U.S. Department
of Transportation
Federal Aviation
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Advisory Circular

Subject: Airworthiness Approval of Positioning and Navigation Systems

Date: 4/7/16
Initiated by: AIR-130

AC No: 20-138D
Change: 2

1. Purpose. Change 2 adds additional information and clarifications to AC 20-138D, Change 1 along with minor updates.

2. Principal Changes. The page control chart indicates which pages have changed.

PAGE CONTROL CHART

Remove Pages	Dated	Insert Pages	Dated
1-3	10/10/14	1-3	4/7/16
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U.S. Department
of Transportation
**Federal Aviation
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Advisory Circular

Subject: Airworthiness Approval of Positioning and Navigation Systems

Date: 10/10/14
Initiated by: AIR-130

AC No: 20-138D
Change: 1

Positioning and navigation equipment may be used for a variety of functions such as navigation, automatic dependent surveillance, and/or terrain awareness and warning systems. This AC addresses the following avionics:

- Global positioning system (GPS) equipment including those using GPS augmentations.
- Area navigation (RNAV) equipment integrating data from multiple navigation sensors.
- RNAV equipment intended for required navigation performance (RNP) operations.
- Baro-VNAV equipment.

This AC does not address new satellite constellations that are planned or currently under construction. This AC will be updated when sufficient documentation is available from the GNSS provider countries and RTCA to support service definition, service performance commitments, and minimum operational performance standards for multi-constellation equipment.

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Chapter 1. General Information.

1-1. Purpose.

This advisory circular (AC) provides guidance material for the airworthiness approval of installed positioning and navigation equipment. Positioning and navigation equipment may be used for a variety of functions such as navigation, automatic dependent surveillance, and/or terrain awareness and warning systems. This AC addresses the following equipment:

a. Global positioning system (GPS) sensors or stand-alone navigation equipment, including those incorporating aircraft-based augmentation system (ABAS), satellite-based augmentation system (SBAS), or ground-based augmentation system (GBAS).

> **Note:** For standardization within this document, the acronyms GPS/SBAS and GPS/GBAS are used to indicate SBAS augmenting GPS and GBAS augmenting GPS respectively.

b. Area navigation (RNAV) integrating data from multiple navigation sensors such as global navigation satellite system (GNSS), inertial reference units (IRU), and distance measuring equipment (DME).

c. RNAV intended for required navigation performance (RNP) operations, including advanced functions and RNP authorization required (AR).

> **Note:** RNP AR was previously named RNP special aircraft and aircrew authorization required (SAAAR). The name was changed to RNP AR for international harmonization, but might not yet be standardized throughout all documents.

d. Barometric vertical navigation (baro-VNAV) equipment.

e. Appendix 8 provides preliminary information for manufacturers that wish to add new satellite constellations or additional frequencies to their GNSS capability. This AC will be updated as new documentation is developed for multi-constellation equipment.

f. This AC supersedes the airworthiness considerations contained in all revisions of AC 90-101, *Approval Guidance for RNP Procedures with AR*, and AC 90-105, *Approval Guidance for RNP Operations and Barometric Vertical Navigation in the U.S. National Airspace System*. Equipment previously approved per the airworthiness guidance in the 90-series ACs is still valid for the operations and conditions stated in their approvals. This AC does not replace the operational guidance found in the RNP 90-series ACs, but does replace the airworthiness guidance in the 90-series ACs. Also, this AC replaces the ACs listed in paragraph 1-3 by incorporating and updating the information they contained.

g. This AC is not mandatory and does not constitute a regulation. This AC describes an acceptable means, but not the only means, to install positioning and navigation equipment. However, if you use the means described in the AC, you must follow it in all important respects.

h. Mandatory terms such as "must" used in this AC are only applicable when following the compliance method outlined. Other terms such as "should" or "recommended" are acceptable compliance methods applicants are encouraged to use. The term "may" is used for optional methods.

i. This AC revision is not intended to modify, change or cancel equipment design or airworthiness approvals previously in existence. However, new installation approvals (TC, ATC, STC or ASTC) should follow the guidance in this AC.

j. The guidance in this AC cannot ensure compliance with Title 14 of the Code of Federal Regulations (CFR) parts 23, 25, 27, and 29 airworthiness regulations for every possible installation configuration. The applicant remains responsible for regulatory compliance and should work closely with their geographic aircraft certification office (ACO) to ensure regulatory compliance.

k. 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 14 CFR. This approval is typically achieved through a project specific issue paper.

1-2. Audience.

This AC is for aircraft manufacturers, avionics manufacturers, installation shops, or other applicants seeking design and/or airworthiness approval for the positioning and navigation systems described in this document.

1-3. Cancellation.

a. This AC supersedes the ACs listed below. Equipment previously approved per the guidance in the superseded ACs is still valid for the operations and conditions stated in their approvals. The following documents are cancelled:

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

(2) AC 20-130A, Airworthiness Approval of Navigation or Flight Management Systems Integrating Multiple Navigation Sensors.

(3) AC 20-138D Change 1, Airworthiness Approval of Positioning and Navigation Systems.

(4) AC 25-4, Inertial Navigation Systems.

b. This AC supersedes the airworthiness considerations in AC 90-45A, *Approval of Area Navigation Systems for use in the U.S. National Airspace System*. Equipment previously approved per the airworthiness guidance in AC 90-45A is still valid for the operations and conditions stated in their approvals.

1-4. Frequently Asked Questions.

This paragraph contains a list of questions concerning the guidance material in this AC. The responses to these questions are intended to help applicants interpret the guidance contained in this AC.

a. Ground Proximity Warning System/Terrain Awareness and Warning System (GPWS/TAWS) Mode 5 alert.

(1) **Question:** Is a GPWS or Class A TAWS Mode 5 alert a hard requirement to add localizer performance with vertical guidance (LPV) or GBAS landing system (GLS) capability?

(2) **Answer:** No. It is not the FAA's intent to burden manufacturers and operators by changing the GPWS or TAWS functions. The intent is simply to recommend a glidepath alerting function to help prevent controlled flight into terrain during LPV, LNAV/VNAV, and GLS approaches. See paragraphs 15-7.8 and 15-9.13 for clarification and additional guidance.

b. Class B TAWS and LPV or GLS Capability.

(1) **Question:** Is a low glideslope alerting function for LPV or GLS required with Class B TAWS for compliance with the guidance in paragraphs 15-7.8 and 15-9.13?

(2) **Answer:** No. It is not the FAA's intent to burden manufacturers and operators by changing the GPWS or TAWS functions. The intent is to simply recommend a glidepath alerting function to help prevent controlled flight into terrain during LPV, LNAV/VNAV, and GLS approaches.

c. Using the term vertical navigation (VNAV).

(1) **Question:** Doesn't RTCA/DO-229D assign a very specific meaning to the term 'VNAV' and dictate the term's specific uses for SBAS-based vertical navigation?

(2) **Answer:** No. RTCA/DO-229D, section 2.2.1.1.7 provides a recommended usage for the 'VNAV' label, but only requires that the label be used in a consistent manner. 'VNAV' can be used for an LNAV/VNAV approach procedure generated by GPS/SBAS-based or barometric-based vertical navigation capability (GPS/GBAS does not provide an LNAV/VNAV approach capability). The 'VNAV' label can also be used for an advisory vertical navigation function that provides vertical path deviation guidance indications on a

non-essential, not-required basis. Refer to the following AC 20-138D, chapters for additional information:

- Chapter 4, Advisory Vertical Guidance;
- Chapter 11, Baro-VNAV;
- Chapter 12, section 12-11, General Human Factors Considerations;
- Chapter 15, section 15-7.6, GPS/SBAS Equipment Annunciations; and,
- Chapter 18, section 18-5, Baro-VNAV integration with GNSS-Provided Vertical Guidance.

d. Tightly-coupled inertial navigation system/global positioning system (INS/GPS).

(1) **Question:** AC 20-138D, section 6-7 c. includes the following statement: "The FAA assumes that there is a limitation on the use of the GPS/inertial position data output to support enroute through lateral navigation (LNAV) approach only." Can you please explain the basis of this assumption? It appears to exclude the use of tightly coupled INS/GPS for oceanic use. Is this the intent? Or, is the intent to exclude it for use for LPV?

(2) **Answer:** Paragraph 6-6 addresses loosely-coupled systems and paragraph 6-7 addresses tightly-coupled systems. There is no intent to exclude either loosely-coupled or tightly-coupled INS/GPS from oceanic use. However, un-augmented GPS, even with tightly-coupled INS, is not adequate for vertical approach capability, and hybrid inertial vertical approach capability is not addressed in RTCA/DO-229D, appendix R. As stated in this AC, a GPS-based vertical approach capability requires GPS/SBAS or GPS/GBAS augmentation.

e. Flight management system (FMS) limitations.

(1) **Question:** AC 20-130A, section 5.d.(2) contained a limitation on FMS use and required an alternate means of navigation for the route flown. AC 20-138D does not include this section or make a mention of this limitation. What was the reasoning behind not including a similar section in AC 20-138D? Is there some higher level guidance that addresses this or is it left up to the safety analysis to address the need for an alternate means of navigation?

(2) **Answer:** It is important to differentiate between operational limitations and equipment performance limitations. AC 20-138D addresses equipment performance limitations while the 90-series ACs produced by Flight Standards address operational limitations (for example, 90-100, 90-101A, 90-105 for RNAV, RNP AR, and RNP respectively) as well as the Aeronautical Information Manual and operational rules (parts 91, 121, 135).

(a) AC 20-130A was written prior to implementing performance-based navigation concepts and the evolving RNAV/RNP-based National Airspace System. An FMS incorporating multiple navigation sensor inputs by its very nature has multiple sources of navigation, but the individual sensors have performance limitations on their navigation capabilities. Accordingly, the FMS functions will meet different requirements depending upon the sensors involved and the intended navigation capability. This AC addresses the performance limitations of the individual sensors contained in the document. These performance limitations must be considered for the overall intended function at the aircraft level during the airworthiness approval (i.e., during the type certificate (TC), amended type certificate (ATC), or supplemental type certificate (STC) approval) to determine any limitations on the aircraft.

(b) In summary, operational rules dictate the navigation equipage requirements. It is up to the operator to determine how to comply based on their specific operating rules and mission needs.

f. Satellite Navigation Terminology.

(1) **Question:** Why are so many different names and acronyms (such as GNSS, WAAS, SBAS, etc.) used for GPS?

(2) **Answer:** The different names and acronyms used depend upon whether the topic is a generic, international reference to satellite navigation, or a particular State's specific implementation.

(a) GNSS is used internationally to indicate any satellite-based positioning system or augmentation system. The acronym 'GNSS' includes satellite constellations, such as GPS, GLONASS, Galileo, or Beidou, along with augmentation systems such as 'SBAS' and 'GBAS'; all of which provide a satellite-based positioning service.

(b) The acronyms 'SBAS' and 'GBAS' are the respective international designations for satellite-based and ground-based augmentation systems complying with the International Civil Aviation Organization (ICAO) standards and recommended practices (SARPs). Several countries have implemented their own versions of 'SBAS' and 'GBAS' that have specific names and acronyms. For example, WAAS is the U.S. implementation of an 'SBAS' while EGNOS is the European implementation. Refer to Appendix 9 for definitions of terms and acronyms.

Note: This AC uses the acronyms GPS/SBAS and GPS/GBAS throughout for consistency and clarity to indicate augmentation systems for the GPS constellation.

g. RNAV versus RNP.

(1) **Question:** Are technical standard order (TSO)-C129(AR) Class A1 GPS and TSO-C146(AR) Class Gamma GPS/SBAS equipment RNAV or RNP systems?

(2) **Answer:** Both. RNAV systems conform to the ICAO performance-based navigation specification for total system error (TSE). RNAV total system error is the 95% probability that the navigation system accuracy remains within the limits defined for the RNAV operation. For example, during an RNAV-1 operation the TSE remains within one nautical mile of the desired path 95% of the time (see Figure 1 below). RNP systems conform to a performance-based navigation specification based on RNAV capability that also includes requirements for on-board performance monitoring and alerting. For example, during an RNP

1.0 operation, the TSE remains within one nautical mile of the desired path 95% of the time, and on-board performance monitoring provides the pilot with an alert when the probability that TSE exceeds 2xRNP is greater than 10^{-5} (see Figure 2 below). RNP is an RNAV subset that also includes a requirement to provide on-board navigation system accuracy performance monitoring and alerting which means an RNP system is also an RNAV system. GNSS equipment provides accuracy performance monitoring and alerting which, by definition, makes it both an RNAV and RNP capable system.

> **Note:** TSO-C129(AR) Class B/C, TSO-C145(AR), and TSO-C196(AR) sensors provide both RNAV and RNP capability when interfaced to an appropriate navigation computer (such as TSO-C115d).

(a) By definition, TSO-C129(AR) Class A1 and all TSO-C146(AR) Class Gamma GNSS equipment provides an RNAV capability that includes on-board performance monitoring and alerting. This equipment has the capability to perform RNAV(GPS) approaches to at least the LNAV line of minima.

(b) RNAV(GPS) approaches require GPS, which includes on-board performance monitoring and alerting. Therefore, an RNAV(GPS) approach is an RNP procedure where the initial, intermediate, and missed approach segments are RNP 1.0. The LNAV final approach segment is RNP 0.3.

(c) None of the preceding statements should be confused with RNP AR that requires special aircraft and aircrew approval. Neither TSO-C129(AR) Class A1 GPS nor TSO-C146(AR) Class Gamma GPS/SBAS can qualify for RNP AR operations without additional aircraft and aircrew approvals (see appendix 2). No RNP AR procedures can be included in the navigation databases of equipment that is not approved for RNP AR operations. RNP AR approach procedures are titled RNAV(RNP) and have an "authorization required" designation printed on the charts.

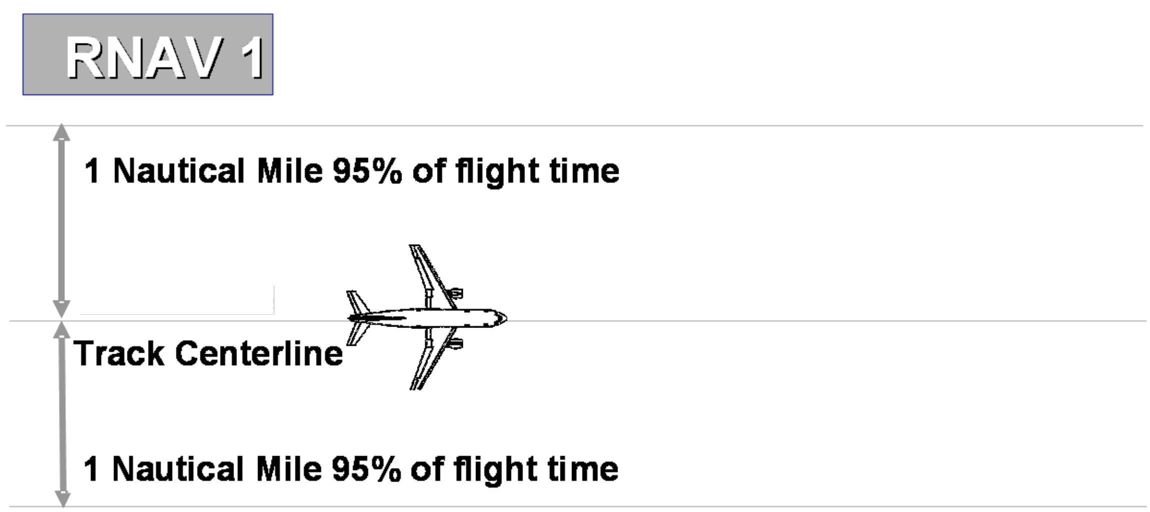

Figure 1. RNAV Depiction

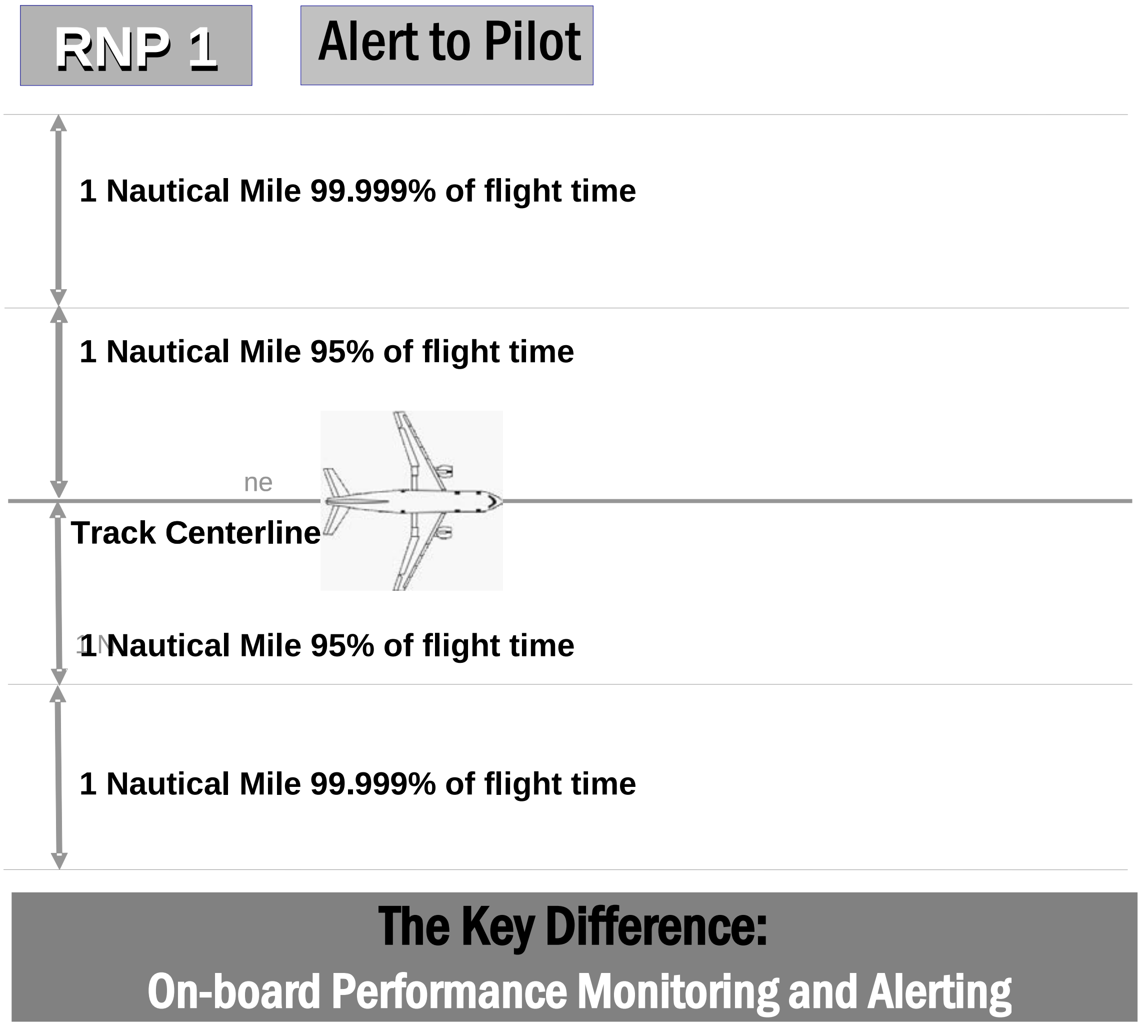

Figure 2. RNP Depiction

h. Incomplete Technical Standard Order (TSO).

