpit displays, to enable a suitably trained pilot to maintain the approach path, make alignment with the runway or go-around.

(v) For Part 25 aircraft, the criteria in AC 120-29A, Appendix 2, should also be considered. The criteria defined for MLS may be used to qualify the LAAS functions.

d. LAAS VDB Receiver Installation

(1) To ensure compatibility between the VDB and VHF communications equipment, a flight test should be accomplished using the highest available VDB broadcast, and transmitting VHF communication at 100 kHz above the VDB channel. For VHF communications equipment that cannot transmit below 118.000 MHz, then 118.000 MHz should be used.

Manager, Aircraft Engineering Division
Aircraft Certification Service

APPENDIX 1. GPS OCEANIC/REMOTE NAVIGATION

The following criteria define an acceptable means of compliance for TSO-C129(a) GPS equipment intended for oceanic and remote operation without reliance on other long-range navigation systems. Note that GPS/WAAS equipment should not be evaluated against this criteria. GPS/WAAS equipment is inherently capable of supporting this operation if the operator obtains a fault detection and exclusion (FDE) prediction program; no additional evaluation is necessary.

1. APPROVAL PROCESS.

a. TSO Authorization. The requirements in this appendix are in addition to the requirements of RTCA/DO-208, Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System, as modified by Technical Standard Order, TSO-C129a. The ACO should issue a separate letter of design approval stating that the equipment (including part number) and software prediction program (including revision number) complies with this appendix.

b. Installation Approval.

(1) The applicant obtains installation approval of the GPS navigation system as described in paragraph 8.b of this AC.

(2) If the manufacturer has previously obtained a letter of design approval as described in paragraph 1.a of this appendix, further evaluation as described in paragraphs 2 and 3 of this appendix is not required.

(3) If the manufacturer has not obtained a letter of design approval, then the applicant must demonstrate compliance with the requirements in paragraphs 2 and 3 of this appendix.

(4) The failure of the long-range navigation function is a major failure condition. For many oceanic/remote operations, this requires equipping the airplane with at least two (or more) independent (i.e., dual control display unit, dual GPS antenna, dual power sources, dual GPS sensors, etc.) navigation systems with a mean time between failures of at least 1000 hours each (for dual equipage).

(5) Once the installation has been approved, the A/RFM(S) must be updated to state: "The XXX GPS equipment as installed has been found to comply with the requirements for GPS oceanic and remote navigation, when used in conjunction with the XXX prediction program. This does not constitute an operational approval."

c. Operational Approval. The applicant should be aware that an operational approval must be obtained before conducting Class II navigation (remote/oceanic). Applicants should contact the appropriate Flight Standards District Office to seek approval (reference HBAT 95-09 Guidelines for Operational Approval of GPS to provide the Primary Means of Class II Navigation in Oceanic and Remote Areas of Operation).

2. EQUIPMENT PERFORMANCE.

a. TSO-C129a. The GPS equipment must meet the criteria of TSO-C129a.

b. Fault Detection and Exclusion (FDE).

(1) The GPS equipment must be able to detect and exclude a GPS satellite failure by means of a fault detection and exclusion (FDE) algorithm including receiver autonomous integrity monitoring (RAIM) for detection. The exclusion of a satellite failure must be automatic: pilot action is not permitted to accomplish exclusion. The specific requirements of the exclusion function are in RTCA/DO-229C, Section 2.1.2.2.2.2.

(2) In addition to FDE, the equipment must use an acceptable means to detect and exclude from the navigation solution any satellite that experiences a failure which causes a pseudorange step. A pseudorange step is a sudden change in the measured distance to a satellite. It can be written as:

$$PR_{STEP} = | PR_{PREDICTED} - PR_{MEASURED} |$$

where $PR_{PREDICTED}$ is the predicted pseudorange at the time of measurement, based on previous measurements, and $PR_{MEASURED}$ is the pseudorange at the time of the measurement.

(3) The equipment must detect a pseudorange step error greater than 1000 meters, including steps, which cause loss of lock for less than 10 seconds.

(4) If a pseudorange step is detected for a satellite, that satellite must be excluded from use in the navigation algorithm until its integrity can be verified through fault detection (RAIM). The manufacturer is free to choose any method to calculate the predicted pseudorange. However, any method used should properly take into account satellite movement and aircraft dynamics up to a groundspeed of 750 knots (kts) and accelerations up to 14.7 meters/second/second (1.5 g's).

(5) The GPS equipment must exclude, without pilot action, any satellite designated unhealthy by any of the GPS navigation data. The satellite must be excluded within 5 minutes of the designation as unhealthy by the satellite. A description of the parameters that must be checked are in RTCA/DO-229C, section 2.1.1.5.5.

(6) If a GPS satellite failure results in loss of GPS navigation (due to the failure to exclude or to loss of a critical satellite), an appropriate indication [TSO-C129a, paragraphs (a)(3)(xiii)1c, (a)(4)(iv)10, and (a)(5)(iv)9)] of the failure must be provided to the flight crew.