(1) **Question:** Is it possible to receive an incomplete TSOA for a GPS or GPS/SBAS receiver circuit card assembly providing the functional performance of a sensor unit?

(2) **Answer:** No. The basis for a TSOA is that the applicant has sufficient control over the design and production to assure the system meets the minimum performance standard published by the FAA. However, we do allow for incomplete systems to obtain an authorization, as explained in the latest revision of AC 21-46, *Technical Standard Order Program*.

(a) The incomplete authorizations are applicable to a complete unit that performs a subset of the required performance or functionality of the TSO (see AC 21-46 (latest revision), paragraph 5-3). A GNSS receiver circuit card assembly is not a complete unit; it is a part that must be incorporated into another box to function properly. AC 20-170 (latest revision) *Integrated Modular Avionics Development, Verification, Integration, and Approval Using*

RTCA/DO-297 and Technical Standard Order-C153, addresses a somewhat similar situation for integrated modular avionics (IMA). But, navigation and non-navigation avionics equipment that incorporate GNSS receiver circuit card assemblies are not an IMA. Therefore, the IMA guidance is not applicable.

(b) However, the FAA recognizes that GNSS receiver circuit card assemblies are more than "component parts" and fundamentally provide the GNSS sensor functional capability. In essence, the only difference between a complete GNSS sensor unit and a receiver circuit card assembly is the sensor unit includes a power supply and enclosure shielding. But this difference is significant relative to the performance tests in the minimum operational performance standard (MOPS) specified by the GNSS TSOs. The concern is that a bare receiver circuit card assembly could pass the MOPS performance testing in isolation, but not maintain that performance when integrated into another device where it might be exposed to significant radio frequency interference from other circuit card assemblies or devices. The FAA has created three new TSOs to address this concern and provide certification credit for the functional capabilities in GNSS receiver circuit card assemblies. But the GNSS receiver circuit card assembly's end-user must repeat selected MOPS performance tests with the circuit card assembly installed in the end-use equipment and apply for the applicable GNSS sensor unit TSO (see paragraph 3-5).

i. Incorporating Step-down Fixes in Navigation Databases.

(1) **Question:** The latest ARINC 424 format has fields for both named and un-named step-down fixes. Is it acceptable for equipment manufacturers to include approach procedure step-down fixes in the navigation database; particularly when LPV capability is included?

(2) **Answer:** Yes. But ARINC 424 is not a TSO-specified standard, so there is no "requirement" to include step-down fixes or use all the fields. Having step-down fixes in the navigation database can present challenges for the airworthiness approval when LPV capability is included since step-down fixes are not applicable to LPV and the LPV requirements are designed to mimic an instrument landing system (ILS). The airworthiness applicant must ensure there is no confusing or disparate information presented to flight crews due to the cockpit arrangement. This can be a significant issue in legacy cockpits that have limited display capabilities. See paragraph 12-8 for guidance when including step-down fixes in the navigation database.

j. Using RTCA Inc. document (RTCA)/(DO)-178C *Software Considerations in Airborne Systems and Equipment Certification*, dated December 13, 2011.

(1) **Question:** Is it acceptable for equipment manufacturers to use RTCA/DO-178C in lieu of RTCA/DO-178B?

(2) **Answer:** Yes. In the U.S. it is acceptable for software development to use revision 'C' for TSOs that specify revision 'B' thru the deviation process. The project ACOs may approve deviation requests to use revision 'C' in lieu of revision 'B' without Headquarters

coordination. Refer to AC 20-115C for additional guidance on software qualification, including re-using software qualified to previous RTCA/DO-178 revisions.

Chapter 2. Technical Standard Order Authorization (TSOA) and Airworthiness Approval Considerations - General.

2-1. Guidance for TSOA/Letter of Design Approval (LODA) and Airworthiness Approvals.

Title 14 CFR part 21; subparts D, E, and O provide the regulatory basis defining changes to TC (major/minor changes to aircraft type design), STC, and TSOAs. The regulations and TSOs can be found at: http://rgl.faa.gov. This chapter provides general guidance on TSOA/LODA and airworthiness approval considerations specific to positioning and navigation equipment.

2-2. TSOA.

a. Several TSOs are available for positioning and navigation-related equipment and components (see appendix 10 of this AC). New TSOs will be written to address modernized GPS and other GNSSs once appropriate equipment standards are in place. It is beneficial to involve the ACO (both engineers and flight test pilots) in equipment evaluations as early as possible for four primary reasons:

(1) Obtaining a TSOA/LODA does not ensure that the equipment will satisfy all of the applicable operational requirements and/or airworthiness regulations when it is installed.

(2) Positioning and navigation equipment has become increasingly more complex and workload intensive with no standardized pilot interface. The human factors evaluation of the equipment can be subjective.

(3) There is no one, single standard for interfacing positioning and navigation equipment to other equipment on-board the aircraft such as displays, autopilots, and terrain warning systems. Positioning and navigation equipment manufacturers should develop compatibility data relative to other equipment for inclusion within the installation manual.

(4) The installed intended function for the equipment needs to be compatible with the original design for the system, including software and hardware design assurance levels and data process assurance levels. For example: a decision by the positioning and navigation equipment manufacturer to develop system software to RTCA/DO-178B Level C, may limit installation eligibility if that equipment contributes to failure conditions of other systems that perform critical functions to a higher software design assurance level.

> **Note:** AC 20-115C provides guidance on using RTCA/DO-178C including re-using software qualified to previous RTCA/DO-178 revisions.

b. It is recommended that the positioning and navigation equipment manufacturer elect to obtain an STC for equipment installation concurrent with obtaining the TSOA/LODA. This has proven to be an effective method to aid installations.

> **Note:** Any applicant may apply for an equipment installation STC. It is not this paragraph's intent to limit

positioning and navigation installation STCs solely to avionics manufacturers.

c. The installation manual and other data approved during the TSOA process can be used as a source of approved data to support an installation airworthiness compliance finding provided the data is applicable to the installation airworthiness requirements (see AC 21-50 (latest revision), *Installation of TSOA Articles and LODA Appliances*).

2-3. STC-Approved Model List (AML).

a. All STC applicants are encouraged to use an AML for aircraft makes/models (including 14 CFR parts 23, 25, 27, and 29 aircraft) with similar characteristics and compatible equipment configurations to streamline the approval of subsequent installations. Applicants and ACOs need to contact the applicable directorate for specific policy and guidance information on obtaining an STC-AML.

b. Using the STC-AML method can simplify follow-on installations for makes/models on the AML. The installer needs access to the STC approved data; apply the approved data; and comply with the detailed installation instructions. The installer then needs only complete FAA Form 337, *Major Repair and Alteration (Airframe, Powerplant, Propeller, Appliance)*, identifying the nature of the change to return the aircraft to service (see AC 43.9-1 (latest revision), *Instructions for Completion of FAA Form 337*).

c. GPS and GPS/SBAS equipment airworthiness approval is not considered novel or unusual per 14 CFR 21.16 and applicants can use designees during the STC process.

2-4. Type Certificate.

Positioning and navigation equipment manufacturers are also encouraged to work with TC holders. This has also proven to be an effective method to aid installations.

Chapter 3. TSO Authorization.

3-1. TSO-C196(AR).

a. TSO-C196(AR), *Airborne Supplemental Navigation Sensors for Global Positioning System Equipment Using Aircraft-Based Augmentation*, defines an acceptable standard for GPS equipment without ground-based or space-based augmentations. The TSO has been updated to revision ‘b’ for harmonization with TSO-C129a’s cancellation and for TSO-C206 circuit card assemblies. TSO-C196(AR) is intended as the aircraft-based augmentation GPS sensor standard for TSOA/LODA applicants. TSO-C196(AR) equipment has a performance limitation that requires other positioning and navigation systems appropriate to the operation on-board the aircraft.

> **Note:** TSO-C129a has been cancelled, but this does not affect equipment with an existing TSOA/LODA (see paragraph 3-1.c).

b. TSO-C196(AR) defines GPS sensor equipment that incorporates many processing improvements found in the GPS/SBAS equipment MOPS; but, without the GPS/SBAS requirements. Two improvement examples are: a requirement for the receiver to properly account for satellite range error if it is reflected in the User Range Accuracy index (commonly referred to as being “Selective Availability aware”), and requirements to ensure performance is not degraded due to an increasing radio frequency noise environment as other satellite systems become available.

(1) TSOA/LODA applicants may wish to have a previously approved TSO-C145b (or later revision), *Airborne Navigation Sensors Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS)*, sensor approved as a TSO-C196b sensor. It is acceptable for TSO-C196b applicants to take certification credit by re-using data developed during a previous revision ‘b’ or later TSO-C145 TSOA/LODA approval. RTCA/DO-316, *Minimum Operational Performance Standards for Global Positioning System/Aircraft-Based Augmentation System Airborne Equipment*, dated April 14, 2009, implemented by TSO-C196(AR) was developed from RTCA/DO-229D, *Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System (GPS/WAAS) Airborne Equipment*, dated December 3, 2006, implemented by TSO-C145b/c (revision ‘d’ implements RTCA/DO-229D, Change 1). Both RTCA/DO-229D and RTCA/DO-229D, Change 1 meets or exceeds the performance requirements for TSO-C196b. The original RTCA/DO-178B or ‘C’ documentation can be re-used if there are no software changes.

(2) Applicants seeking a TSO-C196b TSOA/LODA based on a previously approved revision ‘b’ or later TSO-C145 sensor must maintain separate part numbers for each unit. It is not acceptable to have both a TSO-C145(AR) and TSO-C196(AR) TSOA/LODA simultaneously on the same article (see paragraph 3-6.b(4)).

> **Note:** Maintaining separate part numbers might only require different software part numbers.

(3) It is acceptable for TSOA/LODA applicants with revision 'b' or later TSO-C145 sensors to simply disable the GPS/SBAS tracking loops in their equipment to apply for a TSO-C196b TSOA/LODA. The applicant will need to supply substantiation that the SBAS tracking loops are permanently disabled along with the data from their revision 'b' or later TSO-C145 TSOA/LODA.

(4) TSOA/LODA applicants with TSO-C145a sensors will need to show requirements traceability between RTCA/DO-229C and RTCA/DO-316 along with data applicability to receive appropriate certification credit. In particular, applicants will need to show compliance to all RTCA/DO-316 requirements not addressed in RTCA/DO-229C, and requirements that are more stringent such as enroute/terminal mode accuracy and the broadband external interference noise environment.

c. TSO-C129a was cancelled effective October 21, 2011, but there is no plan to withdraw TSO-C129(AR) authorizations. TSO-C129a cancellation will not affect existing authorizations. Manufacturers can continue production according to their existing TSO-C129(AR) TSOA/LODA. Additionally, the equipment is still eligible for installation according to existing airworthiness approvals and is eligible to receive new airworthiness approvals.

(1) No new TSO-C129a TSOAs/LODAs will be granted.

(2) Major changes to an existing TSO-C129a equipment design will require a new application according to 14 CFR 21.619(b) for either TSO-C145d, TSO-C146d or TSO-C196b.

3-2. TSO-C145(AR)/C146(AR).

a. TSO-C145d, *Airborne Navigation Sensors Using the Global Positioning System (GPS) Augmented by the Satellite-Based Augmentation System (SBAS)* and TSO-C146d, *Stand-Alone Airborne Navigation Equipment Using the Global Positioning System (GPS) Augmented by the Satellite Based Augmentation System (SBAS)* define an acceptable standard for GPS/SBAS equipment. There is no equipment performance limitation for GPS/SBAS-equipped aircraft to have other positioning and navigation systems on-board.

> **Note:** Refer to the appropriate operating rules and operational guidance documents for equipage requirements.

b. RTCA/DO-229D referenced by the GPS/SBAS TSOs will remain as the MOPS for single-frequency GPS/SBAS equipment. Future multi-frequency/multi-constellation equipment will have a separate MOPS and TSO.

c. There is no plan to withdraw authorizations to the earlier TSO revisions, so manufacturers of TSO-C145/C146 revision 'a' through 'c' equipment can continue production according to their TSOA/LODA; and the equipment is still eligible for installation in accordance with the guidance in this AC.

d. The difference between revisions 'b' and 'c' to the GPS/SBAS TSOs is eliminating a 3 decibel (dB) broadband intra-system noise credit for operational Class 1 and Class 2 equipment in RTCA/DO-229D. TSO-C145b/C146b operational Class 3 and Class 4 equipment fully complies with the requirements in TSO-C145c/C146c and is automatically eligible for a revision 'c' authorization, i.e., no further evaluation is necessary.

e. The difference between revisions 'c' and 'd' to the GPS/SBAS TSOs is: recognizing TSO-C204/C205 circuit card assemblies; and using Change 1 to RTCA/DO-229D.

f. TSO-C145b/C146b operational Class 1 and Class 2 equipment that did not claim the 3dB noise credit is also eligible for a revision 'c' authorization. The TSOA/LODA holder only needs to provide substantiation that they did not take the noise credit during the original certification.

g. Displays or navigation computers (such as FMSs) may receive a TSO-C146d Class 1, 2, or 3 (functional Class Gamma) incomplete TSOA/LODA provided they meet the applicable Class Gamma requirements in RTCA/DO-229D and are linked by part number to compatible TSO-C145(AR) sensors in the TSO application documentation. This is an effective method to aid GPS/SBAS installation approvals to make a complete system (sensor, navigation computer, display) at the aircraft level.

> **Note:** See paragraph 3-4 for additional information on FMS incomplete TSO-C146c Class Gamma TSOA/LODAs and Class Delta-4 FMS implementations.

3-3. TSO-C161a/C162a.

a. TSO-C161a, *Ground Based Augmentation System Positioning and Navigation Equipment*, defines an acceptable standard for GPS/GBAS equipment that provides precision approach capability and position/velocity/time (PVT) information to navigation management equipment. TSO-C162a, *Ground Based Augmentation System Very High Frequency Data Broadcast Equipment*, defines an acceptable standard for GPS/GBAS equipment designed to receive a very high frequency data broadcast (VDB) and output the VDB messages to GPS/GBAS positioning and navigation equipment.

b. TSO-C161a and TSO-C162a invoke only the requirements in RTCA/DO-253C, *Minimum Operational Performance Standards for GPS Local Area Augmentation System Airborne Equipment*, dated December 16, 2008, that are needed to support Category I (CAT I) precision approach and, if applicable, the GPS/GBAS positioning service. The equipment may output PVT based on either the GPS/GBAS positioning service, or PVT from GPS or GPS/SBAS. The PVT based on GPS/GBAS is only available when the ground station supports the positioning service. TSO-C161a equipment must also obtain a TSO-C145d, TSO-C146d, or TSO-C196b TSOA. Requirements in RTCA/DO-253C needed to support precision approaches beyond CAT I are not invoked in these TSOs as these requirements have not been validated. Once validated, the FAA will either publish TSO revisions or new TSOs.

c. TSO-C161a and TSO-C162a compliant equipment does not address any RNAV capability. A partial missed approach capability is an option in the GPS/GBAS equipment but is not required (see note). RNAV capability for the initial, intermediate, and missed approach segments must be addressed during the aircraft GPS/GBAS integration (see paragraph 15-9.1).

> **Note:** Equipment meeting the RTCA/DO-253C precision and navigation (PAN) requirements can include an optional capability to provide guidance for the initial, straight-out portion of the missed approach segment. However, this capability doesn't provide guidance for the complete missed approach segment.

3-4. TSO-C115(AR).

a. TSO-C115d, *Required Navigation Performance (RNP) Equipment Using Multi-Sensor Inputs* defines an acceptable certification standard for obtaining design and production approval for multi-sensor navigation systems or FMSs integrating data from multiple navigation sensors. There is no plan to withdraw TSO authorizations granted under earlier TSO-C115 revisions. Manufacturers of earlier TSO-C115 revisions can continue production according to their TSOA/LODA; and the equipment is still eligible for installation in accordance with the guidance in this AC. However, integrating GNSS into TSO-C115/C115a multi-sensor navigation equipment is considered a major change and requires an application for a TSO-C115dTSOA/LODA.

(1) TSO-C115b only addressed TSO-C129 Class B and C sensors because it was published prior to TSO-C129a, TSO-C145(AR), TSO-C161(AR), and TSO-C196(AR). It is acceptable to integrate any GNSS sensor with TSO-C115b equipment.

> **Note:** The multi-sensor navigation system or FMS must comply with TSO-C115 revision 'b' (or a later revision) when integrating GNSS sensors if TSO-C115 is the approval basis. It is not acceptable to use systems certified to earlier TSO-C115 revisions for GNSS sensor integration (see paragraph 3-6.b(1)).

(2) Localizer performance without vertical guidance (LP)/localizer performance with vertical guidance (LPV) is considered a severe major/hazardous failure condition for misleading information (see paragraph 12-2.a). Equipment manufacturers may design FMSs for either a TSO-C146d Class Gamma-3, or Class Delta-4 architecture when integrating LP/LPV capability.

(a) A TSO-C115b (or later revision) FMS designed as a Class Gamma-3 architecture typically has level B software for the LP/LPV processing functions. It is acceptable to have the GPS/SBAS capability and level B software partitioned from other functions in the FMS. See paragraph 3-4.b for additional information on incomplete TSO-C146c Class Gamma TSOA/LODAs.

(b) TSO-C146d Class Delta-4 provides an ILS look-alike for LP/LPV final approach segment-only capability. A TSO-C115b (or later revision) FMS designed for a Class Delta-4 architecture does not process LP/LPV inputs; does not output LP/LPV deviations, path construction, alerts, etc.; and, does not require the FMS to have a TSO-C146d TSOA/LODA. The aircraft integration must include a GPS/SBAS sensor that has a TSO-C146d Class Delta-4 TSOA/LODA. See paragraph 3-4.c for additional information on Class Delta-4 implementations.

b. FMS manufacturers may add an incomplete TSO-C146d TSOA/LODA to FMSs certified to TSO-C115b (or later revision). An appropriate operational class incomplete TSO-C146d Class Gamma TSOA/LODA provides an established means for the installed FMS to demonstrate navigation computer compliance as a GPS/SBAS system.

Note 1: FMSs that do not meet the applicable RTCA/DO-229D Class Gamma performance requirements can still receive PVT inputs from a TSO-C145(AR) sensor and apply them consistent with their existing approvals. Using a TSO-C145(AR) sensor can remove certain performance limitations associated with a TSO-C129(AR) sensor (see paragraphs 5-5.2.b and 5-5.2.c).

Note 2: There is significant overlap in requirements between TSO-C146d Class Gamma implementation of RTCA/DO-229D and TSO-C115d implementation of RTCA/DO-283B *Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation* requirements. Where requirements overlap exists it is acceptable to re-use compliance information from RTCA/DO-229D as the method of demonstrating RTCA/DO-283B compliance. However, applicants remain responsible to ensure all RTCA/DO-283B requirements are satisfied.