(7) The equipment must provide, upon request, an indication of the current estimate of position uncertainty in terms of nautical miles (NM). This estimate must be based on measurement inconsistency and must bound the true error with high confidence (approximately 99.9 percent). It is related to the test statistic calculated as part of FDE. This estimate will not be available if there are only four measurements available (because there is no redundancy). This output is intended to provide information about the approximate magnitude of a potential positioning failure, when the horizontal integrity limit (HIL) exceeds the alert limit or when a positioning failure has been detected but not excluded.

3. PREDICTION PROGRAM. A prediction program is required to support operational departure restrictions. See paragraph 12 of this AC.

APPENDIX 2. INTEGRATION OF GLONASS WITH GPS OR GPS/WAAS

GLONASS must be supplemental to other approved means of navigation. This appendix defines an acceptable means of compliance for GNSS equipment to use GLONASS.

1. APPROVAL PROCESS.

a. TSO Authorization. Equipment that complies with the criteria of this Appendix can obtain a TSO-C145, TSO-C146, or TSO-C129a authorization. The ACO should issue a separate letter of design approval, stating that the appliance (including part number) complies with this Appendix.

b. Installation Approval.

(1) The applicant obtains installation approval of the GPS navigation system as described in paragraph 8b of this AC.

(2) If the manufacturer has previously obtained a letter of design approval as described in paragraph 1a of this appendix, further evaluation as described in paragraph 2 of this appendix is not required.

(3) If the manufacturer has not obtained a letter of design approval, then the applicant must demonstrate compliance with the requirements in paragraph 2 of this appendix.

(4) Approval of equipment which does not satisfy the interference criteria specified in paragraph 2f of this appendix should include a limitation in the A/RFM(S): "The GLONASS capability may be lost due to interference encountered during normal operations, and is limited to be a supplement to other navigation."

c. Operational Approval.

(1) Until the FAA declares GLONASS operational for U.S. aviation, GLONASS signals cannot be used in predicting RAIM availability for nonprecision approach, or for FDE availability for oceanic/remote operations (see appendix 1 of this AC).

(2) When the FAA declares GLONASS operational, integrated GPS/GLONASS equipment which meets the interference criteria in paragraph 2f of this Appendix will be able to take advantage of GLONASS signals when predating RAIM approach availability and availability of FDE for oceanic and remote operations. For equipment that does not meet the interference criteria, no predictive credit can be given for GLONASS even after it is declared operational for U.S. aviation.

2. EQUIPMENT PERFORMANCE.

a. Performance without GLONASS. In the absence of GLONASS signals, the equipment must satisfy all of the requirements for GPS/WAAS or GPS equipment as described in this AC. This includes susceptibility to in-band and out-of-band interference.

b. GLONASS Receiver. GLONASS functions must be developed in accordance with the GLONASS Interface Control Document.

c. Accuracy. Use of GLONASS must not degrade the system accuracy. The accuracy requirements of TSO-C129a and RTCA/DO-208 must be satisfied using both GPS and GLONASS. Differences between GPS and GLONASS in reference time and coordinate reference frames must be addressed. Interfrequency bias among GLONASS channels, and between GPS and GLONASS must be considered.

d. Integrity. Failure of GLONASS space or control segment must not cause misleading information. Therefore, the receiver must be capable of detecting all position errors that result from using GLONASS.

e. Continuity. Failure of GLONASS space or control segment must not cause loss of navigation unless navigation is not possible with GPS alone. Therefore, the receiver must be able to exclude GLONASS measurements when a failure is detected, reverting to using only GPS if necessary. Issues, which must be addressed, include:

(1) If the system can detect multiple GLONASS failures, can it also exclude them? It is acceptable, when a failure is detected but cannot be isolated, to exclude all GLONASS measurements and revert to GPS navigation. If the resulting set of GPS satellites does not provide fault detection the equipment must indicate that RAIM is not available.

f. Interference Environment.

(1) The interference environment for GLONASS is specified below. GLONASS accuracy must be maintained in the specified interference environment.

(2) GLONASS equipment, which does not meet this requirement, can be approved, but is limited to supplemental operation and no credit can be taken for GLONASS capabilities. Regardless of the signal rejection in the GLONASS band, the GPS(WAAS) portion of the integrated equipment must satisfy its requirements for interference. Approval of equipment which does not satisfy the interference criteria specified above should include a limitation: "The GLONASS capability may be lost due to interference encountered during normal operations, and is limited to be a supplement to GPS navigation."

(3) Prior to the year 2005, the required signal rejection results in the rejection of GLONASS channels f7 through f24. Implementing this rejection before 2005 would reduce the size of the usable GLONASS constellation to those satellites using channels f0 through f6. Equipment may be designed to use satellites above f6 to receive as many signals as possible, but since the U.S. is not committed to protecting GLONASS operation above 1605 MHz then such equipment would also allow interference into its passband, precluding the use of any GLONASS satellites.

(4) GLONASS Spectrum Considerations. Prior to 1998, GLONASS will operate between 1602.5625 MHz and 1615.5 MHz, ± 0.511 MHz. By 2005, the GLONASS operating band will be 1598.0625 MHz to 1605.375 MHz. GLONASS channel assignments are defined as shown in Table 1.

(5) GLONASS Interference Environment. International policy is still being developed for the frequency protection of GLONASS signals. The criteria defined below are based on the U.S. position, which is to protect the use of GLONASS in its final configuration for precision approach operations. In addition, the use of GLONASS channels within the final band will be protected for nonprecision approach operations from now until the GLONASS transition is complete. Two levels of interference are specified: one applies to equipment intended for en route through NPA operations, and one applies to equipment intended to support precision approach operations.

(6) All interference levels specified within this appendix are defined relative to received satellite signal levels (at antenna port) of -135.5 dBm. This satellite signal level represents that received at the antenna port given a minimum standard antenna gain of -4.5 dBi. For non-standard antennas with a different minimum gain, the signal and interference levels can be adjusted accordingly, as long as the relative interference-to-signal level is maintained. In other words, if the minimum antenna gain were 0 dBi, then the received satellite signal and the interference level would be increased by 4.5 dB.

(i) Narrowband Interference. Continuous Wave (CW) interfering signals can be as high as shown in figure 1. The corner frequencies in this figure are as stated in Table 2.

Table 1

GLONASS Channel	Frequency (±0.511 MHz)	1998-2005	2005-
f_{-7}	1598.0625 MHz		in use
f_{-6}	1598.6250		in use
f_{-5}	1599.1875		in use
f_{-4}	1599.7500		in use
f_{-3}	1600.3125		in use
f_{-2}	1600.8750		in use
f_{-1}	1601.4375		in use
f_0	1602.0000	in use	in use
f_1	1602.5625	in use	in use
f_2	1603.1250	in use	in use
f_3	1603.6875	in use	in use
f_4	1604.2500	in use	in use
f_5	1604.8125	in use	test
f_6	1605.3750	in use	test
f_7	1605.9375	in use	
f_8	1606.5000	in use	
f_9	1607.0625	in use	
f_{10}	1607.6250	in use	
f_{11}	1608.1875	in use	
f_{12}	1608.7500	in use	
f_{13}	1609.3125		
f_{14}	1609.8750		
f_{15}	1610.4375		
f_{16}	1611.0000		
f_{17}	1611.5625		
f_{18}	1612.1250		
f_{19}	1612.6875		
f_{20}	1613.2500		
f_{21}	1613.8125		
f_{22}	1614.3750		
f_{23}	1614.9375		
f_{24}	1615.5000		

(ii) In-band and Near-band Interference. The equipment could receive an interfering signal with a center frequency on any GLONASS center frequency, and with a total bandwidth of BWI, that is as high as the levels shown in Figure C-2 of appendix C to RTCA/DO-229C. The values in Figure C-1 apply to equipment intended for precision approach operations (Class 3, 4) and to equipment only intended to support nonprecision approach operations (Class 2).

(iii) Pulsed Interference. Integrated GPS/GLONASS equipment must continue tracking GPS and GLONASS signals without degradation to the position solution or integrity performance with in-band or out-of-band pulse interference sources with the following characteristics:

Peak Power	+20 dBm
Pulse Width	1 ms
Pulse Duty Cycle	10%

Figure 1

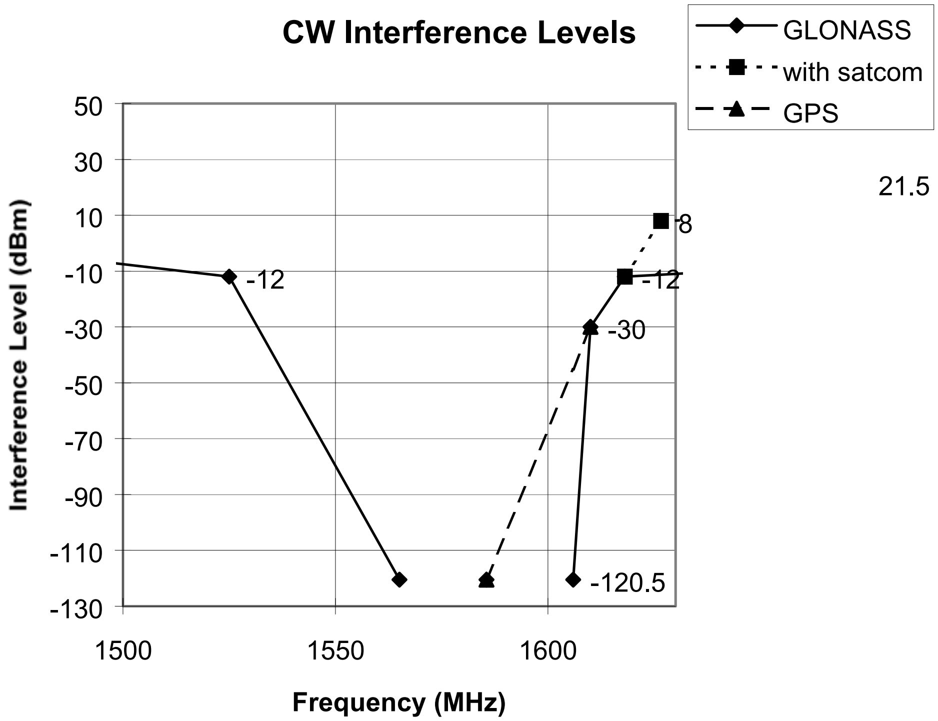


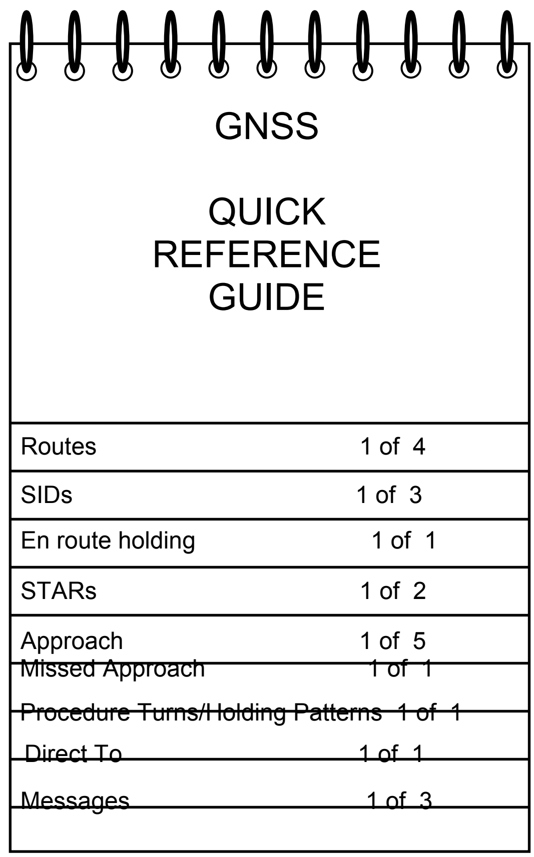
Table 2

Frequency (MHz)	Interference Level (dBm)		
	GLONASS	GPS	With Satcom (both)
1315	25.5	25.5	
1525	-12	-12	
1565	-120.5	-120.5	
1585.5	-120.5	-120.5	
1605.886	-120.5	-45.2	
1610	-30	-30	
1618	-12	-12	-12
1626.5	-11.3	-11.3	8
2000	21.5	21.5	21.5

APPENDIX 3. EXAMPLE FORMAT FOR A QUICK REFERENCE GUIDE

A quick reference guide should be provided with the GNSS equipment as a training aid for the operation of the GNSS equipment. The quick reference guide should not be used as a checklist or as a replacement for the procedures and limitations of the equipment as stated in the FAA-approved A/RFM(S).

Arrange the quick reference guide in sections to provide the pilot a quick reference to those procedures and clarifications applicable for that mode of operation. Sections may be added or deleted as appropriate. Example CDU page displays and page flows are encouraged.



EXAMPLE FORMAT FOR A QUICK REFERENCE GUIDE (Continued)

Creating Routes

1. Rotate left outer knob to FPL.
2. Rotate left inner knob to blank flight plan pages.
3. Press left CRSR
4. Rotate left inner and outer knobs to input desired waypoint.
5. Press ENT
6. Press ENT
7. Repeat 4, 5, and 6 until all desired waypoints are entered.

Routes	1 of 4
SIDs	1 of 3
En route holding	1 of 1
STARs	1 of 2
Approach	1 of 5
Missed Approach	1 of 1
Procedure Turns/Holding Patterns	1 of 1
Direct To	1 of 1
Messages	1 of 3

Activating Routes

1. Press left CRSR
2. Press ENT

Editing Routes

Inserting waypoints

1. Rotate left outer knob to flight plan pages.
2. Rotate left inner knob to desired flight plan page.
3. Press left CRSR
4. Rotate left outer knob to the point in the flight plan where you want to insert the new waypoint.
5. Rotate left inner and outer knobs to input new waypoint.

See next page for more instructions.

Routes 2 of 4

5. Press ENT
6. Press ENT

Deleting Routes

1. Rotate left outer knob to flight plan pages.
2. Rotate left inner knob to desired flight plan page.
3. Press left CRSR
4. Rotate left outer knob to place cursor over waypoint to be deleted.
5. Press CLR
6. Press ENT

Routes	3 of 4
SIDs	1 of 3
En route holding	1 of 1
STARs	1 of 2
Approach	1 of 5
Missed Approach	1 of 1
Procedure Turns/Holding Patterns	1 of 1
Direct To	1 of 1
Messages	1 of 3

EXAMPLE FORMAT FOR A QUICK REFERENCE GUIDE (Continued)

Reversing Routes

9. Rotate left outer knob to flight plan pages.
10. Rotate left inner knob to select flight plan to be reversed.
11. Press left CRSR
12. Rotate left outer knob to display blinking "USE?INVRT?" page.
13. Press ENT

Routes 4 of 4

If steps 9 – 10 are not required, go to step 13.

If required to choose a SID runway:

9. Rotate right outer knob to select desired runway.
10. Press ENT

If steps 10 – 11 are not required, go to step 13.