Note 3: TSO-C146d Class Gamma has alert limits for navigation system error (NSE) at 1 x RNP value and assumes a fixed, manual flight technical error (FTE). The TSO-C146d Class Gamma FTE assumption and NSE alert meets the 2 x RNP TSE alerting requirement for RNP operations. TSO-C115d does not assume a fixed FTE value which allows applicants to trade off FTE and NSE when meeting the 2 x RNP TSE alerting requirement.

(1) TSO-C146d will take precedence when adding an incomplete TSO-C146d Class Gamma TSOA/LODA to an FMS with an existing TSO-C115b or later TSOA/LODA if there are any conflicts between the two TSOs.

(2) TSO-C115d requires the FMS meet the minimum performance standard documentation and qualification requirements for Class A or Class B specified in sections 2.1 and 2.2 of RTCA/DO-283B. Class A includes full VNAV and advanced RNP capability while Class B includes only 2-dimensional RNP navigation functions. Class B applicants that wish to

include baro-VNAV capability or receive advanced RNP recognition must comply with the appropriate RTCA/DO-283B requirements. See RTCA/DO-283B, Table 2-13 for a complete list of the required Class A and Class B functions. The baro-VNAV guidance in this AC must be used when including baro-VNAV for approach capability. See appendix 3 for guidance on advanced RNP recognition.

(3) FMSs may qualify as TSO-C146d Class Gamma navigation computer systems when receiving inputs from a TSO-C145d Class Beta sensor. An incomplete TSO-C146d Class Gamma approval (Gamma-2 or -3 as appropriate) can be added to the TSO-C115b (or later revision) approval, or replace the TSO-C129(AR) approval if one exists, to provide GPS/SBAS-based VNAV approach capability. Class Gamma-1 can be used for FMSs that don't intend to process GPS/SBAS vertical deviations.

> **Note:** Several issues must be considered for FMSs integrating both baro-VNAV and GPS/SBAS to provide LNAV/VNAV capability. For example; unambiguous navigation source and approach service level annunciation, discontinuities or jumps when switching from baro-VNAV to GPS/SBAS vertical guidance, and prioritizing when to use which source (see paragraphs 6-3.b, 16-2.a, and 18-5).

c. For Class Delta-4 architectures, FMSs in typical federated avionics architectures do not need an incomplete TSO-C146d Class Delta-4 TSOA/LODA for LPV capability since the FMS does not provide or process flight path deviation data or GPS/SBAS alerting functions during the final approach segment. The complete system (sensor with Class Delta-4 TSOA/LODA, level B path, and display) will be confirmed at the time of installation. See paragraph 15-2.a regarding displays and path for legacy aircraft retrofit installations previously certified with ILS.

(1) It is acceptable for the Class Delta-4 sensor to reside within the FMS itself provided the LP/LPV outputs are not processed or altered by the FMS (similar to an ILS).

(2) The FMS may provide an interface for pilot control of the Class Delta-4 equipment (such as selecting the approach) and may host the Final Approach Segment (FAS) database for input to the Class Delta-4 equipment. The Class Delta-4 TSOA/LODA holder must list the specific compatible FMS(s) or provide a detailed interface description to establish FMS compatibility in the installation manual.

(3) At the aircraft level, Class Delta-4 implementations depend upon the entire path for the guidance deviations complying with a severe major/hazardous failure condition in modern aircraft with digital data busses. See paragraph 15-2.a regarding displays and path for legacy aircraft retrofit installations previously certified with ILS.

(4) Non-federated FMS architectures, such as integrated modular avionics, may have the Class Delta-4 LP/LPV final approach segment capability residing within the FMS functions or components. The applicable modules for these FMSs will need a TSO-C146d Class Delta-4 TSOA/LODA and appropriate software level for the Class Delta-4 performance

requirements listed in RTCA/DO-229D that they provide.

> **Note:** It is also acceptable for applicants with non-federated FMS architectures to consider pursuing incomplete TSO-C146d Class Gamma approval for the navigation computer functions/components.

(5) An FMS that is part of an aircraft-level TSO-C146d Class Delta-4 integration normally provides the RNP capability for the initial and intermediate approach segments to place the aircraft in proper position for the Class Delta-4 GPS/SBAS equipment to conduct the LP/LPV final approach segment. The FMS also provides the RNP capability for the missed approach segment.

> **Note:** RNP capability for the initial, intermediate, and missed approach segments can be accomplished by the FMS according to its TSO-C115b (or later revision) or other GNSS TSO approval. However, the FMS will be limited to its approved functions per those TSOs or as modified if receiving PVT inputs from a TSO-C145(AR) sensor (see paragraphs 5-5.2.b and 5-5.2.c).

d. Multi-sensor systems must also comply with the appropriate TSO requirements for the individual sensors that are integrated. For example, if distance measuring equipment (DME) is integrated, then the system must also comply with TSO-C66c, *Distance Measuring Equipment (DME) Operating Within the Radio Frequency Range of 960 to 1215 Megahertz, for DME equipment*. Refer to AC 90-100 (latest revision), *U.S. Terminal and Enroute Area Navigation (RNAV) Operations*, for operational approval of terminal and enroute area navigation systems for use in the U.S. national airspace system.

3-5. TSO-C204/C205/C206.

a. The FAA created three new TSOs to recognize the functional capability of GNSS sensor circuit card assemblies and enable end-use manufacturers to incorporate these devices for navigation and non-navigation uses. The intent is to ease the GNSS sensor TSO burden for end-use equipment manufacturers; particularly for non-navigation equipment such as ADS-B or TAWS. But FMS, multi-mode receiver, or other navigation equipment manufacturers could also benefit from these TSOs.

b. The three circuit card assembly TSOs are matched to the three existing GNSS sensor TSOs as follows:

- TSO-C204 to TSO-C145d
- TSO-C205 to TSO-C146d Class Delta-4
- TSO-C206 to TSO-C196b

Note: TSO-C205 is not appropriate for TSO-C146d Class Gamma functionality since Class Gamma is a combined sensor/navigation computer/display. However, TSO-C204 can be used for the sensor portion of a Class Gamma unit similar to using TSO-C204 in an FMS or multi-mode receiver.

c. Appendix 1 in TSO-C145d/C146d/C196b contains information on the MOPS performance tests the end-use manufacturer must re-accomplish to receive the appropriate TSOA. The end-use manufacturer must mark their equipment with the appropriate GNSS sensor TSO and assumes full responsibility for the GNSS sensor TSOA per the 14 CFR Part 21 Subpart O regulations.

d. The purpose of the new TSOs is to provide certification credit to the end-use equipment manufacturer for the following items performed by the circuit card assembly manufacturer:

- compliance with the requisite MOPS section 2 requirements,
- hardware/software development,
- failure condition classification, and;
- partial MOPS performance testing.

However, the circuit card assembly TSOs have limitations requiring the end-use manufacturer to apply for the latest revision of TSO-C145, TSO-C146 Class Delta-4, or TSO-C196, consistent with the circuit card assembly TSO.

e. The end-use equipment manufacturer receives credit for the items in paragraph 3-5.d by virtue of the circuit card assembly TSO. To receive a GNSS sensor TSOA the end-use equipment manufacturer data submittal is:

(1) The TSO on the circuit card assembly;

(2) The repeated MOPS performance testing according to the GNSS TSO appendix 1;

(3) All other documentation associated with the GNSS sensor TSO, including environmental testing.

3-6. Multiple TSO Authorizations.

a. Multiple TSO authorizations may be granted for equipment that accomplishes multiple functions. However, the number of TSO markings on positioning and navigation equipment should be minimized to avoid confusion during installation and approval.

b. The following combinations of TSO authorizations must not be granted, as the TSOs either contradict each other or are superfluous to a TSO with broader scope:

(1) TSO-C115/C115a with TSO-C129(AR), TSO-C145(AR)/C146(AR), TSO-C196(AR), or TSO-C161a/C162a).

(2) TSO-C129(AR) Class A with TSO-C146(AR) Class Gamma.

(3) TSO-C129(AR) Class B or Class C with TSO-C145(AR), TSO-C146(AR) or TSO-C196(AR).

(4) TSO-C196(AR) with TSO-C145(AR) or TSO-C146(AR).

Note: The intent is that combinations not specifically prohibited by paragraphs 3-5.b(1) through 3-5.b(4) are acceptable.

Chapter 4. Equipment Performance - Advisory Vertical Guidance.

4-1. Introduction.

Positioning and navigation equipment may provide vertical path deviation guidance indications on a non-essential, not-required basis as an aid to help pilots meet barometric altitude restrictions. Equipment that has this capability typically uses GNSS or baro-VNAV, but may use any method to generate the vertical path information. Advisory vertical guidance does not provide approved vertical guidance deviation indications for operational credit. Only vertical guidance deviation indications for LNAV/VNAV or LPV approach procedures are approved for operational credit.

> **Note 1:** Advisory vertical guidance is an optional capability implemented at the equipment manufacturer's discretion for enroute, terminal, and/or approach operations; not a requirement for positioning and navigation equipment.
>
> **Note 2:** Paragraph 4-1 does not apply to ILS.
>
> **Note 3:** We recommend that equipment manufacturers provide a means for pilots to inhibit advisory vertical guidance to support non-precision approach training requirements.

4-2. Implementations.

a. It is acceptable to provide advisory vertical guidance as a descent aid during oceanic/remote, enroute, and terminal operations.

b. GPS equipment without GPS-provided approved vertical capability (TSO-C129(AR), TSO-C196(AR), TSO-C145/C146(AR) Operational Class 1) and no baro-VNAV integration in the aircraft may provide advisory vertical guidance deviation indications on any approach using the LNAV line of minima.

c. Some aircraft integrations may use GPS equipment without GPS-provided approved vertical capability (TSO-C129(AR), TSO-C196(AR), TSO-C145/C146(AR) Operational Class 1) to provide lateral path deviation indications and an approved baro-VNAV installation to provide vertical path deviation indications for an approach to the LNAV/VNAV line of minima.

(1) **This integration constitutes approved vertical guidance to conduct a charted instrument approach procedure to the LNAV/VNAV line of minima and should not be confused with advisory vertical guidance applications.**

(2) There may be occasions where it is operationally advantageous to use the LNAV line of minima rather than the LNAV/VNAV minima during an instrument approach procedure. It is acceptable for approved baro-VNAV installations to provide advisory vertical guidance when using the LNAV line of minima. **However, during these operations, the**

flight crew must use the primary barometric altimeter as the primary reference for compliance with all altitude restrictions associated with the instrument approach procedure; including compliance with all associated step-down fixes (see paragraphs 12-8 and 18-2.b)**.**

> **Note 1:** Baro-VNAV integrations may use non-GPS RNAV position sources to generate lateral path deviations for approaches that do not require GPS.

> **Note 2:** Baro-VNAV is subject to performance limitations that could potentially cause advisory vertical path guidance to fall below step-down fixes on LNAV approaches.

d. During RNAV (GPS) instrument approach operations, TSO-C145/C146(AR) Operational Class 2 equipment may provide advisory vertical guidance when the procedure defines only the LNAV line of minima (i.e., procedures without a charted LNAV/VNAV and/or LPV line of minima). GPS/SBAS Operational Class 2 equipment is not capable of performing LP approaches, but may provide advisory vertical guidance for the LNAV line of minima on instrument approach procedures that define both an LNAV and LP line of minima.

(1) It is possible for GPS/SBAS Operational Class 2 equipment to also provide advisory vertical guidance for LNAV minima on instrument approach procedures that also contain LNAV/VNAV or LPV lines of minima as published, but with the additional considerations listed below. The reason is due to the wide range of displays, cockpit configurations, and potential confusion over "advisory" versus "approved" vertical guidance and which line of minima applies.

(a) LNAV with "advisory" vertical guidance must only be selectable prior to the FAF.

(b) The "advisory" vertical guidance indication must be unambiguous and easily distinguishable from the "approved" vertical guidance indication.

(c) The installation instructions/manual (or equivalent documents) must define the minimum display capability and cockpit configuration.

(d) The equipment must have an installation limitation or method to inhibit the function for non-qualifying installations.

(2) It is not acceptable for GPS/SBAS Operational Class 2 equipment to provide "advisory" vertical guidance in a "fail-down" mode from LNAV/VNAV to LNAV minima during the final approach segment.

> **Note 1:** GPS/SBAS equipment manufacturers should exercise care when implementing "advisory" vertical guidance for LNAV minima collocated with LNAV/VNAV or LPV minima as published. The cockpit configuration and display capability can influence the

ability to provide an unambiguous, easily distinguishable vertical guidance indication during the airworthiness approval.

Note 2: Both the design approval applicant and airworthiness approval applicant have a responsibility to ensure the implementation is properly configured. Airworthiness approval applicants should contact their ACO early for concurrence on the proposed implementation.

e. During RNAV (GPS) instrument approach operations, TSO-C145/C146(AR) Operational Class 3 equipment may provide advisory vertical guidance when the procedure defines only the LNAV and/or LP line of minima (i.e., procedures without a charted LNAV/VNAV and/or LPV line of minima).

Note 1: LP approach procedures will never be published with other lines of minima that contain approved vertical guidance (i.e., LNAV/VNAV or LPV). LNAV and LP lines of minima can be published on the same approach chart; and, it is acceptable to provide advisory vertical guidance, either GPS/SBAS or baro-VNAV, during approach operations using these lines of minima.

Note 2: Per RTCA/DO-229D it is not appropriate for GPS/SBAS Operational Class 3 equipment to "fail-down" from LP to LNAV.

(1) It is possible for GPS/SBAS Operational Class 3 equipment to also provide advisory vertical guidance for LNAV minima on instrument approach procedures that also contain LNAV/VNAV or LPV lines of minima as published, but with the additional considerations listed below. The reason is due to the wide range of displays, cockpit configurations, and potential confusion over "advisory" versus "approved" vertical guidance and which line of minima applies.

(a) LNAV with "advisory" vertical guidance must only be selectable prior to the FAF.

(b) The "advisory" vertical guidance indication must be unambiguous and easily distinguishable from the "approved" vertical guidance indication.

(c) The installation instructions/manual (or equivalent documents) must define the minimum display capability and cockpit configuration.

(d) The equipment must have an installation limitation or method to inhibit the function for non-qualifying installations.

(2) It is not acceptable for GPS/SBAS Operational Class 3 equipment to provide

"advisory" vertical guidance in a "fail-down" mode from LPV or LNAV/VNAV to LNAV minima during the final approach segment.

> **Note 1:** GPS/SBAS equipment manufacturers should exercise care when implementing "advisory" vertical guidance for LNAV minima coincident with LNAV/VNAV and display capability can influence the ability to provide an unambiguous, easily distinguishable vertical guidance indication during the airworthiness approval.

> **Note 2:** Both the design approval applicant and airworthiness approval applicant have a responsibility to ensure the implementation is properly configured. Airworthiness approval applicants should contact their ACO early for concurrence on the proposed implementation.

f. TSO-C146(AR) Operational Class 4 (Functional Class Delta) equipment provides an "ILS look-alike" capability for LPV and LP only. GPS/SBAS Operational Class 4 equipment indicates LP by flagging the vertical guidance indications. It is acceptable for Class Delta equipment to provide advisory vertical guidance during approach procedures to LP minimums. However, it is not acceptable for Operational Class 4 equipment to provide advisory vertical guidance when the equipment "fails-down" from LPV to LNAV minima during the final approach segment due to potential confusion over advisory versus approved vertical guidance and which line of minima applies.

> **Note:** Per RTCA/DO-229D it is not appropriate for GPS/SBAS Operational Class 4 equipment to "fail-down" from LP to LNAV.

g. Advisory vertical guidance may be provided during very high frequency omni-directional range (VOR) and non-directional beacon (NDB) instrument approach operations (including overlays with "or GPS" in the title) and also for older GPS instrument approach operations titled "GPS RWY XX".

4-3. Limitations.

a. There are no TSO requirements or MOPS standards regarding advisory vertical guidance minimum performance or how advisory vertical guidance is generated (see notes). Positioning and navigation equipment manufacturers can generally use their discretion when choosing to implement this capability. However, the equipment manufacturers cannot claim any operational or certification credit for advisory vertical guidance. When implementing advisory vertical guidance, the equipment manufacturer must provide an equipment limitation in the installation/instruction manual for inclusion in the airplane flight manual (supplement)/rotorcraft flight manual (supplement) (AFM(S)/RFM(S)) and may also include the information in the operations manual. The limitation should state the following or be equivalent:

"Advisory vertical guidance deviation information is only an aid to help pilots comply with altitude restrictions. When using advisory vertical guidance, the pilot must use the primary barometric altimeter to ensure compliance with all altitude restrictions, particularly during instrument approach operations."

Note 1: RTCA/DO-229D, referenced by the GPS/SBAS TSOs, does provide some cursory requirements related to GPS/SBAS-provided advisory vertical guidance.

Note 2: The pilot using the primary barometric altimeter to ensure compliance with altitude restrictions is generally considered the mitigation for misleading or erroneous advisory vertical guidance information (i.e., 14 CFR XX.1309 compliance). However, each installation should be individually evaluated.

b. The AFM(S)/RFM(S) and/or installation manual limitation does not preclude positioning and navigation equipment from outputting advisory vertical guidance deviations to an autopilot provided applicable autopilot requirements are satisfied. However, demonstrating autopilot compatibility or compliance is beyond the scope of this AC (see the latest revision of AC 23-17, *Systems and Equipment Guide for Certification of Part 23 Airplanes*, AC 25.1329-1, *Approval of Flight Guidance Systems*, AC 27-1, *Certification of Normal Category Rotorcraft*, or AC 29-2, *Certification of Transport Category Rotorcraft*, for autopilot guidance information).

c. Positioning and navigation equipment manufacturers should consider providing a method to differentiate advisory vertical guidance indications from those used for approved vertical guidance to reduce potential crew confusion. If practical, the vertical deviation indications for each mode of vertical guidance should be unique and distinct.

Chapter 5. Equipment Performance - GNSS.

5-1. Introduction.

a. There have been questions on whether GNSS is an RNAV or RNP system. The answer is GNSS is both an RNAV and RNP system because RNP is a subset of RNAV that also includes a requirement to provide on-board navigation system accuracy performance monitoring and alerting. Therefore, an RNP system is also capable of RNAV. GNSS equipment provides accuracy performance monitoring and alerting which, by definition, makes it an RNP-capable system. Paragraph 1-4.f contains a frequently asked question and more detailed answer explaining RNAV, RNP and GNSS qualification. Chapters 7 - 10 provide more information about RNP.

b. The TSOs and MOPS for various types of GNSS equipment have been published over a span of several years. Despite efforts to harmonize all the GNSS documents, there are differences among the documents because of this publication time gap; particularly for characterizing the broadband external interference noise environment. The broadband external interference noise is defined in RTCA/DO-235B, *Assessment of Radio Frequency Interference Relevant to the GNSS L1 Frequency Band*, dated March 1, 2008. Table 1 below summarizes the effective noise density for acquisition, tracking, and re-acquisition that GNSS equipment manufacturers should use when certifying new equipment. Equipment not meeting the effective noise density in Table 1 (e.g., TSO-C129(AR)) may experience performance degradation as more GNSS satellites are launched. Equipment intended for use beyond 2020 in applications such as ADS-B should be qualified using the effective noise density shown in Table 1.

Receiver Function	Effective Noise Density (dBm/Hz)
Initial Acquisition (GPS Only)	-172.2
GPS Tracking and Re-acquisition	-171.9
SBAS Tracking and Re-acquisition	-172.8

Table 1. Effective Noise Density for All GNSS Sources

c. It is acceptable to run GPS/SBAS testing separately using a total GNSS noise (I_{GNSS}) of -172.8 dBm/Hz for accuracy verification and/or collection of the GPS/SBAS message loss rate data.

d. TSO-C145b/c and TSO-C146b/c equipment use a slightly earlier broadband external interference noise standard that is very close to the Table 1 effective noise density. This equipment should not experience any difficulty with the increasing noise environment. However, manufacturers should use the values listed in Table 1 when conducting the test scenarios described in RTCA/DO-229D.

> **Note:** RTCA/DO-229D, Change 1 contains the latest noise standards and is implemented by TSO-C145d/C146d. TSO-C196(AR) equipment also incorporates the Table 1 effective noise density.

e. TSO-C145a/C146a equipment complies with RTCA/DO-229C that uses the broadband external interference noise characterized by a previous RTCA/DO-235 revision. TSO-C145a/C146a equipment may experience performance degradation when other GNSS services are launched because future interference management and prevention will be based on the RTCA/DO-235B-defined broadband external interference noise environment.

f. TSO-C129(AR) equipment has no broadband external interference noise requirements comparable to RTCA/DO-235B. This equipment is more likely to experience performance degradation when other GNSS services are launched because future interference management and prevention will be based on the RTCA/DO-235B-defined environment.

g. Improperly used or installed GNSS re-radiators can present misleading information to GNSS equipment. Equipment manufacturers should consider measures to mitigate against the use of erroneous data for GNSS position and navigation solutions. Possible measures to consider are: implementing or enabling cross-checks of GNSS sensor data against independent position sources and/or other detection monitors using GNSS signal metrics or data.

5-2. GPS (TSO-C129(AR) and TSO-C196(AR) receivers).

a. TSO-C129(AR) and TSO-C196(AR) GPS equipment may be used on RNAV 'T' and 'Q' routes and for RNAV approaches to LNAV minimums within the contiguous U.S.. AC 90-100 (latest revision) contains specific information on performance requirements for RNAV routes.

> **Note:** TSO-C129a has been cancelled, but this does not affect equipment with an existing TSOA/LODA (see paragraph 3-1.c).

b. Equipment requirements for 'T' and 'Q' routes in Alaska differ due to infrastructure and other unique characteristics of Alaskan airspace. Special Federal Aviation Regulation (SFAR) 97 provides guidance on flying in Alaska. Alaska Q routes require GNSS (TSO-C129(AR), TSO-C196(AR), TSO-C145(AR) or TSO-C146(AR)) and radar surveillance. Alaska T routes require TSO-C145(AR) or TSO-C146 (AR). There is an ongoing program to either revise or delete the SFAR 97 requirements. See enroute charts, Notices to Airman Publication (NTAP), and Notice to Airmen (NOTAMs) for latest equipment requirements in Alaska.

5-2.1 Antennas.

a. It is recommended that receiver manufacturers seeking antennas for equipment certified to TSO-C129(AR) and TSO-C196(AR) use antennas compliant with the applicable antenna TSOs described below (see paragraph 5-5.4 for a complete discussion on antenna re-use/replacement). However, combinations where both the antenna and receiver were certified together as a unit under TSO-C129/C129a will need a new certification if antennas meeting the original TSOA are no longer available. Using a different antenna specification constitutes a major design change that requires a new TSOA/LODA unless the original

TSOA/LODA contains part numbers for multiple antennas.

(1) Either passive or active antennas are acceptable for TSO-C129(AR) and TSO-C196(AR) GPS equipment. The current TSOs for passive and active antennas are listed below, but antennas previously certified to TSO-C144 are also acceptable (see Table 2).

(2) TSO-C144a, *Passive Airborne Global Navigation Satellite System (GNSS) Antenna*, that references RTCA/DO-228, Change 1, paragraph 2.2.1, defines an acceptable passive GPS antenna. A passive antenna is defined as one that does not include a low noise power amplifier as part of the antenna assembly.

(3) TSO-C190, *Active Airborne Global Navigation Satellite System (GNSS) Antenna*, that references RTCA/DO-301, defines an acceptable active GPS antenna. An active antenna is defined as one that includes a low noise power amplifier as part of the antenna assembly.

b. To aid compatibility findings, antenna manufacturers should identify the antenna minimum DC supply current, and nominal amplifier gain/tolerance for active antennas in the installation instructions. Receiver manufacturers need this information to define installation instructions that integrate the antenna and receiver. Additionally, the antenna manufacturer should identify the antenna minimum radiation pattern gain at 5 degrees and the antenna minimum gain/equivalent input noise temperature (G/T) ratio in the installation instructions so that receiver manufacturers can take advantage of performance better than the minimum MOPS requirement. Documenting the improved performance facilitates the antenna/receiver installation and integration.

5-2.2 Sensors.

a. TSO-C129(AR) and TSO-C196(AR) are positioning and navigation systems with equipment limitations for the aircraft to have other navigation equipment available appropriate to the operation and for alternate airport flight planning (see paragraph 15-6).

> **Note 1:** TSO-C129(AR) Class A equipment is a sensor/navigation computer combination.
>
> **Note 2:** TSO-C129a has been cancelled, but this does not affect equipment with an existing TSOA/LODA (see paragraph 3-1.c).

b. TSO-C129(AR) systems will not have an equipment limitation for the aircraft to have other navigation equipment in oceanic and remote areas provided additional requirements are met (see appendix 1).

c. TSO-C196(AR) systems will not have an equipment limitation for the aircraft to have other navigation equipment in oceanic and remote areas provided the operator obtains a fault detection and exclusion (FDE) prediction program (see paragraph 5-2.3).

d. The intent for TSO-C196(AR) equipment is to take advantage of signal processing improvements found in RTCA/DO-229D without including the GPS/SBAS requirements. TSO-C196(AR) equipment is intended as a direct replacement for Class B & C sensors certified to TSO-C129(AR). Additionally, TSO-C145(AR) equipment can also replace TSO-C129(AR) Class B & C sensors.

> **Note 1:** Applicants will have to establish sensor/antenna compatibility when replacing TSO-C129(AR) sensors with either TSO-C196(AR) or TSO-C145(AR) sensors.

> **Note 2:** GPS/SBAS TSO-C146(AR) Class Gamma equipment is considered the direct replacement for a Class A sensor/navigation computer combination certified to TSO-C129(AR).

5-2.3 Prediction Program.

a. GPS satellite failures have a non-intuitive impact on operational capability unlike conventional ground-based navigation aids that have a direct correlation between a facility outage (VOR fails) and the loss of an operational capability (VOR approach is unavailable). The operator is responsible for considering the effects of satellite outages during flight planning. Flight Standards defines the operational requirements to review NOTAMs, review published aeronautical information, and perform pre-departure receiver autonomous integrity monitoring (RAIM) or FDE availability checks. Prediction programs and availability assessments are essential to enabling the operator to fulfill this responsibility. The FAA currently provides availability service through NOTAMs for GPS/SBAS equipment for domestic navigation operations, and plans to provide prediction services through the aeronautical information system. Either the FAA (through NOTAM or aeronautical information system) or the service provider provides these services for GPS/GBAS equipment for domestic navigation operations depending upon the specific ground facility status; Federal or non-Federal. Paragraph 5-2.3 applies to operations that require a prediction program.

b. The following guidelines apply to any prediction program applicable to a particular model TSO-C129(AR) or TSO-C196(AR) receiver that is intended to assess the operational impact of satellite outages for flight planning purposes. Some operators are required to have an approved prediction program. A prediction program with the characteristics described below is acceptable.

> **Note:** The guidelines also apply to prediction programs for TSO-C145/C146(AR) if the equipment is intended for oceanic/remote operations without limitations (see appendix 1 and paragraph 5-3.2.a.

c. TSO-C129(AR) equipment may have either a fault detection-only algorithm or an FDE algorithm. TSO-C196(AR) equipment is required by RTCA/DO-316 to have an FDE algorithm. The prediction program must include the appropriate capability for the intended receiver.

d. Operational guidance on predictive RAIM requirements may be found in the *Aeronautical Information Manual* (or other FAA guidance). The best performance model most likely comes from the original GPS equipment manufacturer.

> **Note:** The FAA has transitioned to the service availability prediction tool (SAPT) for RAIM predictions which is available at www.sapt.faa.gov. However, SAPT does not provide FDE predictions for oceanic operations.

e. The prediction program can be provided on any processing platform (in the GPS equipment or elsewhere).

f. The prediction program software should be developed in accordance with at least RTCA/DO-178B or 'C' level D guidelines or equivalent.

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

h. The program should calculate RAIM or FDE availability based on the same satellite mask angle used in the equipment, but not less than 2 degrees for enroute/terminal operations or 5 degrees for approach.

i. The program should have the capability to manually or automatically designate GPS satellites which are expected to be out-of-service for the intended flight.

j. The program should allow the user to select the intended route (including declared alternates) and the time and duration of the flight. The program should identify the maximum RAIM or FDE outage time, and any predicted navigation capability outages.

(1) For approach operations, the maximum RAIM or FDE outage duration cannot exceed 5 minutes.

(2) For RNAV 1 and 2 operations, the maximum RAIM or FDE outage duration cannot exceed 5 minutes when TSO-C129(AR) or TSO-C196(AR) receivers are used as the only means of RNAV 1 and 2 compliance.

(3) For oceanic/remote operations, the maximum FDE outage duration cannot exceed 25 minutes for RNP 4.0 operation, 34 minutes for RNP 10 operation, and 51 minutes for minimum navigation performance standards (MNPS) operation.

> **Note:** Prediction programs must use FDE for oceanic/remote operations (See appendix 1). SAPT does not provide FDE predictions for oceanic operations.

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

l. Prediction programs supporting ADS-B out should meet the requirements in 14 CFR 91.227(c)(1)(i) and 14 CFR 91.227(c)(1)(iii). The program should identify the maximum RAIM or FDE outage time, and any predicted surveillance capability outages.

5-3. GPS/SBAS (TSO-C145/C146(AR) receivers).

5-3.1 Antenna.

a. This paragraph provides guidance on acceptable GPS/SBAS antennas. See Table 2 for a list of acceptable standard antenna TSOs matched with GPS/SBAS receiver TSO revision and operational class.

b. TSO-C190, that references RTCA/DO-301, defines an acceptable GPS/SBAS antenna.

> **Note:** RTCA/DO-229D, paragraph 2.1.1.10 allows receiver manufacturers to designate manufacturer-specified antennas to take advantage of unique antenna performance rather than using the “minimum standard” antenna defined by TSO-C190.

c. A number of “passive” and “active” antennas were authorized under TSO-C144 for TSO-C145a/C146a compliant GPS/SBAS receivers. These antennas remain acceptable for those receiver installations according to their original TSOA/LODA. Receiver manufacturers are encouraged to use a TSO-C190 antenna whenever a replacement becomes necessary for a TSO-C144 antenna.

d. Major modifications to TSO-C145a/146a receivers that require a new TSOA/LODA upgrade to the latest TSO revision (for operational class 2, 3, and 4) must use either a TSO-C190 or a receiver manufacturer-specified antenna that meets current requirements in RTCA/DO-229D (such as, sensitivity and dynamic range, geostationary orbit satellite (GEO) bias, broadband interference, and group delay).

5-3.2 Sensor and Sensor/Navigation Computer Configuration.

a. GPS/SBAS equipment has two different TSOs depending on whether the equipment is designed as a position sensor only, or a sensor/navigation computer combination. TSO-C145d defines an acceptable standard for GPS/SBAS sensors (Class Beta) while TSO-C146d defines two configurations; a complete sensor/navigation computer (Class Gamma) and an “ILS look-alike” (Class Delta). Both TSOs reference RTCA/DO-229D, Change 1 for operations within and outside of the GPS/SBAS service provider coverage area. When outside of a GPS/SBAS service provider’s coverage area the receivers can revert to using FDE for integrity. The receiver will use GPS/SBAS integrity or FDE; whichever provides the best protection level. GPS/SBAS equipment will not have any limitations in oceanic and remote areas provided the operator obtains an FDE prediction program (see paragraph 5-2.3).

> **Note:** GPS/SBAS equipment may continue using GEO data and range measurements when outside the GPS/SBAS service provider's coverage area per the requirements in RTCA/DO-229D (RTCA/DO-229C for TSO revision 'a' equipment).

b. GPS/SBAS equipment that complies with the standards implemented by TSO-C145(AR)/C146(AR) does not have an equipment limitation for the aircraft to be equipped with other navigation systems appropriate to the operation. With GPS/SBAS equipment it is also acceptable to flight plan an alternate using an RNAV(GPS) approach to LNAV minimums at the alternate airport rather than a ground-based approach aid (see paragraph 15-7.1). Additionally, GPS/SBAS equipment may be used on RNAV 'T' and 'Q' routes within the contiguous U.S. and Alaska. AC 90-100 (latest revision), contains specific information on performance requirements for RNAV routes. These capabilities should be clearly indicated in receiver manufacturer's operating instructions.

> **Note:** Refer to the appropriate operating rules and operational guidance documents for equipage requirements.

c. Although GPS/SBAS does not have an equipment limitation for other navigation systems onboard the aircraft, the receiver manufacturer's operating instructions should encourage operators to retain back-up navigation systems to guard against outages or interference events.

d. Class 3 and Class 4 GPS/SBAS equipment that complies with the TSO revision 'b' or later has the capability to do LP approaches. TSO-C145a/C146a manufacturers may provide LP capability in their equipment. LP approaches use the horizontal accuracy and integrity values of LPV but do not provide approved vertical guidance deviation indications for operational credit. The intent is to provide LP approaches only at locations where some issue prevents implementing LPV vertical guidance, so LP should be the exception rather than the rule. Therefore, LP is not operationally similar to a localizer-only approach on an ILS because LP and LPV are mutually exclusive. That is, LP and LPV lines of minima will never be on the same approach chart.

e. GPS/SBAS equipment manufacturers need to use caution when implementing LP capability because some LP procedures cannot support a visual descent angle due to obstructions. The FAS datablock glide path angle field coding uses a zero in these instances. Equipment manufacturers need to ensure a zero in the glide path angle field does not cause unintended software issues; for example, a divide by zero problem.

f. Manufacturers that request a deviation from the LP capability requirement in TSO-C145d/C146d for their Class 3 or Class 4 GPS/SBAS equipment must provide an appropriate limitation for the installation instructions (or equivalent installation documentation) as part of their TSO application package. The limitation must be included in the AFM(S)/RFM(S).

5-3.3 Navigation Database - Data Conversion for GPS/SBAS LNAV/VNAV Approaches.

a. For LNAV/VNAV approaches collocated with LPV approaches, GPS/SBAS equipment must use the final approach segment (FAS) data block to define the final approach segment as described in RTCA/DO-229D, Change 1. But, a FAS data block is not provided for stand-alone LNAV/VNAV approaches. The vertical path for such approaches is defined by the threshold location, threshold crossing height, and glidepath angle. However, the altitude of the threshold is published as the height above/below mean sea level (MSL), rather than as the height above/below the WGS-84 ellipsoid. Therefore, the published MSL height (interpreted as a height above/below the WGS-84 geoid) must be converted to height above/below the WGS-84 ellipsoid prior to being used. Actual decision altitude (DA) must be based on the barometric altimeter.

b. The data conversion is not considered alteration of data since it changes the reference system but not the actual vertical location (reference RTCA/DO-200B, *Standards for Processing Aeronautical Information*, dated June 18, 2015, paragraph 2.4.2)

c. Receiver manufacturers may consider performing the conversion within the GPS/SBAS equipment or using a database process that provides threshold crossing height directly as height above/below the WGS-84 ellipsoid for GPS/SBAS approaches. However, GPS/SBAS integrations with baro-VNAV will need to address the issue of WGS-84 ellipsoid versus MSL height. This can be done through conversion or storing threshold data as both WGS-84 ellipsoid and MSL height to use for GPS/SBAS or baro-VNAV as appropriate.

5-4. GPS/GBAS (TSO-C161a/C162a receivers).

The GPS/GBAS equipment supports Category I precision approach and, optionally, a GPS/GBAS differentially corrected positioning service (DCPS). When the GPS/GBAS avionics supports both levels of service, whether or not the DCPS is available is determined by the GPS/GBAS ground station. All GPS/GBAS ground stations provide precision approach service, but not all ground stations are expected to provide DCPS.

5-4.1 Antennas.

a. TSO-C190 that references RTCA/DO-301, defines an acceptable GPS/GBAS antenna.

b. TSO-C162a GPS/GBAS equipment also requires a VHF antenna to receive the GPS/GBAS ground facility information broadcast. Installed antennas approved for ILS localizer/VOR can be used to receive the VDB signals. Unlike ILS ground antenna arrays, a GBAS VHF data broadcast transmitter may be located anywhere on the airport or in its vicinity. This means the VHF broadcast must be received from any direction. The ILS localizer/VOR antennas may, or may not, be included under TSO-C162a. See paragraphs 13-1.1.b, 15-8, and 21-2.3 for installation considerations.

> **Note:** RTCA/DO-253C gives GPS/GBAS equipment manufacturers an option for an antenna/receiver

combination or a receiver only. Both can be certified by TSO-C162a.

5-4.2 VHF Data Broadcast Receiving Equipment (TSO-C162a).

The equipment should comply with the RTCA/DO-253C, section 2 requirements as modified by TSO-C162a. The equipment receives the GPS/GBAS VDB and outputs the VDB messages to the sensor/navigation computer (see section 5-4.3). TSO-C162a equipment must be used with TSO-C161a, or equivalent, equipment to provide Category I precision approach guidance or PVT based on GPS/GBAS.

5-4.3 Sensor/Navigation Computer (TSO-C161a).

a. Category I Precision Approach.

(1) The equipment should comply with the RTCA/DO-253C, section 2 requirements as modified by TSO-C161a. The equipment outputs lateral and vertical deviations relative to an approach path defined in the VHF data broadcast. The entire precision approach must be contained within the region defined by the broadcast parameter Dmax. Outside of Dmax, the avionics may not use the differential corrections and the GPS/GBAS equipment will not provide deviations.

(2) GPS/GBAS approaches will not have LNAV/VNAV or LNAV minimums published with the GBAS landing system (GLS) procedure. There is no fail-down option if guidance is lost during a GPS/GBAS final approach.

b. Position Output.

(1) When the GPS/GBAS ground station does not support positioning service, the GPS/GBAS airborne receiver PVT solution must comply with either TSO-C196(AR) or TSO-C145/C146(AR) receiver outputs.