If required to choose a SID runway transition:

11. Rotate right outer knob to select desired transition.
12. Press ENT and go to step 13
13. Press ENT

SIDs 2 of 3

Selecting SIDs

1. Rotate right outer knob to airport pages.
2. If the desired airport is not displayed, press right CRSR
3. Rotate right inner and outer knobs to input desired airport.
4. Press right CRSR
5. Rotate right inner knob to select APT 7 page.
6. Press right CRSR
7. Rotate right outer knob to select desired SID.
8. Press ENT

See next page for more instructions.

SIDs	1 of 3
En route holding	1 of 1
STARs	1 of 2
Approach	1 of 5
Missed Approach	1 of 1
Procedure Turns/Holding Patterns	1 of 1
Direct To	1 of 1
Messages	1 of 3

Flying the selected SID

1. Press left CRSR
2. Rotate right outer knob to desired waypoint
3. Press D→
4. Press ENT

SIDs	3 of 3
En route holding	1 of 1
STARs	1 of 2
Approach	1 of 5
Missed Approach	1 of 1
Procedure Turns/Holding Patterns	1 of 1
Direct To	1 of 1
Messages	1 of 3

EXAMPLE FORMAT FOR A QUICK REFERENCE GUIDE (Continued)

En route holding

1. Press GPS CRS switch to display "OBS".
2. Press D→
3. Press ENT
4. Set course for intercept into HSI.

Selecting STARs

1. Rotate right outer knob to airport pages.
2. If desired airport is not displayed, press right CRSR
3. Rotate right inner and outer knobs to input desired airport.
4. Press right CRSR
5. Rotate right inner knob to APT 7 page.
6. Press right CRSR
7. Rotate right outer knob to select desired STAR.
8. Press ENT

See next page for more instructions.

EXAMPLE FORMAT FOR A QUICK REFERENCE GUIDE (Continued)

If steps 9 – 10 are not required, go to step 11.

If required to choose a STAR transition:

9. Rotate right outer knob to select desired transition.
10. Press ENT and go to step 11.
11. Press ENT

STARs 2 of 2

If steps 10 – 11 are not required, go to step 12.

If required to choose an IAF:

10. Rotate right outer knob to select desired IAF.
11. Press ENT and go to step 12
12. Press ENT

Arming approaches

1. If GPS APR switch is in proper position, approach will auto arm and switch will display "ARM".
2. If within 30 miles of destination, and GPS APR switch does not display "ARM", press GPS APR switch

Approach 2 of 5

Selecting approaches

1. Rotate right outer knob to airport pages.
2. Rotate right inner knob to APT 1 page.
3. If desired airport is not displayed, press right CRSR
4. Rotate right inner and outer knobs to select desired airport.
5. Press right CRSR
6. Rotate right inner knob to APT 8 page.
7. Press right CRSR
8. Rotate right outer knob to select desired approach.
9. Press ENT

See next page for more instructions.

Approach	1 of 5
Missed Approach	1 of 1
Procedure Turns/Holding Patterns	1 of 1
Direct To	1 of 1
Messages	1 of 3

Vectored approaches

This function not available

Repeating an approach

1. Rotate left outer knob to select "FPL 0" page.
2. press left CRSR
3. Rotate left outer knob to select desired approach waypoint from which to repeat the approach.
4. Press D▸
5. Press ENT

If steps 6 – 11 are not required, go to step 12.

If required to intercept approach course:

6. Rotate left outer knob to select "FPL 0" page.

See next page for more instructions.

Approach	3 of 5
Missed Approach	1 of 1
Procedure Turns/Holding Patterns	1 of 1
Direct To	1 of 1
Messages	1 of 3

EXAMPLE FORMAT FOR A QUICK REFERENCE GUIDE (Continued)

7. Press GPS CRS switch to display "OBS".
8. Set desired course into HSI.
9. Press left CRSR
10. Rotate left outer knob to waypoint at end of desired course segment.
11. Press D and go to step 12.
12. Press ENT →

Approach 4 of 5

Changing an approach

1. Rotate left outer knob to select "FPL 0" page.
2. Press left CRSR
3. Rotate left outer knob to display blinking "CHANGE APR" page.
4. Press ENT
5. Rotate right outer knob to select desired approach.
6. Press ENT

If steps 7 – 8 are not required, go to step 9.

If required to choose an IAF:

7. Rotate right outer knob to select desired IAF.
8. Press ENT and go to step 9.
9. Press ENT

Approach 5 of 5

Missed Approach 1 of 1

Procedure Turns/Holding Patterns 1 of 1

Direct To 1 of 1

Messages 1 of 3

Missed approach

Direct to a waypoint

1. Press D→
2. Press ENT

Intercepting a course to a waypoint

1. Press GPS CRS switch to display "OBS".
2. Press D→
3. Press ENT
4. Set inbound course into HSI.

Missed Approach 1 of 1

Procedure Turns/Holding Patterns 1 of 1

Direct To 1 of 1

Messages 1 of 3

EXAMPLE FORMAT FOR A QUICK REFERENCE GUIDE (Continued)

Procedure turns

1. Prior to the FAF outbound, press [GPS CRS switch] to display "OBS".
2. Fly outbound course and procedure turn as specified.
3. Set inbound course into HSI.
4. Prior to the FAF inbound, press [GPS CRS switch] to display "LEG".