(2) When the GPS/GBAS ground station supports positioning service and the distance (slant range) between the aircraft and the GPS/GBAS reference point is less than or equal to the maximum GPS/GBAS usable distance, Dmax, the GPS/GBAS airborne receiver PVT solution should comply with either TSO-C161a, TSO-C196(AR) or TSO-C145/C146(AR) receiver outputs (i.e., GPS/GBAS-provided PVT possible).

(3) When the GPS/GBAS ground station supports positioning service and the distance (slant range) between the aircraft and the GPS/GBAS reference point is greater than the maximum GPS/GBAS usable distance, Dmax, the GPS/GBAS airborne receiver PVT solution should comply with either TSO-C196(AR) or TSO-C145/C146(AR) receiver outputs (i.e., no GPS/GBAS-provided PVT).

> **Note 1:** The GPS/GBAS positioning service coverage region is defined by Dmax for GPS/GBAS ground stations supporting differential positioning service.

Note 2: These paragraphs are consistent with TSO-C161a. Applicants may use TSO-C129(AR) GPS receivers if the outputs are shown to be equivalent to TSO-C196(AR).

5-5. GNSS Upgrades.

GNSS equipment installations have become very complex due to compatibility issues with the wide range of other installed equipment such as displays, flight guidance systems (FGS), terrain warning systems, etc. GNSS TSOs typically do not include requirements or standards related to installation compatibility or standardized outputs as part of the design and production approval. Therefore, it is recommended that, concurrent with their design and production approvals, equipment manufacturers also pursue an airworthiness approval that includes detailed installation instructions and equipment compatibility lists. See chapter 3 for more information regarding design, production and airworthiness approvals and paragraph 15-2.a for guidance on navigation displays during retrofit installations.

Note: GPS and GPS/SBAS equipment airworthiness approval is not considered novel or unusual per 14 CFR 21.16 and applicants can use designees during the STC process.

5-5.1 Adding Additional GNSS Equipment.

Compatibility must be established between the existing GNSS equipment and whatever new GNSS equipment is added. As an example, some installation applicants may retain existing TSO-C129(AR) equipment and add GPS/SBAS equipment. In this instance, the original TSO-C129(AR) installation should not be re-evaluated, except for modifications made as part of the GPS/SBAS installation. The re-evaluation should be to the affected functions or performance. For example, if the equipment shares a GNSS antenna there will be additional signal loss for the original equipment and compliance to the original TSO-C129(AR) installation instructions should be verified.

5-5.2 Replacing GNSS Equipment.

a. The TSO-C196(AR) sensor is intended as a direct replacement for a TSO-C129(AR) Class B or C sensor provided the installation applicant or TSOA/LODA holder ensures compatibility with the display and navigation computer. The complete sensor/navigation computer/display system will continue to have the limitations noted in paragraphs 5-2.2.a and 15-6.

b. It is also possible to use either a TSO-C145(AR) sensor or a combined TSO-C145(AR)/C146(AR) Class Delta-4 sensor to replace a TSO-C129(AR) Class B or Class C sensor provided the installation applicant or TSOA/LODA holder ensures compatibility with the display and navigation computer. In such a sensor replacement, the aircraft operator can derive additional benefits and navigation capability such as removing the limitations noted in paragraphs 5-2.2 and 15-6. However, the benefits do not automatically extend to enabling GPS/SBAS-provided LNAV/VNAV or LP/LPV capability. See paragraph 3-2 for compliance to TSO-C146d and the appropriate sections of RTCA/DO-229D, Change 1 as a complete system in the aircraft.

c. Using a TSO-C145(AR) or TSO-C196(AR) sensor as a direct replacement for a TSO-C129(AR) sensor may be advantageous to remove performance or operational limitations other than those associated with redundant navigation sources onboard the aircraft even though the complete system retains its original TSO-C129(AR) certification basis. For example, the sensor processing improvements obviate the need to perform a RAIM prediction check 2 NM (nautical miles) prior to the final approach fix (FAF) as required by the original TSO-C129(AR) TSOA.

> **Note:** RTCA/DO-229D, Change 1 and RTCA/DO-316 both have a fault detection prediction requirement that applicants can use to perform the prediction check if needed for integration compatibility. But, the equipment requirement is there primarily to support an operational requirement for pre-departure fault detection checks for TSO-C196(AR) equipment or when flying outside of the GPS/SBAS service provider's coverage area for TSO-C145(AR) equipment.

5-5.3 GPS/SBAS Upgrade.

It is possible to upgrade TSO-C196(AR) equipment to TSO-C145d compliance. Receiver manufacturers who provide an upgrade path are encouraged to use an STC-AML to streamline the installation approvals (see paragraph 2-3).

> **Note:** It may be difficult to upgrade TSO-C129(AR) or TSO-C145a/C146a equipment to TSO-C145d/C146d compliance. Proposed upgrades for this equipment to TSO-C145d/C146d will have to be carefully evaluated.

5-5.4 GNSS Antenna Re-Use/Replacement.

a. There are no re-use or replacement possibilities for antennas certified under TSO-C129/C129a as part of the receiver TSOA/LODA. For receiver/antenna combinations certified by this method to use a different antenna design or specification is a major design change that invalidates the original TSOA/LODA.

b. For a TSO-C129/C129a receiver, it is possible to replace the original antenna if the antenna was certified to a separate antenna TSO. In this case, a TSO-C190 antenna, or antennas approved under TSO-C144(AR), can be used as replacements for any class of TSO-C129/C129a receiver.

c. For TSO-C196(AR) receivers it is possible to re-use or replace both "active" and "passive" antennas approved under TSO-C144(AR). TSO-C190 "active" antennas can be used as well.

d. For TSO-C145/C146(AR) operational Class 1 receivers and all classes of TSO-C145a/C146a receivers (see note below), it is possible to re-use both "passive" and "active" antennas approved under TSO-C144(AR). TSO-C145/C146(AR) operational Class 1 receivers are limited to enroute through LNAV approaches.

(1) The standards for equipment previously certified to TSO-C145a/C146a do permit using either TSO-C144 "passive" or "active" antennas for all receiver operational classes. However, receiver manufacturers are encouraged to use a TSO-C190 antenna when replacing the original antenna.

(2) If the receiver manufacturer chooses to not use a TSO-C190 antenna, they should use a TSO-C144 "active" antenna that complies with the intra-system noise environment, test procedures/methodologies, and 25 nanosecond differential group delay requirements found in RTCA/DO-301. Failure to do so may cause performance degradation due to GEO bias and an increasing broadband interference noise environment.

e. For TSO-C145/C146 revision 'b' or later operational Class 2, 3, or 4 receivers, "passive" TSO-C144(AR) antennas cannot be re-used. TSO-C190 describes the standard "active" antenna for TSO-C145/C146 revision 'b' or later operational Class 2, 3, or 4 receivers. It may be possible to re-use an "active" TSO-C144 antenna for these receivers as a manufacturer-specified antenna per RTCA/DO-229D, paragraph 2.1.1.10.

f. In all cases, a TSO approval does not guarantee antenna/receiver installation compatibility. Installation compatibility must be established by the antenna or receiver manufacturer and documented in the approved installation instructions. Also, there can be 14 CFR 21.611 issues related to major versus minor alterations. Each project must be evaluated according to 14 CFR 21.611 to address the alteration regulatory issues.

Antenna Type / Receiver Type						
TSO-C144(AR) Passive		X	X	X	X	
TSO-C144 Active		X	X	X	X	See Note
TSO-C190		X	X	X	X	X
TSO-C129 TSOA Antenna/Receiver Combination	X					

Table 2. Acceptable Standard Antennas

> **Note:** An active TSO-C144 antenna may be acceptable for TSO-C145/C146 revision 'b' or later Operational Class 2, 3, and 4 equipment as a receiver, manufacturer-specified antenna per RTCA/DO-229D, paragraph 2.1.1.10.

5-5.5 Marking.

The marking must be modified to reflect the new configuration and approval when equipment is upgraded to a new TSO (such as from TSO-C196(AR) to TSO-C145d Operational Class 1). This marking change can be accomplished by a certificated person in accordance with the TSOA/LODA holder's instructions. A certificated person in this context is defined as one who is authorized under 14 CFR 43.3, persons authorized to perform maintenance, rebuilding, and alterations.

5-6. Navigation Database.

a. For all combined sensor/navigator GNSS equipment, the navigation database is an essential component for the equipment to perform its intended function (see paragraphs 7-1.c and 19-8). Detailed guidance pertaining to the navigation database can be found in AC 20-153 (latest revision).

b. For GNSS equipment to perform its intended function the database configuration, as specified by the equipment manufacturer's data quality requirements, must be consistent with the equipment capability. Procedures the GNSS equipment does not support should not be accessible to the flight crew (see paragraphs 12-7, 12-8 and 15-5).

5-6.1 Database Installation Instructions.

The TSOA/LODA installation instructions/manual must contain a limitation identifying the requirements for the navigation database. This limitation will also be included in the AFM(S)/RFM(S).

5-6.2 Database Process.

a. The GNSS equipment manufacturer is usually the last link in the aeronautical data processing chain, since the format for the data loaded in the final database is typically proprietary. The applicant for a TSOA/LODA must identify an aeronautical data process accessible to the equipment users. The approval of the process is included as part of the TSOA/LODA for GNSS equipment.

b. AC 20-153 (latest revision) defines an acceptable means of qualifying aeronautical database processes. The applicant is encouraged to submit the Compliance Plan early in the development process. Early submittal will allow timely resolution of issues such as tool qualification and database process assurance levels.

c. The data process assurance level needed to support the intended function of the equipment should be defined in the data quality requirements. Data process assurance levels including tool qualification should be verified during the Letter of Acceptance (LOA) review.

5-7. GNSS Geometric Altitude.

GNSS-provided geometric altitude is not adequate for compliance with air traffic control altitude requirements in the national airspace system (NAS) or internationally. The primary barometric altimeter must be used for compliance with all air traffic control altitude regulations, requirements, instructions, and clearances. GNSS geometric altitude may be used to increase situation awareness, but must be clearly distinguished from a barometric source. The label GSL may be used to indicate GNSS sea level.

5-8. Terrain Awareness and Warning System (TAWS).

GNSS equipment is used to provide positioning inputs to TAWS/helicopter terrain awareness and warning system (HTAWS) equipment. Each type of GNSS equipment described in chapter 5 is acceptable as an input to TAWS/HTAWS equipment.

Chapter 6. Equipment Performance - RNAV Multi-Sensor Equipment.

6-1. Introduction.

This chapter provides guidance related to the basic functions and performance of a multi-sensor unit. This chapter identifies issues associated with equipment performance that applies to all types of equipment. Each individual sensor must meet the navigation performance and operation criteria contained in the respective TSO and AC applicable to that type sensor.

6-2. Navigation Database.

a. For area navigation equipment, the navigation database is an essential component for the equipment to perform its intended function (see paragraphs 7-1.c and 19-8). Guidelines pertaining to the navigation database can be found in AC 20-153 (latest revision).

b. For RNAV multi-sensor equipment to perform its intended function the database configuration, as specified by the equipment manufacturer's data quality requirements, must be consistent with the equipment capability. Procedures the RNAV multi-sensor equipment does not support should not be accessible to the flight crew (see paragraphs 12-7, 12-8 and 16-5).

6-2.1 Database Installation Instructions.

The TSOA/LODA installation instructions/manual must contain a limitation identifying the requirements for the navigation database. This limitation will also be included in the AFMS/RFMS.

6-2.2 Database Process.

a. The RNAV multi-sensor equipment manufacturer is usually the last link in the aeronautical data processing chain, since the format for the data loaded in the final database is typically proprietary. The applicant for a TSOA/LODA must identify an aeronautical data process accessible to the equipment users. The approval of the process is included as part of the TSOA/LODA for RNAV multi-sensor equipment.

b. AC 20-153 (latest revision) defines an acceptable means of qualifying aeronautical database processes. The applicant is encouraged to submit the compliance plan early in the development process. Early submittal will allow timely resolution of issues such as tool qualification and database process assurance levels.

c. The data process assurance level needed to support the intended function of the equipment should be defined in the data quality requirements. Data process assurance levels including tool qualification should be verified during the LOA review.

6-3. GNSS.

a. When GNSS is integrated in an RNAV multi-sensor system, the GNSS position sensor should comply with the acceptable methods as defined by this AC in paragraph 5-2.2 for

GPS not augmented by ground- or space-based systems, paragraph 5-3.2 for GPS/SBAS, and paragraph 5-4 for GPS/GBAS. The GNSS position sensor should be installed in accordance with guidelines provided in chapters 12 through 16 and 19 through 22.

> **Note:** See paragraphs 15-7.8 and 15-9.13 for GNSS installation considerations regarding glidepath low deviation alerting functions.

b. See paragraph 3-4 for TSO-C115(AR) compliance guidance on RNAV multi-sensor equipment integrating GPS/SBAS capability. RTCA/DO-229D, section 2, addresses the use of GPS/SBAS vertical position (referenced to WGS-84 ellipsoid) as used on the final approach segment of an LNAV/VNAV or LPV approach procedure or as advisory guidance on an LNAV approach procedure. It is acceptable to provide advisory vertical guidance for LP approaches using the method described in RTCA/DO-229D for LNAV (see paragraph 4-2.d).

c. See paragraph 3-3 for TSO compliance guidance on RNAV multi-sensor equipment integrating GPS/GBAS capability.

d. Many RNAV multi-sensor systems have implemented baro-VNAV for use in all phases of flight, and baro-VNAV can be used for vertical guidance on an LNAV/VNAV approach procedure.

(1) The RNAV multi-sensor system manufacturer should address the GPS/SBAS and/or GPS/GBAS integration issues associated with equipment designs that also include baro-VNAV capability. In particular, the RNAV multi-sensor equipment must provide a smooth guidance transition between baro-VNAV and GPS/SBAS and/or GPS/GBAS vertical guidance and a clear mode annunciation to the pilot.

(2) Paragraph 18-5 of this AC provides additional guidance for baro-VNAV, GPS/SBAS, and GPS/GBAS integrations.

6-4. DME/DME.

The FAA is responsible for evaluating DME/DME coverage and availability against a minimum standard DME/DME RNAV system for each route and procedure. This paragraph defines the minimum performance and functions (baseline) for DME/DME RNAV systems intended to support RNAV 1 and RNAV 2 routes, as well as RNAV 1 departure procedures (DPs) and standard terminal arrival routes (STARs).

a. The DME/DME RNAV system must:

(1) Provide position update within 30 seconds of tuning DME navigation facilities.

(2) Auto-tune multiple DME facilities.

(3) Provide continuous DME/DME position updating.

Note: Given a third DME facility or a second pair has been available for at least the previous 30 seconds, there must be no interruption in DME/DME positioning when the RNAV system switches between DME stations/pairs.

b. The FAA cannot ensure all DME signals within reception distance of U.S. airspace meet ICAO standards. These could include non-U.S. DME facilities, or Department of Defense (DOD) maintained DME facilities excluded from the NAS database. DME/DME RNAV procedure design will only use DME facilities listed in the airport/facility directory (A/FD). Although a procedure design issue, applicants may mitigate this restriction by:

(1) Having the DME/DME RNAV system only use DME facilities listed in the A/FD.

(2) Requiring exclusion of non-NAS DME facilities from the aircraft's navigation database when the RNAV routes or procedures are within reception range of these non-NAS DME facilities.

(3) Demonstrating to the FAA that their RNAV system performs reasonableness checks to detect errors from the non-NAS DME facilities and excludes these facilities from the navigation position solution when appropriate (e.g., using the ARINC 424 coding to preclude tuning co-channel DME facilities when the signals-in-space overlap). See paragraph 6-4.1 for guidance on reasonableness check testing.

c. When needed to generate a DME/DME position, the DME/DME RNAV system (also referred to as a FMS) must use, as a minimum, DMEs with a relative angle between 30° and 150°. The FMS may use DME pairs outside these angles (for example, 20° to 160°).

d. The RNAV system may use any receivable DME facility (listed in the A/FD) regardless of its location. When needed to generate a DME/DME position, as a minimum, the RNAV system must use an available and valid low altitude and/or high altitude DME anywhere within the following region around the DME facility:

(1) Greater than or equal to 3 NM from the facility;

(2) Less than 40 degrees above the horizon when viewed from the DME facility; and

(3) For facilities with an ARINC 424 figure of merit (FOM), the RNAV system may use the FOM value from Table 3 as the acceptable, usable region.

If the ARINC 424 FOM is:	**The aircraft's DME/DME RNAV system must be**:	
	Less than or equal to:	**And less than:**
0	40 NM from the facility	12,000 ft above facility elevation
1	70 NM from the facility	18,000 ft above facility elevation
2	130 NM from the facility	--
3	160 NM from the facility	--

Table 3. DME Usable Range

Note 1: RNAV systems may use additional DME facilities (for example, a localizer (LOC)/DME facility may be used but is not required to be used for positioning). RNAV systems are not required to use the FOM value.

Note 2: RNAV routes and procedures may include new FOMs with expanded service volumes.

Note 3: DME facility reasonableness checks are an acceptable means to protect the robustness of DME selection outside the published service volume and FOM limitations, while ensuring no misleading information occurs when using DME/DME positioning.

(4) A valid DME facility:

(a) Broadcasts an accurate facility identifier signal;

(b) Satisfies the minimum field strength requirements; and

(c) Is protected from other interfering DME signals according to the co-channel and adjacent channel requirements.

e. There is no requirement to use VOR, LOC, NDB, IRU or attitude heading reference system (AHRS) during normal operation of the DME/DME RNAV system.

f. When the RNAV system is using a minimum of two DME facilities that satisfy the criteria in paragraph 6-4, and any other valid DME facilities not meeting that criteria, the 95% position estimation error must be better than or equal to 1.75 NM. An FTE contribution not exceeding 1.0 NM (95%) may be assumed for RNAV 2 operations.

Note 1: This performance requirement is met for any navigation system that uses two DME stations simultaneously, limits the DME inclusion angle to between 30° and 150° and uses DME sensors that meet the accuracy requirements of TSO-C66c. If the RNAV system uses DME facilities outside the range identified above, the DME signal-in-space error can be assumed to be 0.1 NM 95%.

Note 2: When using a minimum of two DME facilities satisfying the criteria above, the 95% position estimation error must be better than or equal to the following equation:

$$2\sigma_{DME/DME} \leq 2\frac{\sqrt{\left(\sigma_{1,air}{}^2 + \sigma_{1,sis}{}^2\right) + \left(\sigma_{2,air}{}^2 + \sigma_{2,sis}{}^2\right)}}{\sin\alpha}$$

Single facility reference, where:

σ_{sis} = 0.05 NM

σ_{air} = max[0.085 NM, (0.125% of distance)]

$\alpha =$ inclusion angle (30^{o} to 150^{o})

g. The RNAV system must ensure co-channel DME facilities do not cause erroneous guidance. This could be accomplished by including VOR reasonableness checking when initially tuning a DME facility, or excluding a DME facility when there is a co-channel DME within line-of-sight. See paragraph 6-4.1 for guidance on testing reasonableness checks.

Note: The DME assessment cannot use a DME facility when there is a co-channel DME facility within line-of-sight.

h. The RNAV system must use operational DME facilities. DME facilities listed by NOTAM as unavailable (for example, under test or other maintenance) could still reply to an airborne interrogation. Therefore, non-operational facilities must not be used. An RNAV system may exclude non-operational facilities by checking the identification or inhibiting the use of facilities identified as not operational.

i. Operational mitigations defined to qualify equipment with this AC will not require pilot action during critical phases of flight, pilot monitoring of the RNAV system's navigation updating source(s), or time intensive programming/blackballing of multiple DME stations prior to executing a procedure.

(1) Blackballing single facilities listed by NOTAM as out-of-service and/or programming route/procedure-defined "critical" DME is acceptable when this mitigation requires no pilot action during a critical phase of flight. A programming requirement also does not imply the pilot should complete manual entry of DME facilities not in the navigation database. Instead, this allows RNAV systems to tune a critical DME, as appropriate to a specific route or procedure.

(2) The critical phase of flight is normally from the final approach fix on an approach procedure through missed approach, or from field elevation to 2,500 ft above airport elevation on a departure.

6-4.1 Reasonableness Checks.

a. Many FMSs perform a reasonableness check to verify valid DME measurements. Reasonableness checks are very effective against database errors or erroneous system acquisition (such as co-channel facilities), and typically fall into two classes:

(1) Those the FMS uses after it acquires a new DME. The FMS compares the aircraft's position before using the DME to the aircraft's range to the DME; and

(2) Those the FMS continuously uses, based on redundant information (for example, extra DME signals or IRU data).

b. The reasonableness checks are intended to prevent navigation aids from being used for navigation update in areas where the data can lead to radio position fixing errors due to co-channel interference, multipath, and direct signal screening. In lieu of using radio navigation aid published service volume, the navigation system should provide checks, which preclude use of duplicate frequency navigation aids (NAVAIDs) within range, over-the-horizon NAVAIDs, and use of NAVAIDs with poor geometry.

c. Under certain conditions, reasonableness checks can be invalid.

(1) Do not assume a DME signal remains valid just because it was valid when acquired.

(2) Do not assume extra DME signals are available. The intent of this baseline is to support operations where the infrastructure is minimal (for example, when only two DMEs are available for parts of the procedure).

d. When an FMS manufacturer uses a reasonableness check to satisfy any criteria in this AC, they must test the effectiveness of the check under stressing conditions. An example of this condition is a DME signal that is valid at acquisition and "ramps off" during the test (similar to what a facility under test might do), when there is only one other supporting DME or two signals of equal strength. A "ramp off" rate would be significantly higher or slower than the normal range of groundspeed.

6-4.2 Performance Confirmation.

a. New systems may demonstrate compliance with these criteria as part of the airworthiness approval. For existing systems, the applicant should determine compliance with the equipment and aircraft criteria in this chapter.

b. Aircraft manufacturers (TC holders) incorporating FMS and DME/DME positioning should review the available data for the integrated navigation system, and obtain additional data as appropriate, to determine compliance with the criteria in this AC.

c. Equipment manufacturers (typically DME and FMS TSOA/LODA holders) need to consider DME accuracy. DME sensors have been demonstrated to a variety of performance requirements per TSO-C66. TSO-C66 performance standards have evolved as follows:

(1) TSO-C66: (Aug 1960) RTCA/DO-99.

(2) TSO-C66a: (Sep 1965) RTCA/DO-151, accuracy requirement as total error with 0.1 NM attributed to ground facility, airborne equipment accuracy of 0.5 NM or 3% of distance, whichever is greater, with a maximum of 3 NM.

(3) TSO-C66b: (Nov 1978) RTCA/DO-151a, accuracy requirement as total error with 0.1 NM attributed to ground facility, airborne equipment accuracy of 0.5 NM or 1% of distance, whichever is greater, with a maximum of 3 NM.

(4) TSO-C66c: (Sept 1985) RTCA/DO-189, accuracy requirement as total error for the airborne equipment of 0.17 NM or 0.25% of distance, whichever is greater.

d. The accuracy required by TSO-C66c is adequate to support the criteria in this AC. DME equipment approved under revision ‘c’ does not require further evaluation for RNAV 1 and RNAV 2 operations. Applicants with equipment built to earlier TSO revisions may use the following process to establish more accurate performance than originally credited to support RNAV 1 and RNAV 2 operations.

(1) Rather than relying on original demonstrated performance, the applicant may elect to review the original TSO or TC/STC test data to determine the demonstrated accuracy and/or make any appropriate changes to qualification tests to determine achieved accuracy.

> **Note:** When conducting accuracy analysis, the DME signal-in-space error can be assumed to be 0.1 NM 95% (both inside and outside the published service volume). If demonstrating accuracy under bench or flight test conditions, the actual accuracy of the bench equipment or ground facility should be considered.

(2) New testing should be performed under the same conditions used to demonstrate compliance with the original TSO-C66 standard.

(3) Applicants who have demonstrated more accurate DME performance should state the demonstrated accuracy in a letter to their customers.

6-4.3 Multi-Sensor System FMS.

a. The FMS or aircraft manufacturer should review the available data for the integrated navigation system, and obtain additional data as appropriate, to determine compliance with the criteria in paragraph 6-4. Applicants who have determined compliance should state such in the operating instructions or AFMS/RFMS, along with any limitations (for example, if the pilot is expected to manually inhibit the use of facilities that are listed by NOTAM as unavailable). The applicant's certification may limit the compliance to specific DME systems, or may reference any DME qualified to the accuracy requirements of TSO-C66c.

b. FMS accuracy is dependent on a number of factors including: latency effects, the selection of DME facilities, the method of combining information from multiple DMEs, and the effects of other sensors used to determine a position. For FMSs using two (or more) DMEs at the same time and limiting the DME include angle to between 30° and 150°, the accuracy requirement can be met if the DME sensors meet the accuracy requirements of TSO-C66c. For FMSs without these characteristics, the accuracy should be evaluated under poor DME geometry scenarios and should consider the demonstrated DME sensor accuracy. Poor geometry scenarios may include angles at the limits specified earlier, with or without additional DME facilities available outside those conditions.

c. Identify those conditions that would result in failure to meet the accuracy requirement and the means to preclude those identified conditions.

6-5. VOR/DME.

a. Multi-sensor equipment may incorporate VOR/DME updating and must meet the performance for the route to be flown. However, terminal and enroute RNAV implementation in the U.S. does not require using VOR, so any use of VOR must include reasonableness checking and demonstrate that positional accuracy from an erroneous VOR signal-in-space will not exceed 1.75 nm for RNAV 2 and 0.87 nm for RNAV 1 (reference AC 90-100A, appendix 1, paragraph 2.h). This could be accomplished by not using VOR signals when DME/DME will be available or weighting and/or monitoring the VOR signal with DME/DME to ensure it does not mislead position results (for example, through reasonableness checks). See paragraph 6-4.1 for guidance on testing reasonableness checks.

b. For times when the multi-sensor equipment is using data from only a single collocated VOR/DME (such as during an RNAV (VOR/DME) approach), the total maximum position fixing error of the airborne multi-sensor equipment must be equal to or less than that shown in Table 4. To find the cross track (xtk) and along track (atk) error at this point, enter the Table with the tangent distance in nautical miles and distance along track in nautical miles from the tangent point.

Tangent Distance NM		Along-Track Distance (NM)																	
		0	5	10	15	20	25	30	35	40	50	60	70	80	90	100	110	120	130
0	xtk		0.6	0.8	1.1	1.4	1.7	2.0	2.3	2.6	3.2	3.9	4.5	5.2	5.8	6.4	7.1	7.7	8.4
	atk		0.6	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1.0	1.0	1.1	1.2	1.3	1.4	1.5	1.6
5	xtk	0.6	0.6	0.8	1.1	1.4	1.7	2.0	2.3	2.6	3.3	3.9	4.5	5.2	5.8	6.4	7.1	7.7	8.4
	atk	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7
10	xtk	0.6	0.7	0.9	1.1	1.4	1.7	2.0	2.3	2.6	3.3	3.9	4.5	5.2	5.8	6.5	7.1	7.7	8.4
	atk	0.8	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.7	1.8
15	xtk	0.6	0.7	0.9	1.1	1.4	1.7	2.0	2.3	2.6	3.3	3.9	4.5	5.2	5.8	6.5	7.1	7.7	8.4
	atk	1.0	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.7	1.8	1.9
20	xtk	0.6	0.7	0.9	1.2	1.4	1.7	2.0	2.3	2.7	3.3	3.9	4.6	5.2	5.8	6.5	7.1	7.7	8.4
	atk	1.3	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4	1.5	1.6	1.6	1.7	1.8	1.9	1.9	2.0	2.1
25	xtk	0.7	0.8	1.0	1.2	1.5	1.8	2.1	2.4	2.7	3.3	3.9	4.6	5.2	5.8	6.5	7.1	7.8	8.4
	atk	1.5	1.5	1.6	1.6	1.6	1.6	1.6	1.7	1.7	1.7	1.8	1.9	1.9	2.0	2.1	2.1	2.2	2.3
30	xtk	0.7	0.8	1.0	1.2	1.5	1.8	2.1	2.4	2.7	3.3	3.9	4.6	5.2	5.9	6.5	7.1	7.8	8.4
	atk	1.8	1.8	1.8	1.8	1.9	1.9	1.9	1.9	2.0	2.0	2.1	2.1	2.2	2.2	2.3	2.4	2.4	2.5
35	xtk	0.8	0.8	1.0	1.3	1.5	1.8	2.1	2.4	2.7	3.3	4.0	4.6	5.2	5.9	6.5	7.1	7.8	8.4
	atk	2.1	2.1	2.1	2.1	2.1	2.2	2.2	2.2	2.2	2.3	2.3	2.4	2.4	2.5	2.5	2.6	2.7	2.7
40	xtk	0.8	0.9	1.1	1.3	1.5	1.8	2.1	2.4	2.7	3.3	4.0	4.6	5.2	5.9	6.5	7.1	7.8	8.4
	atk	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.5	2.5	2.5	2.6	2.6	2.7	2.7	2.8	2.9	2.9	3.0
50	xtk	0.9	1.0	1.1	1.3	1.6	1.9	2.2	2.5	2.8	3.4	4.0	4.6	5.3	5.9	6.5	7.2	7.8	8.4
	atk	2.9	2.9	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.1	3.1	3.2	3.2	3.3	3.3	3.4	3.4	3.5
60	xtk	1.0	1.0	1.2	1.4	1.7	1.9	2.2	2.5	2.8	3.4	4.0	4.7	5.3	5.9	6.6	7.2	7.8	8.5
	atk	3.5	3.5	3.5	3.5	3.5	3.6	3.6	3.6	3.6	3.6	3.7	3.7	3.8	3.8	3.8	3.9	3.9	4.0
70	xtk	1.0	1.1	1.3	1.5	1.7	2.0	2.3	2.6	2.9	3.5	4.1	4.7	5.3	6.0	6.6	7.2	7.9	8.5
	atk	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.2	4.2	4.2	4.2	4.3	4.3	4.4	4.4	4.4	4.5	4.5
80	xtk	1.1	1.2	1.4	1.6	1.8	2.1	2.3	2.6	2.9	3.5	4.1	4.7	5.4	6.0	6.6	7.3	7.9	8.5
	atk	4.6	4.7	4.7	4.7	4.7	4.7.	4.7	4.7	4.7	4.8	4.8	4.8	4.9	4.9	5.0	5.0	5.0	5.1
90	xtk	1.2	1.3	1.4	1.6	1.9	2.1	2.4	2.7	3.0	3.5	4.2	4.8	5.4	6.0	6.7	7.3	7.9	8.6
	atk	5.2	5.2	5.2	5.2	5.2	5.3	5.3	5.3	5.3	5.3	5.4	5.4	5.4	5.5	5.5	5.5	5.6	5.6
100	xtk	1.3	1.4	1.5	1.7	1.9	2.2	2.4	2.7	3.0	3.6	4.2	4.8	5.4	6.1	6.7	7.3	7.9	8.6
	atk	5.8	5.8	5.8	5.8	5.8	5.8	5.9	5.9	5.9	5.9	5.9	6.0	6.0	6.0	6.1	6.1	6.1	6.2
110	xtk	1.4	1.5	1.6	1.8	2.0	2.3	2.5	2.8	3.1	3.6	4.2	4.9	5.5	6.1	6.7	7.3	8.0	8.6
	atk	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.5	6.5	6.5	6.5	6.6	6.6	6.6	6.7	6.7	6.7
120	xtk	1.5	1.6	1.7	1.9	2.1	2.3	2.6	2.8	3.1	3.7	4.3	4.9	5.5	6.1	6.8	7.4	8.0	8.6
	atk	6.9	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.1	7.1	7.1	7.1	7.2	7.2	7.2	7.3	7.3
130	xtk	1.6	1.7	1.8	2.0	2.2	2.4	2.6	2.9	3.2	3.7	4.3	4.9	5.6	6.2	6.8	7.4	8.0	8.7
	atk	7.5	7.5	7.5	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.7	7.7	7.7	7.7	7.8	7.8	7.8	7.9

Table 4. 2D Accuracy Requirements for Equipment Using a Single Co-located VOR/DME

Note 1: Equipment error assumes a waypoint input resolution of 0.01 minute, and output resolution of 0.01 minute for approach and 0.1 minute otherwise.

Note 2: Equipment error assumes the maximum allowable difference between the displayed cross-track deviation and the computed cross-track deviation.

Note 3: Multi-sensor equipment accuracy shown in the Table 4 does not necessarily satisfy accuracy requirements for operation in certain airspace. For example, navigation on published J and V routes requires a distance along-track from the tangent point to VOR/DME to be less than approximately 50 NM to meet airway width criteria.

Note 4: Table 4 is a result of the root-sum-square combination of the error elements shown below in Table 5. Table 4 is computed assuming the waypoint is always at the tangent point and the aircraft is at the along-track distance measured from the same tangent point. This is important in the test procedures because the resulting cross-track error from the course setting is a function of the distance to waypoint.

GROUND EQUIPMENT ERROR	AIRBORNE EQUIPMENT ERROR
VOR 1.4 degrees	VOR 3.0 degrees
DME 0.1 nm	DME 0.2 nm + 1%
	Course Setting Error 1.6 degrees
	Computation Error 0.5 nm

Table 5. Error Elements

6-6. INS/IRU.

a. An INS/IRU installation is an acceptable lateral positioning source during a significant portion of the flight provided it meets the requirements described in 14 CFR part 121, appendix G while in inertial mode.

b. Attitude heading reference systems, including an AHRS with inputs from air data computers, do not qualify as instrument navigation devices similar to an INS/IRU. An AHRS is not acceptable as an INS/IRU substitute or replacement for operational use under instrument flight rules on any RNAV or RNP instrument route or procedure. The foundation for the airworthiness approval of a gyro as an AHRS is not equivalent to the foundation for the airworthiness approval of a similar gyro approved as an INS/IRU.

Note 1: Paragraph 6-6 applies to both "stand-alone" and loosely coupled inertial integrations.

Note 2: RTCA Special Committee-159 working group 2C is developing a MOPS for GNSS-aided inertial systems including GNSS-aided inertial systems not meeting 14CFR part 121, appendix G. Paragraphs 6-6 and 6-7 in this AC will be updated when the new MOPS and TSO are published.

6-7. INS/IRU – GNSS Integration.

a. The guidance in paragraph 6-7 is applicable for tightly-coupled integrations, and is in addition to the guidance in paragraph 6-6.

b. For GNSS sensors, both RTCA/DO-229D, Change 1 and RTCA/DO-316, appendix R, provides INS/IRU – GNSS integration requirements (appendix R is the same in both documents). The GNSS/inertial hybrid outputs of the INS/IRU must meet the equipment requirements of appendix R. However, appendix R is not invoked by any TSO. It is acceptable for tightly coupled INS/IRU – GNSS hybrid sensors meeting appendix R to be integrated with FMS or multi-mode receivers for operational use under instrument flight rules on RNAV or RNP instrument routes or procedures.

c. The FAA assumes that GPS/inertial position data is limited to enroute through LNAV approach horizontal positioning. Using this position data for operations requiring higher precision would require other integrity and accuracy enhancements such as GPS/SBAS, GPS/GBAS, or other integrity/accuracy monitor function. Since hybrid vertical position and integrity has not been addressed by appendix R, any use should be identified and resolved as part of the appendix R approval process.

(1) No exclusion is intended for previously certified equipment meeting the requirements of RTCA/DO-229C, appendix R. It is acceptable to use previously certified GNSS sensors integrated with INS/IRU systems meeting the requirements specified in RTCA/DO-229C, appendix R. However, RTCA/DO-229C, appendix R assumed selective availability was 'on', so it may not adequately describe system performance if the applicant wishes to take credit for selective availability being 'off.'

(2) Aircraft with GPS/inertial installations approved for LNAV approaches can also include a baro-VNAV installation to provide the vertical guidance deviations acceptable for LNAV/VNAV approaches. Chapters 11, 18, and 23 describe baro-VNAV performance and installation considerations.

d. Tightly coupled INS/IRU systems integrated with GNSS sensors outputting PVT that is the same as GNSS may be demonstrated to be equivalent to either TSO-C145d, or TSO-C196b and receive a GNSS TSOA/LODA. Any discrepancies should be identified and resolved as part of the TSO approval, but appendix R will take precedence. It may be necessary to conduct further evaluation during any follow-on approval since the characteristics and performance required for the inertial integration are closely linked to aircraft architecture, integration method, and GNSS failure modes.

(1) TSO-C129a has been cancelled so no new approvals to that standard are possible.

(2) Tightly coupled INS/IRU systems with an existing TSO-C129(AR) TSOA/LODA may still be produced and integrated with GNSS sensors that have an existing TSO-C129(AR) TSOA/LODA.

(3) Applicants requesting a TSO-C196b or TSO-C145d TSOA/LODA for their tightly coupled INS/IRU systems will need to include part number differentiation and installation instructions limiting integration to GNSS sensors approved to the same TSO.

e. When demonstrating RAIM or RAIM equivalency, the GPS signal-in-space failure modes to be used for the demonstration should be proposed and agreed upon as part of the TSO approval. For example, the applicant should address the correlated effects of multiple erroneous pseudoranges due to ionospheric activity. After exclusion of a faulty satellite, show that the position solution is valid and the inertial states/models are not corrupted by the faulty GPS data prior to its detection and exclusion.

f. All attitude and heading data output by the integrated system must comply with the relevant regulations under all foreseeable operating conditions. This includes during GPS signal-in-space failures (including prior to detection and after exclusion).

g. In the absence of any GPS input, the attitude and heading data output by the integrated system must comply with the relevant regulations, including those conditions addressed in the aircraft functional hazard assessment (FHA).