Holding Patterns

1. Press [GPS CRS switch] to display "OBS".
2. Press [D→]
3. Press [ENT]
4. Set course for intercept into HSI.

Procedure Turns/Holding Patterns	1 of 1
Direct To	1 of 1
Messages	1 of 3

Direct to the nearest airport

1. Press [MSG]
2. Press [ENT]
3. Pull out [right inner knob]
4. Rotate [right inner knob] to select desired airport.
5. Push in [right inner knob]
6. Press [D→]
7. Press [ENT]

Direct to the nearest waypoint

This function available only for airports.

Direct to the FAF

1. Rotate [left outer knob] to select flight plan pages.
2. Rotate [left inner knob] to select desired flight plan.
3. Press [left CRSR]
4. Rotate [left outer knob] to place cursor over the FAF.
5. Press [D→]
6. Press [ENT]

Direct To	1 of 1
Messages	1 of 3

EXAMPLE FORMAT FOR A QUICK REFERENCE GUIDE (Continued)

Messages

ADJ NAV IND CRS TO _____
1. Set course into HSI.
2. Press MSG

ARM GPS APPROACH
1. Press GPS APR switch

BAD SATELLITE GEOMETRY
1. See EPE on "STS 2" page, **or**
2. Use other means of navigation

BAD SATELLITE GEOMETRY
and
RAIM NOT AVAILABLE
1. Appears only when receiver is in approach active mode.
2. Use other means of navigation.

PRESS ALT TO SET BARO
1. Press ALT
2. Rotate left inner and outer knobs to input altitude.
3. Press left CRSR
4. Press ALT

Messages 1 of 3

RAIM NOT AVAILABLE
APR MODE INHIBITED
PREDICT RAIM ON STA 5
1. Rotate left outer knob to STAT
2. Predict RAIM to determine when approach can be flown.
3. Rotate left inner knob to "STAT 5" page.

RAIM NOT AVAILABLE
CROSS CHECK POSITION
1. Cross-check with other means of navigation.

RAIM POSITION ERROR
CROSS CHECK POSITION
1. Cross-check with other means of navigation.

Messages 2 of 3

SATELLITE COVERAGE
INADEQUATE FOR NAVIGATION
1. Use other means of navigation.

Messages 3 of 3

APPENDIX 4. SAMPLE AIRPLANE/ROTORCRAFT FLIGHT MANUAL

Installation Center/Repair Station
123 Fourth Street
Anytown, USA

Model XXX GPS
Navigation System

FAA APPROVED AIRPLANE FLIGHT MANUAL SUPPLEMENT
ABC MODEL XXX GPS NAVIGATION SYSTEM

AIRPLANE MAKE:
AIRPLANE MODEL:
AIRPLANE SERIAL NO.:
REGISTRATION NO.:

This document must be carried in the airplane at all times. It describes the operating procedures for the ABC Model XXX GPS navigation system when it has been installed in accordance with <*manufacturer's installation manual number and date*> and FAA Form 337 dated <*insert date*>.

For airplanes with an FAA Approved Airplane Flight Manual, this document serves as the FAA Approved ABC Model XXX GPS Flight Manual Supplement. For airplanes that do not have an approved flight manual, this document serves as the FAA Approved ABC Model XXX GPS Supplemental Flight Manual.

The information contained herein supplements or supersedes the basic Airplane Flight Manual dated <*insert date*> only in those areas listed herein. For limitations, procedures, and performance information not contained in this document, consult the basic Airplane Flight Manual.

FAA APPROVED

____
Title
Office
Federal Aviation Administration
City, State

FAA Approved
Date: ________

Page <> of <>

SAMPLE AIRPLANE/ROTORCRAFT FLIGHT MANUAL (Continued)

Installation Center/Repair Station
123 Fourth Street
Anytown, USA

Model XXX GPS
Navigation System

Table of Contents

FAA Approved
Date: ________

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SAMPLE AIRPLANE/ROTORCRAFT FLIGHT MANUAL (Continued)

Installation Center/Repair Station
123 Fourth Street
Anytown, USA

Model XXX GPS
Navigation System

SECTION 1 - GENERAL

<Include the appropriate statement to describe the equipment capability:>

GPS TSO-C129 Class A1: The installed ABC system complies with AC 20-138A for IFR navigation using GPS for en route, terminal area, and non-precision approach operations (including "GPS", "or GPS", and "RNAV" approaches).

GPS TSO-C129 Class A2: The installed ABC system complies with AC 20-138A for IFR navigation using GPS for en route and terminal area operations.

GPS/WAAS TSO-C146 Class 3: The installed ABC equipment complies with AC 20-138A for navigation using GPS and WAAS (within the coverage of a Space-Based Augmentation System complying with ICAO Annex 10) for en route, terminal area, non-precision approach operations (including "GPS", "or GPS", and "RNAV" approaches), approach procedures with vertical guidance (including "LNAV/VNAV" and "LPV"), and precision approaches (including "GLS" approaches).