> **Note:** It may be necessary to revise the FHA to address failure conditions unique to the GPS/inertial system.

h. If the system sustains integrity coasting capability, the INS/IRU equipment manufacturer must document the coasting performance and limitations. That is, document the coasting time while sustaining performance at the desired navigation performance level, horizontal alert limit (HAL) or RNP. This documentation must be consistent with the alerting algorithms for the aircraft (e.g., RNP). The coasting performance should consider factors that could influence coasting times (e.g., inertial sensor accuracy, gyro misalignment, inertial parameter calibration accuracy prior to loss of GPS signals, aircraft maneuvers prior to and during the coasting period, and aircraft speed).

6-8. INS/IRU - DME/DME Integration.

a. Paragraph 6-8 defines a minimum DME/DME/IRU (D/D/I) RNAV system baseline performance capable of supporting RNAV 1 and RNAV 2 routes, as well as RNAV 1 DPs and STARs. For routes and procedures designed using this performance standard, the FAA will decide if adequate DME coverage is available using FAA computer modeling and flight inspection assets. This assessment of DME coverage will also determine if an expanded service volume is necessary for select DME facilities.

b. The minimum DME/DME requirements of paragraph 6-4 apply and are not repeated here, except where additional performance is required. The performance confirmation process in paragraph 6-4.2 also applies to paragraph 6-8.

c. There is no requirement to use VOR, NDB, LOC, or AHRS during normal operation of the DME/DME/IRU RNAV system.

d. The 95% position estimation error must be better than or equal to the value obtained using the equation referenced in paragraph 6-4.f note 2 given any two DME facilities satisfying the criteria in paragraphs 6-4.b thru 6-4.d, and any combination of other valid DME facilities not meeting that criteria.

> **Note:** Based on an evaluation of IRU performance, the growth in position error after reverting to IRU can be expected to be less than 2 NM per 15 minutes.

e. Inertial system performance must satisfy the criteria in paragraph 6-6.

f. Additional required FMS capabilities are:

(1) Automatic position updating from the DME/DME solution.

> **Note:** Equipment manufacturers or airworthiness applicants should note in the appropriate documentation for the flight crew if any inertial coasting annunciation is suppressed following loss of radio updating.

(2) Accepting a position update immediately prior to takeoff.

(3) Excluding VORs greater than 40 NM from the aircraft.

g. The total system error (TSE) must be less than or equal to 1.0 NM (95%) throughout the route. To maximize the amount of IRU coasting allowed, the flight technical error for D/D/I aircraft on terminal procedures should be limited to 0.5 NM (95%).

> **Note:** The FAA assures that systems meeting the D/D/I RNAV minimum performance standard satisfy this requirement on all identified routes and procedures, and these RNAV systems do not require further evaluation. Systems seeking approval using different RNAV system characteristics or performance must demonstrate this performance for each published route or procedure.

Chapter 7. Equipment Performance - RNP (General).

7-1. Introduction.

a. The intent of the RNP chapters 7-10 and 17 along with appendix 2 and 3 is to provide the airworthiness guidance manufacturers need for implementing RNP capability when used in conjunction with the performance and installation chapters in this AC applicable to the equipment. The airworthiness information in this AC supersedes the airworthiness guidance in all revisions of ACs 90-101 and 90-105. **Applicants should not base their new RNP AR or RNP airworthiness applications on the 90-series ACs because that guidance is not complete for airworthiness purposes.** However, previous airworthiness approvals based on those ACs remain valid.

b. RTCA/DO-236C, Chg 1, *Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation*, dated June 19, 2013, and RTCA/DO-283B are closely linked to provide coherent RNP standards at both the aircraft level and RNP equipment level respectively.

(1) Aircraft manufacturers that use the type certificate process for all design, production and airworthiness approval of RNP capability may use RTCA/DO-236C, Chg 1 as the compliance standard at the aircraft level. While the RNP equipment is included as part of the type certificate, it should comply with RTCA/DO-283B (as modified by TSO-C115d) although requirements trade-offs are possible as long as the aircraft performance meets the requirements of RTCA/DO-236C, Chg 1.

(2) RNP equipment manufacturers building equipment for later installations (i.e., not associated with an aircraft OEM type certificate) cannot anticipate the installed RNP airworthiness capability at the aircraft level. These projects should use the standards in RTCA/DO-283B, as modified by TSO-C115d, for their RNP equipment.

> **Note:** TSO-C115d includes significant modifications to the standards in RTCA/DO-283B. Manufacturers choosing to use the standards in RTCA/DO-283B must incorporate the TSO-C115d modifications.

c. A database is an essential component necessary for RNP equipment to perform its intended function. RNP equipment operational approval for IFR use is based upon a database assurance process through a type 2 LOA. A type 2 LOA provides database objective evidence of integrity consistent with the monitoring and alerting requirement for RNP systems.

d. Chapter 8 is specific to the equipment performance considerations for RNP approach (RNP APCH) procedures; chapter 9 is specific to the equipment performance considerations for RNP enroute and terminal operations; and chapter 10 is specific to the equipment performance considerations for oceanic RNP. Chapter 17 describes installation considerations for RNP. Airworthiness guidance for RNP AR, including installation considerations, is addressed in appendix 2 of this AC while appendix 3 of this AC describes advanced RNP functions. Appendix 7 contains templates to demonstrate RF leg capability. RNP AR and RNP operational approval guidance can be found in the latest revisions of ACs

90-101 and 90-105, respectively.

> **Note:** RNP AR was previously named RNP SAAAR. The name has been changed to RNP AR for international harmonization.

e. A foundation for RNP operations in the U.S. NAS relies on the ability to perform RNP 2.0, RNP 1.0, and RNP APCH operations (excluding RNP AR operations) to the LNAV line of minima. It is important to understand that RNP is an aircraft-level capability comprising the sensor, navigation computer, database, display systems, and flight guidance integration; not just an FMS function or TSO label. In general, aircraft with properly installed GNSS systems qualify for RNP 2.0, RNP 1.0, and RNP APCH to LNAV minima, but there are some additional considerations (see chapters 8 and 9 for specific guidance).

f. Aircraft may have additional RNP capabilities such as RNP APCH to LNAV/VNAV or LPV line of minima, or advanced RNP functions.

(1) GPS/SBAS and FMS equipment manufacturers should provide a statement in the RNP capabilities document for these additional RNP capabilities provided the equipment is installed according to the installation instructions/manual. Reference paragraphs 12-7.b and A5-2 for more information regarding the RNP capabilities document. The statement of RNP capabilities should be part of the installation instructions/manual.

(2) These additional capabilities have aircraft integration dependencies that must be considered during the airworthiness approval before the RNP capability can be approved at the aircraft-level.

g. TSO-C129(AR) equipment may not support all foundational RNP operations due to the minimum requirements in those TSOs. See chapters 8 and 9 for specific guidance on aircraft with TSO-C129(AR) equipment.

h. GPS/SBAS and GPS/GBAS sensors can be approved on aircraft without baro-VNAV to provide vertical path guidance for RNP 0.3 operations and RNP AR operations as low as RNP 0.1. However, all aircraft and FMS requirements for RNP and RNP AR operations still apply. Refer to chapters 15 and 17 of this AC (appendix 2 for RNP AR) for airworthiness guidance, and the latest revisions of AC 90-101, and AC 90-105 for operational guidance.

> **Note:** TSO-C146(AR) invokes either RTCA/DO-229 revision 'C' or 'D', section 2.2 for Class Gamma GPS/SBAS equipment. The navigation computer requirements in section 2.2 invoked by TSO-C146(AR) are a specific method of complying with the RNP requirements for RNP 2.0, RNP 1.0 and RNP APCH to LNAV minima. Class 2 and Class 3 equipment provide vertical guidance for RNP approaches when operating within GPS/SBAS coverage.

i. GPS/SBAS and GPS/GBAS used for RNP and RNP AR do not require the baro-VNAV temperature mitigations; however, the aircraft must be within the service provider's coverage area to use GPS/SBAS or GPS/GBAS for RNP and RNP AR operations. The following are performance advantages for GPS/SBAS or GPS/GBAS compared to baro-VNAV for RNP and RNP AR:

(1) An accurate and repeatable vertical flight path with consistent alignment of the glide path angle (GPA) with visual landing cues and landing aids (e.g., visual approach slope indicator (VASI) or precision approach path indicator (PAPI)).

(2) No temperature restrictions on using the procedure.

(3) GPS/SBAS and GPS/GBAS can meet the RNP AR 0.1 vertical performance contours without independent system monitoring.

(4) The flight path is not affected by manual or Automated Traffic Information System (ATIS) altimeter setting errors.

7-2. Special Characteristics of RNP Instrument Approaches.

a. GNSS is the primary navigation system to support RNP approach procedures. The missed approach segment may be based upon a conventional NAVAID (e.g., VOR, DME, NDB), but DME/DME-based systems are not acceptable for RNP APCH.

b. Tightly-coupled GPS/IRU or GPS/SBAS/IRU systems can provide a coasting capability in the event GPS positioning is not available.

7-3. Special Characteristics of RNP 1.0 and RNP 2.0 Operations.

a. RNP 1.0 is used on the initial, intermediate and missed approach segments of instrument approaches along with obstacle departure procedures (ODPs), standard instrument departures (SIDs), and STARs. DME/DME/IRU and/or GNSS are the primary navigation systems supporting RNP 1.0 operations.

b. RNP 2.0 routes are intended for operations in oceanic and remote areas. GNSS is the primary navigation system to support RNP 2.0 operations.

Chapter 8. Equipment Performance - RNP Approach.

8-1. Introduction.

This chapter provides guidance on the performance and functional criteria for systems used to conduct RNP approach operations, which are designated under part 97 as RNAV (GPS) or GPS and categorized as RNP APCH in ICAO. The baro-VNAV equipment performance applicable to RNP approaches is specified in chapter 11. Baro-VNAV systems are optional capabilities that are not a minimum requirement to fly RNAV (GPS) or GPS approaches using the LNAV line of minima.

8-2. Aircraft and System Criteria.

a. Aircraft with the following avionics equipment that meet the applicable installation chapters in this AC automatically qualify for RNP APCH to LNAV minima capability without further documentation by virtue of the avionics TSO and airworthiness approval:

- TSO-C115c (or later revision) FMS with a TSO-C129(AR) Class B1 or C1, TSO-C145(AR), or TSO-C196(AR) sensor;

  Note: See paragraph 8-3.g(2) for "TO/TO" navigation computers.

- TSO-C146 Class Gamma equipment;
- TSO-C129(AR), Class A1 equipment; or,
- Aircraft with an RNP AR approval.

b. A TSO-C115b FMS using a TSO-C129(AR) Class B1/C1, TSO-C145(AR), or TSO-C196(AR) sensor with documented compliance to the RNP requirements in RTCA/DO-236 (revision 'B' or later) or RTCA/DO-283 (revision 'A' or later) as part of the approval basis also provides RNP APCH to LNAV minima capability without further evaluation.

> **Note:** See paragraph 8-3.g(2) for "TO/TO" navigation computers.

c. Avionics or aircraft manufacturers may provide a service bulletin for a pilot or equipment operating handbook entry, or other notification stating aircraft with the equipment in paragraphs 8-2.a and 8-2.b, and an appropriate airworthiness approval, has RNP APCH to LNAV line of minima capability.

> **Note 1:** Aircraft with RNP APCH to LNAV minima capability based on TSO-C129(AR) and TSO-C196(AR) GNSS have limitations requiring operators to perform pre-departure RAIM checks.

> **Note 2:** TSO-C129a has been cancelled so it is not possible to receive a new TSO-C129a TSOA. But equipment with an existing TSO-C129a TSOA may still be produced and installed.

> **Note 3:** New airworthiness approval applicants should consider including RNP APCH to LNAV minima as part of their application and document the capability in the AFM(S)/RFM(S). Doing so could benefit customers seeking operational approvals.

d. Multi-sensor systems that use DME/DME or DME/DME/IRU as the only means of RNP compliance are not authorized to conduct RNP APCH to LNAV minima. However, operators still retain the option to develop special RNP approaches using these systems.

8-3. Performance and Functional Criteria for RNP Systems.

a. Accuracy.

(1) During operations on the initial and intermediate segments and for the missed approach of a RNP APCH procedure, the lateral TSE must be within ±1 NM for at least 95 percent of the total flight time. The along-track error must also be within ±1 NM for at least 95 percent of the total flight time.

(2) During operations on the final approach segment, the lateral TSE must be within ±0.3 NM for at least 95 percent of the total flight time. The along-track error must also be within ±0.3 NM for at least 95 percent of the total flight time.

(3) Table 9 in chapter 17 indicates allowable "FTE credit" for various RNP operations when using autopilot, flight director, or manual flight control. Applicants may use these FTE values toward meeting TSE for the desired RNP operation without further demonstration or evaluation. Applicants may use different FTE values provided they demonstrate the aircraft complies with the appropriate TSE specified for the operation in paragraphs 8-3.a(2) and 8-3.a(3).

> **Note:** Applicants may use a deviation indicator with 1 NM full-scale deflection on the initial, intermediate and missed approach segments and 0.3 NM full-scale deflection on the final approach segment. It is acceptable to use smaller deviation scaling, such as 0.3 NM full-scale deflection for the initial, intermediate, and final approach segment. However, the final approach segment scaling must not be smaller than 0.3 NM (not applicable to RNP AR, LP/LPV, GLS, or when using RTCA/DO-229() angular scaling).

b. Integrity.

Malfunction of the aircraft navigation equipment that causes the TSE to exceed 2 times the RNP value without annunciation is classified as a Major failure condition under airworthiness regulations (i.e., 10^{-5} per hour).

c. Continuity.

Loss of function is classified as a minor failure condition if the operator can revert to a different navigation system and safely proceed to a suitable airport.

d. Performance Monitoring and Alerting.

During operations on the initial, intermediate, and the missed approach segments, the RNP System or the RNP system and pilot in combination must provide an alert if the accuracy requirement is not met or if the probability that the lateral TSE exceeds 2 NM is greater than 10^{-5}. During operations on the final approach segment, the RNP system must provide an alert if the accuracy requirement is not met or if the probability that the lateral TSE exceeds 0.6 NM is greater than 10^{-5}.

e. Path Definition.

Aircraft performance is evaluated around the path defined by the published RNP APCH procedure. RNP equipment should provide lateral guidance so aircraft remain within the lateral boundaries of the defined RNP APCH procedure. Aircraft performance should comply with RTCA/DO-236C, Chg 1. Additionally, when constructing the descent path for the final approach segment of an RNP instrument approach procedure, the RNP equipment must always use the procedure-defined flight path angle.

> **Note:** RNP instrument approach procedures may have a final approach fix with an 'AT' altitude constraint. The intent of the guidance in paragraph 8-3.e is to use the published flight path angle for descent path construction. This is to ensure geometric point-to-point between two 'AT' constraints is not used for the final approach segment.

f. Signal in Space.

During GNSS operations on the initial, intermediate, and missed approach segments, the aircraft navigation equipment must provide an alert if the probability of signal-in-space errors causing a lateral position error greater than 2 NM exceeds 10^{-7} per hour. During GNSS operations on the final approach segment, the aircraft navigation equipment must provide an alert if the probability of signal-in-space errors causing a lateral position error greater than 0.6 NM exceeds 10^{-7} per hour.

> **Note:** There are no RNP requirements for the missed approach if it is based on conventional means (VOR, DME, and NDB) or on dead reckoning.

g. Functional Criteria for Navigation Displays.

(1) The RNP system must have the following navigation displays and functions installed in accordance with this AC. Navigation data, including a TO/FROM indication and a failure indicator, must be displayed on a lateral deviation display (course deviation indicator (CDI), electronic horizontal situation indicator (EHSI)) and/or a navigation map display. These must be used as primary flight instruments for aircraft navigation, for maneuver anticipation, and for failure/status/integrity indication.

> **Note:** Unlike traditional, ground-based instrument procedures, some navigation computers construct RNP procedures by navigating to each procedure defined waypoint. This is referred to as "TO/TO navigation". See paragraph 8-3.g(2) for guidance on RNP systems with navigation computers using TO/TO navigation algorithms.

(2) RNP systems using TO/TO navigation algorithms do not require a navigation display with a TO/FROM indication during RNP instrument procedures. Displays supporting TO/TO navigation computers can fully comply with all RNP-related criteria in this AC without a TO/FROM indication. At a minimum, the navigation display supporting a TO/TO RNP system should display the active waypoint and active waypoint name. However, TO/TO RNP systems must accommodate route discontinuities and continue providing navigation information.

(a) If an aircraft's sensor suite intends to support traditional navigation using ground-based navigation aids (such as executing a VOR-DME instrument approach procedure), then the aircraft and avionics manufacturers must ensure the aircraft installation properly accommodates these traditional, ground-based instrument flight procedures. A TO/FROM indication is essential to qualify the aircraft for these traditional procedures because they may rely on navigation to and from a navigation aid, an ad hoc fix assigned by air traffic control, or a defined fix.

(b) Additionally, a TO/FROM indication is necessary when the RNP system uses GNSS substitution for the ground-based navigation aid(s) defining a traditional instrument procedure.

(3) A non-numeric lateral deviation display (for example, CDI, EHSI), with a TO/FROM indication and a failure annunciation, used as primary flight instruments for aircraft navigation, for maneuver anticipation, and for failure/status/integrity indication, should have the following attributes:

> **Note:** see paragraph 8-3.g(2) for TO/TO navigation computer displays.

(a) The displays must be visible to the pilot and located in the primary field of view.

(b) The lateral deviation display scaling should agree with any alerting and annunciation limits, if implemented.

(c) The lateral deviation display must have a full-scale deflection suitable for the current phase of flight and must be based on the TSE requirement. Scaling of ±1 NM for the initial, intermediate, and missed approach segments and ±0.3 NM for the final segment is acceptable. It is also acceptable for the scaling to be more conservative than the TSE; for example, ±0.3 NM for the initial, intermediate, and missed approach segments.

(d) The display scaling may be set automatically by default logic or set to a value obtained from a navigation database. The full-scale deflection value must be known or must be available for display to the pilot commensurate with approach values.

(e) The lateral deviation display must be automatically slaved to the RNP computed path. It is recommended that the course selector of the deviation display be automatically slewed to the RNP computed path.

Note: This does not apply for installations where an electronic map display contains a graphical display of the flight path and path deviation.

(f) As an alternate means, a navigation map display must provide equivalent functionality to a lateral deviation display with appropriate map scales (scaling may be set manually by the pilot). To be approved as an alternative means, the navigation map display must be shown to meet the TSE and be located in the primary field of view.

(4) It is not necessary for navigation displays, particularly primary flight displays, to include an actual navigation performance (ANP) or RNP accuracy value. The displays only need to provide an alert if the RNP criteria for the operation cannot be met.

h. System Capabilities.

The following system capabilities are required as a minimum:

(1) The capability to continuously display to the pilot flying, on the primary flight instruments for aircraft navigation (primary navigation display), the RNP computed desired path and aircraft position relative to the path. For operations where the required minimum flight crew is two pilots, a means for the pilot not flying (pilot monitoring) must also be provided to verify the desired path and the aircraft position relative to the path.