GPS/WAAS TSO-C146 Class 2: The installed ABC equipment complies with AC 20-138A for navigation using GPS and WAAS (within the coverage of a Space-Based Augmentation System complying with ICAO Annex 10) for en route, terminal area, non-precision approach operations (including "GPS", "or GPS", and "RNAV" approaches), and approach procedures with vertical guidance (including "LNAV/VNAV").

GPS/WAAS TSO-C146 Class 1: The installed ABC equipment complies with AC 20-138A for navigation using GPS and WAAS (within the coverage of a Space-Based Augmentation System complying with ICAO Annex 10) for en route, terminal area, and non-precision approach operations (including "GPS", "or GPS", and "RNAV" approaches).

GPS/WAAS TSO-C146 Class 1/LAAS: The installed ABC equipment complies with AC 20-138A for navigation using GPS, WAAS (within the coverage of a Space-Based Augmentation System complying with ICAO Annex 10), and LAAS (within the coverage of a Ground-Based Augmentation System complying with ICAO Annex 10) for en route, terminal area, non-precision approach operations (including "GPS", "or GPS", and "RNAV" approaches), approach procedures with vertical guidance (including "LNAV/VNAV" and "LPV"), and precision approaches (including "GLS" approaches).

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Installation Center/Repair Station
123 Fourth Street
Anytown, USA

Model XXX GPS
Navigation System

GPS TSO-C129/LAAS: The installed ABC system complies with AC 20-138A for navigation using GPS and LAAS (within the coverage of a ground-based augmentation system complying with ICAO Annex 10) for en route, terminal area, and non-precision approach operations (including "GPS", "or GPS", and "RNAV" approaches). The installed ABC system complies with AC 20-138A for navigation using GPS and LAAS for precision approach operations (including "GLS" approaches).

<The following statement applies to all types of stand-alone equipment.>
Navigation information is referenced to WGS-84 reference system, and should only be used where the Aeronautical Information Publication (including electronic data and aeronautical charts) conform to WGS-84 or equivalent.

<For TSO-C146 equipment and TSO-C129() equipment that complies with the requirements in Appendix 1 of this AC:>
The ABC equipment as installed has been found to comply with the requirements for GPS primary means of navigation in oceanic and remote airspace, when used in conjunction with the ABC prediction program. This does not constitute an operational approval.

SECTION 2 - LIMITATIONS

1. The ABC Model XXX GPS Pilot's Guide, P/N <*insert part number*>, dated <*insert date*> (or later appropriate revision) must be immediately available to the flight crew whenever navigation is predicated on the use of the system. The software status stated in the pilot's guide must match that displayed on the equipment.

2. The system must utilize software version <*insert version identification*>.

3. Database xxxxxxx-yyy must be installed and contain current data.*<See section 12 of this AC for additional information related to the database limitation.>*

<Limitation for TSO-C129() equipment (whether or not LAAS is also provided):>
4. The aircraft must have other approved navigation equipment installed and operating appropriate to the route of flight.

5. *<Specify any additional limitations applicable to the particular installation.>*

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SAMPLE AIRPLANE/ROTORCRAFT FLIGHT MANUAL (Continued)

Installation Center/Repair Station
123 Fourth Street
Anytown, USA

Model XXX GPS
Navigation System

SECTION 3 - EMERGENCY/ABNORMAL PROCEDURES

EMERGENCY PROCEDURES
No Change

ABNORMAL PROCEDURES

1. If ABC Model XXX GPS navigation information is not available or invalid, utilize remaining operational navigation equipment as appropriate.

2. If Loss of Integrity Monitoring message is displayed, revert to an alternate means of navigation appropriate to the route and phase of flight.

SECTION 4 - NORMAL PROCEDURES

1. Normal operating procedures are outlined in the ABC Model XXX GPS Pilot's Guide, P/N <*insert part number*>, dated <*insert date*> (or later appropriate revision).

2. <Describe approach mode sequencing.>

3. System Annunciators

   a. Waypoint - <*describe each annunciator*>

   b. Message - <*describe each annunciator*>

   c. Approach - <*describe each annunciator*>

   d. <*describe any other annunciators*>

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SAMPLE AIRPLANE/ROTORCRAFT FLIGHT MANUAL (Continued)

Installation Center/Repair Station
123 Fourth Street
Anytown, USA

Model XXX GPS
Navigation System

4. System Switches

   a. Nav/GPS - *<describe switch use and function>*

   b. RMI Switch - *<describe switch use and function>*

   c. *<describe any other switches>*

5. Pilot's Display *<describe the pilot's GPS display(s)>*

6. Flight Director/Autopilot Coupled Operation *<describe the procedures for coupling GPS to the flight director and/or autopilot system(s)>*

7. *<include any other normal operating procedures necessary>*

<u>SECTION 5 - PERFORMANCE</u>

No Change

<u>SECTION 6 - WEIGHT AND BALANCE</u>

<Refer to revised weight and balance data, if applicable.>

<u>SECTION 7 - SYSTEM DESCRIPTION</u>

<Provide a brief description of the system, its operation, installation, etc.>

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Date: ________

Page <> of <>

APPENDIX 5. REQUIRED NAVIGATION PERFORMANCE (RNP) and GNSS

This appendix describes the relationship between RNP and the GNSS standards used throughout this AC.

1. INTRODUCTION.

a. This appendix describes the relationship between WAAS class Gamma (TSO-C146) compliant receivers and the requirements in RTCA/DO-236A, Minimum Aviation System Performance Standards: Required Navigation Performance (RNP) for Area Navigation (RNAV). It documents the assumptions and methods in which TSO-C146 compliant equipment will satisfy the "standard" RNP RNAV types of 2, 1 and 0.3 for en route, terminal area and nonprecision approach, respectively. Those manufacturers who choose to develop receivers that operate in RNP environments other than the standard RNP types should refer to RTCA/DO-236A for requirements pertaining to RNP.

b. The intent of this appendix is to satisfy the RNP requirements without imposing unique operational issues and/or procedures on the equipment and users of that equipment. Operators that are equipped with WAAS TSO-C146a equipment will be able to operate within RNP airspace and can be approved for RNP procedures and routes supporting the basic RNP types, without specific evaluation and without demonstrating compliance to RTCA/DO-236A. In general, this appendix is applicable to general aviation users who do not use a multi-sensor system and may not have access to training specifically related to RNP and its application.

c. Paragraph 2 of this appendix summarizes the basic compliance of TSO-C146 equipment in the 2, 1, and 0.3 RNP RNAV environment described above. Paragraphs 3 and 4 summarize requirements in RTCA/DO-236A not necessarily satisfied by TSO-C146 equipment. All other requirements as specified in RTCA/DO-236A are satisfied with TSO-C146 compliant receivers.

2. PERFORMANCE REQUIREMENTS.

a. RTCA/DO-236A specifies performance using three metrics: accuracy, containment integrity and containment continuity. The accuracy of Class Gamma equipment is assured by the combination of sensor accuracy (negligible) and flight technical error. For the three RNP RNAV types identified, Class Gamma equipment provides lateral deviations with a full-scale deflection equal to the 95 percent value, easily ensuring that the FTE is within the 95 percent requirement.

b. Allocating the cross-track containment limit to the two major error sources of Flight Technical Error (FTE) and Position Estimation Error (PEE) ensures containment integrity. The path definition requirements in RTCA/DO-229C Section 2.2 ensure that path definition error is negligible. Therefore, the horizontal alert limit (HAL) is set to half the containment limit which provides a 10^{-7}/hour probability that the PEE exceeds this limit (this is conservative since the HAL is a radial error bound and containment is specified separately in the cross-track and along-track domains). Similarly, the full-scale deflection is set to half the containment limit to ensure that the rare FTE is within the containment limit. Rare fault-free performance is a region centered around the required flight path where the aircraft would be only under a limited number of conditions (e.g. large wind gradients).

c. Installation guidelines and the GPS/WAAS signal-in-space continuity support the containment continuity requirement.

> NOTE: FAA has issued guidance for RNP-10 (Order 8400.12a) and BRNAV (AC 90-96). This appendix does not mention these RNP types since they have been defined utilizing a 95 percent accuracy component only, and do not require containment. TSO-C146a equipment also satisfies the requirements for these operations.

3. DISPLAY REQUIREMENTS.

a. Navigational Uncertainty (Estimate of Position Uncertainty, EPU). RTCA/DO-236A requires that each navigation system operating in RNP airspace shall make available a continuous estimate of its position uncertainty under the prevailing conditions of flight. The GPS/WAAS MOPS does not require this display in support of the basic RNP types. Mode annunciation, including indication if the containment requirements are not supported, are provided.

b. RNP RNAV Type. RTCA/DO-236A requires that the system display the current RNP RNAV type. Class Gamma equipment does not annunciate an RNP RNAV type, but annunciates the en route, terminal and nonprecision approach modes that equate to RNP-2 RNAV, RNP-1 RNAV, and RNP-0.3 RNAV, respectively.

4. PATH DEFINITION REQUIREMENTS.

a. Leg Types.

(1) RTCA/DO-236A requires that the equipment support RF and holding pattern leg types. RTCA/DO-229C does not require support of these leg types, since testing has indicated that an auto-slewing HSI is necessary to maintain satisfactory FTE through the turn. Minimum TSO-C146 equipment will not be able to conduct procedures that exploit these leg types. Class Gamma equipment is required to annunciate to the flight crew when a procedure is not supported.

(2) Fix-to-an-altitude legs are specified in RTCA/DO-236A but are not specifically addressed in this document. For minimum Class Gamma equipment, they can be accomplished by flying a FROM leg and manually terminating the leg when the published altitude is attained.

(3) RTCA/DO-229C allows for leg that are incompatible with RNP containment. The procedure designer will control the leg types within a RNP procedure.

5. LEG TRANSITION REQUIREMENTS.

a. Fixed Radius Turn. RTCA/DO-236A requires that the equipment be able to define a transition using a fixed turn radius of either 22.5 NM, for high altitudes, or 15 NM, for low altitudes. The navigation database will indicate whether a particular fix, along an airway, is associated with a high altitude or low altitude fixed radius turn. This document does not require support of these leg transitions. However, if an RNP route cannot be supported, the equipment is required to annunciate to the flight crew when a procedure is not supported.