(2) A navigation database, containing current navigation data officially promulgated for civil aviation, which can be updated in accordance with the aeronautical information regulation and control (AIRAC) cycle. The stored resolution of the data must be sufficient to achieve the required track keeping accuracy. The database must be protected against pilot modification of the stored data.

(3) The means to display the navigation data validity period to the pilot.

(4) The means to retrieve and display data stored in the navigation database relating to individual waypoints and navigation aids, to enable the pilot to verify the route to be flown.

(5) Capability to load from the database into the RNP system the whole approach to be flown. The approach must be loaded from the database, into the RNP system, by its name.

(6) The means to display the following items, either in the pilot's primary field of view, or on a readily accessible display page:

(a) Distance between flight plan waypoints;

(b) Distance to go to the waypoint selected by the pilot;

(c) Active navigation sensor type;

(d) The identification of the active (To) waypoint;

(e) The ground speed or time to the active (To) waypoint; and

(f) The distance and bearing to the active (To) waypoint.

(7) The capability to execute a "Direct to" function.

(8) The capability for automatic leg sequencing with display to the pilots.

(9) The capability to execute RNP instrument approach procedures extracted from the onboard database including the capability to execute fly-over and fly-by turns.

(10) The capability to automatically execute leg transitions and maintain tracks consistent with the following ARINC 424 path terminators, or their equivalent:

(a) Initial Fix (IF).

(b) Track to Fix (TF).

(c) Direct to Fix (DF).

Note 1: Path terminators are defined in ARINC Specification 424, and their application is described in more detail in RTCA documents DO-236C Chg 1, DO-283B (as modified by TSO-C115d), and RTCA/ DO-201A, *Standards for Aeronautical Information*, dated April 19, 2000.

Note 2: Numeric values (e.g., RNP values) for procedures must be automatically loaded from the RNP system database.

(11) The capability to display an indication of the RNP system failure in the pilot's primary field of view.

(12) The capability to indicate to the crew when the NSE alert limit is exceeded (alert provided by the "onboard performance monitoring and alerting function").

i. Flight Director/Autopilot.

It is recommended that the flight director (FD) and/or autopilot remain coupled for RNP approaches. If the lateral TSE cannot be demonstrated without these systems, then coupling becomes mandatory. In this instance, operating guidance must indicate that coupling to the FD and/or autopilot from the RNP system is mandatory for approaches.

j. Database Integrity.

The navigation database suppliers must comply with AC 20-153(latest revision). A Type 2 LOA, issued by the appropriate regulatory authority, demonstrates compliance with this requirement. Type 2 LOAs issued prior to this AC are considered compliant.

8-4. System Eligibility and Approval for RNP APCH Operations.

a. Introduction.

The original equipment manufacturer (OEM) or the holder of installation approval for the aircraft (e.g., STC holder), must demonstrate compliance with the appropriate provisions of this AC to the FAA and the approval can be documented in manufacturer documentation (e.g., Service Letters, etc.). AFM/RFM entries are not required provided the FAA accepts the manufacturer's documentation.

b. Eligibility for RNP Instrument Approach Operations.

Systems meeting the criteria in paragraphs 8-2 and 8-3 are eligible for RNP instrument approach operations.

Chapter 9. Equipment Performance - RNP Enroute and Terminal.

9-1. Introduction.

This chapter provides guidance on the performance and functional criteria for RNP 2.0 operations in remote/oceanic enroute areas and RNP 1.0 operations in terminal areas. RNP 1.0 can be used to conduct RNP instrument departure procedures (including RNP ODPs and SIDs) and RNP STARs within the U.S. NAS where domestic air traffic control procedures are applied. Paragraph 9-5 provides guidance on the performance and functional criteria for rotorcraft enroute RNP 0.3 in terminal/enroute and offshore areas.

> **Note:** There is no intent to use RNP 2.0 for domestic enroute operations in the U.S.

9-2. Aircraft and System Criteria for RNP 2.0 and RNP 1.0.

a. Aircraft with the following avionics equipment automatically qualify for RNP 2.0 and RNP 1.0 capability without further documentation by virtue of the avionics TSO and airworthiness approval:

- TSO-C115c (or later revision) with a TSO-C129(AR) Class B1 or C1, TSO-C145(AR), or TSO-C196(AR) sensor.

  > **Note:** See paragraph 8-3.g(2) for "TO/TO" navigation computers.

- TSO-C146(AR) Class Gamma equipment;

- Aircraft with an RNP AR approval.

b. A TSO-C115b FMS using a TSO-C129(AR) Class B1/C1, TSO-C145(AR), or TSO-C196(AR) sensor with documented compliance to the RNP requirements in RTCA/DO-283A as part of the approval basis also provides RNP 2.0 and RNP 1.0 capability without further evaluation.

> **Note:** See paragraph 8-3.g(2) for "TO/TO" navigation computers.

c. Avionics or aircraft manufacturers may provide a service bulletin for a pilot or equipment operating handbook entry, or other notification stating aircraft with the equipment in paragraphs 9-2.a and 9-2.b, and an appropriate airworthiness approval, has RNP 2.0 and 1.0 capability.

> **Note 1:** The pilot or operating handbook entry must describe the steps necessary to access the capability.

> **Note 2:** New airworthiness approval applicants should consider including RNP 2.0 and 1.0 as part of their

application and document the capability in the AFM(S)/RFM(S). Doing so could benefit customers seeking operational approvals.

d. TSO-C129(AR) Class A1 equipment typically supports RNP 1.0 operations associated with instrument approach and departure procedures, but might not support other operations requiring RNP 2.0 or RNP 1.0. TSO-C129(AR) avionics manufacturers should provide an RNP capabilities document stating compliance with the RNP criteria in this chapter for RNP 2.0 and RNP 1.0 capability. Avionics or aircraft manufacturers may provide a service bulletin for a pilot or equipment operating handbook entry, or other notification stating aircraft with this equipment has RNP 2.0 and RNP 1.0 capability based on the avionics manufacturer's statement of compliance.

Note 1: If the equipment supports RNP 2.0 and RNP 1.0 capability, equipment manufacturers can use their AC 90-100A reference as an acceptable RNP statement of compliance.

Note 2: TSO-C129a has been cancelled so it is not possible to receive a new TSO-C129a TSOA. But equipment with an existing TSO-C129a TSOA may still be produced and installed.

e. Multi-sensor systems that use DME/DME/IRU as the only means of RNP compliance must document the equipment meets the performance and functional criteria in paragraph 9-3. RNP 2.0 approvals are based on GNSS, including GNSS/IRU, due to implementation in remote/oceanic areas. Therefore DME/DME/IRU should not be the basis for any RNP 2.0 approvals.

f. RNP aircraft with P-RNAV approval based on GPS capability meet the functional criteria of this AC for RNP 1.0 operations, such as RNP DPs, RNP SIDs, and RNP STARS.

Note 1: RNP 1.0 operations are based on GPS positioning or DME/DME/IRU if adequate DME coverage is available. Positioning data from other types of navigation sensors may be integrated with the GPS data provided it does not cause position errors exceeding the TSE budget. Otherwise, means should be provided to deselect the other navigation sensor types.

Note 2: RNP 2.0 for remote/oceanic operations must meet the continuity requirements associated with a major failure condition.

9-3. Performance and Functional Criteria.

a. Accuracy.

(1) During terminal operations in airspace or on routes designated as RNP 1.0, the lateral TSE must be within ±1 NM for at least 95 percent of the total flight time. The along-track error must also be within ±1 NM for at least 95 percent of the total flight time.

(2) Table 9 in chapter 17 indicates allowable "FTE credit" for various RNP operations when using autopilot, flight director, or manual flight control. Applicants may use these FTE values toward meeting TSE for the desired RNP operation without further demonstration or evaluation.

> **Note:** Using a lateral deviation indicator with 1 NM full-scale deflection is an acceptable means of compliance for maintaining TSE. An autopilot or FD may also be used for maintaining TSE, but roll stabilization systems do not qualify.

(3) During enroute operations in airspace or on routes designated as RNP 2.0, the lateral TSE must be within ±2 NM for at least 95 percent of the total flight time. The along-track error must also be within ±2 NM for at least 95 percent of the total flight time.

(4) Table 9 in chapter 17 indicates allowable "FTE credit" for various RNP operations when using autopilot, flight director, or manual flight control. Applicants may use these FTE values toward meeting TSE for the desired RNP operation without further demonstration or evaluation.

> **Note:** Using a lateral deviation indicator with 2 NM full-scale deflection is an acceptable means of compliance for maintaining TSE. An autopilot or FD may also be used for maintaining TSE, but roll stabilization systems do not qualify.

b. Integrity.

Malfunction of the aircraft navigation equipment that causes the TSE to exceed 2 times the RNP value without annunciation is classified as a major failure condition under airworthiness regulations (i.e., 10^{-5} per hour).

c. Continuity.

Loss of function is classified as a minor failure condition for RNP 1.0 if the operator can revert to a different navigation system and proceed to a suitable airport. For RNP 2.0 remote/oceanic airspace applications, loss of function is a major failure condition.

d. Performance Monitoring and Alerting.

The RNP system, or the RNP system and pilot in combination, must provide an alert if the accuracy requirement is not met, or if the probability that the lateral TSE exceeds:

(1) 2 NM is greater than 10^{-5} for RNP 1.0 operations; or,

(2) 4 NM is greater than 10^{-5} for RNP 2.0 operations.

e. Path Definition.

RNP equipment should provide lateral guidance so aircraft remain within the lateral boundaries of the defined RNP route. Aircraft performance should comply with RTCA/DO-236C, Chg 1.

f. Signal-in-Space.

If using GNSS, the aircraft navigation equipment must provide an alert if the probability of signal-in-space errors causing a lateral position error greater than:

(1) 2 NM exceeds 10^{-7} per hour for RNP 1.0 operations; or,

(2) 4 NM exceeds 10^{-7} per hour for RNP 2.0 operations.

g. Functional Criteria of Navigation Data Displays.

(1) The RNP system must have the following navigation displays and functions installed in accordance with this AC.

(2) Navigation data, including a TO/FROM indication and a failure indicator, must be displayed on a lateral deviation display (CDI, EHSI) and/or a navigation map display. These must be used as primary flight instruments for aircraft navigation, for maneuver anticipation, and for failure/status/integrity indication. A non-numeric lateral deviation display (for example, CDI, EHSI), with a TO/FROM indication and a failure annunciation, used as primary flight instruments for aircraft navigation, for maneuver anticipation, and for failure/status/integrity indication, should have the following attributes:

> **Note:** See paragraph 8-3.g(2) for TO/TO navigation computer displays.

(a) The displays must be visible to the pilot and located in the primary field of view when looking forward along the flight path.

(b) The lateral deviation display scaling must agree with any alerting and annunciation limits.

(c) The lateral deviation display must have a full-scale deflection suitable for the current phase of flight and must be based on the required total system accuracy. Scaling of

±1 NM for RNP 1.0 and ±2 NM for RNP 2.0 is acceptable. It is also acceptable for the scaling to be more conservative; for example, ±1.0 NM for an RNP 2.0 route.

(d) The display scaling may be set automatically by default logic or set to a value obtained from a navigation database. The full-scale deflection value must be known or must be available for display to the pilot.

(e) The lateral deviation display must be automatically slaved to the RNP computed path. It is recommended that the course selector of the deviation display be automatically slewed to the RNP computed path.

Note: This does not apply for installations where an electronic map display contains a graphical display of the flight path and path deviation.

(f) As an alternate means, a navigation map display may be used. The navigation map display must give equivalent functionality to a lateral deviation display with appropriate map scales (scaling may be set manually by the pilot). To be approved as an alternative means, the navigation map display must be shown to meet the TSE criteria and be located in the primary field of view.

(3) It is not necessary for navigation displays, particularly primary flight displays, to include an actual navigation performance (ANP) or RNP accuracy value. The displays only need to provide an alert if the RNP criteria for the operation cannot be met.

h. System Capabilities.

The following are the minimum system capabilities needed in RNP 1.0 or RNP 2.0 equipment:

(1) The capability to continuously display to the pilot flying, on the primary flight instruments for navigation of the aircraft (primary navigation display), the RNP computed desired path and aircraft position relative to the path. For operations where the required minimum flight crew is two pilots, a means for the pilot not flying must also be provided to verify the desired path and the aircraft position relative to the path.

(2) A navigation database, containing current navigation data officially promulgated for civil aviation, which can be updated in accordance with the AIRAC cycle. The stored resolution of the data must be sufficient to achieve the required track keeping accuracy. The database must be protected against pilot modification of the stored data.

(3) The means to display the validity period of the navigation data to the pilot.

(4) The means to retrieve and display data stored in the navigation database relating to individual waypoints and navigation aids, so the pilot can verify the route to be flown.

(5) For RNP 1.0, the capability to load from the database into the RNP system the entire segment of the SID, ODP, or STAR to be flown.

> **Note:** Due to variability in systems, this document defines the segment from the first occurrence of a named waypoint, track, or course to the last occurrence of a named waypoint, track, or course. Heading legs prior to the first named waypoint or after the last named waypoint do not have to be loaded from the database.

(6) The means to display the following items, either in the pilot's primary field of view, or on a readily accessible display page:

(a) The active navigation sensor type;

(b) The identification of the active (To) waypoint;

(c) The ground speed or time to the active (To) waypoint; and

(d) The distance and bearing to the active (To) waypoint.

(7) The capability to execute a "Direct to" function.

(8) The capability for automatic leg sequencing with display to the pilots.

(9) The capability to execute RNP 1.0 terminal procedures extracted from the onboard database including the capability to execute fly-over and fly-by turns.

(10) The system must have the capability to automatically execute leg transitions and maintain tracks consistent with the following ARINC 424 path terminators:

(a) Initial fix (IF) (only for RNP 1.0);

(b) Course to fix (CF);

(c) Direct to fix (DF); and

(d) Track to fix (TF).

> **Note:** Path terminators are defined in ARINC Specification 424, and their application is described in more detail in RTCA documents DO-236C Chg 1, DO-283B (as modified by TSO-C115d) and RTCA/DO-201A.

(11) The system must have either an automatic or a manual capability to fly the aircraft on a heading to intercept a course or to go direct to another fix after reaching a procedure-specified altitude. The system may use heading to altitude (VA), heading to manual

(VM) and heading to intercept (VI) path terminators for automatic capability.

(12) The system must have either an automatic leg transition capability or a manual capability to permit the pilot to readily designate a waypoint and select a desired course to or from a designated waypoint. The system may use course to altitude (CA) and fix to manual termination (FM) path terminators for automatic capability.

(13) The capability to load a procedure from the database, by procedure name, into the area navigation system.

(14) The capability to display an indication of the RNP system failure in the pilot's primary field of view.

(15) The capability to indicate to the crew when the NSE alert limit is exceeded (i.e., the alert provided by the "onboard performance monitoring and alerting function").

i. Database Integrity.

The navigation database suppliers must comply with AC 20-153(latest revision). A Type 2 LOA, issued by the appropriate regulatory authority, demonstrates compliance with the criteria. Type 2 LOAs issued prior to this AC are considered compliant.

9-4. System Eligibility and Approval for RNP 2.0 and RNP 1.0 Operations.

Systems meeting the criteria in paragraphs 9-2 and 9-3 are eligible for RNP 2.0 and RNP 1.0 operations.

9-5. Rotorcraft Enroute, Terminal, and Offshore RNP 0.3.

9-5.1 Introduction.

Section 9.5 provides guidance on the performance and functional criteria for rotorcraft enroute RNP 0.3 and the installed GPS/SBAS equipment, at a minimum, must meet the criteria for RNP 2.0, RNP 1.0 and RNP APCH to LNAV minima. The intent is to use rotorcraft enroute RNP 0.3 capability for enroute, terminal, departure, arrival, and offshore rotorcraft operations. Rotorcraft enroute RNP 0.3 is based on GPS/SBAS equipage and the rotorcraft must be approved for IFR operations. The reason is to take advantage of the known functionality, performance and availability GPS/SBAS provides. It is not acceptable to use GPS or DME/DME/IRU for rotorcraft rotorcraft enroute RNP 0.3 operations.

9-5.2 Rotorcraft and System Eligibility for Rotorcraft Enroute RNP 0.3 Operations.

a. The rotorcraft must be approved for IFR operations. Any limitations required for normal IFR operation such as a functioning stability augmentation system, multiple crewmembers, autopilot coupling, etc. will also apply to rotorcraft enroute RNP 0.3.

b. GPS/SBAS stand-alone equipment must be approved in accordance with TSO-C146(AR) Class 1, 2, or 3. These systems must be installed for IFR use in accordance with this AC.

c. GPS/SBAS sensors used in multi-sensor system equipment (e.g., FMS) must be approved in accordance with TSO-C145(AR) Class 1, 2, or 3. These systems must be installed for IFR use in accordance with this AC.

d. Multi-sensor systems must be approved in accordance with TSO-C115b (or later revision), but may also have a TSO-C146(AR) Class Gamma approval (see paragraphs 3-2.g and 3-4). The GPS/SBAS sensors and multi-sensor equipment must comply with the applicable GPS/SBAS equipment chapters and chapters 6, 12-14, 16, 19-20, and 22 of this AC and be installed for IFR use in accordance with this AC.

9-5.3 Performance and Functional Criteria.

a. Accuracy.

(1) During operations on rotorcraft enroute RNP 0.3 routes, the lateral TSE must be within ±0.3 NM for at least 95 percent of the total flight time. The along-track error must also be within ±0.3 NM for at least 95 percent of the total flight time. To satisfy the accuracy requirement, the FTE should not exceed 0.25 NM (see paragraph 9-5.3.i).

(2) Table 9 in chapter 17 indicates allowable "FTE credit" when using an autopilot and/or flight director.

b. Integrity.

Malfunction of the aircraft navigation equipment that causes the TSE to exceed 2 times the RNP value without annunciation is classified as a Major failure condition.

c. Continuity.

(1) Loss of function is classified as a Major failure condition for offshore and remote area operations. The rotorcraft must have dual, independent long-range navigation system equipage for offshore and remote area operations.

(2) Loss of function is classified as a Minor failure condition for domestic rotorcraft enroute RNP 0.3 operations if the operator can revert to a different navigation system and proceed safely to a suitable airport.

d. Performance Monitoring and Alerting.

During rotorcraft enroute RNP 0.3 operations, the RNP system must provide an alert if the accuracy requirement is not met or if the probability that the lateral TSE exceeds 0.6 NM is greater than 10^{-5}.

e. Path Definition.

RNP equipment should provide lateral guidance so aircraft remain within the lateral boundaries of the defined RNP route (see also paragraph 9-5.3.h.7). Aircraft performance should comply with RTCA/DO-236C, Chg 1.

f. Signal-in-Space.

The aircraft navigation equipment must provide an alert if the probability of signal-in-space errors causing a lateral position error greater than 0.6 NM exceeds 10^{-7} per hour.

g. Functional Criteria for Navigation Displays.

(1) The rotorcraft enroute RNP 0.3 system must have the following navigation displays and functions installed in accordance with this AC.

(2) Navigation data, including a TO/FROM indication and a failure indicator, must be displayed on a lateral deviation display (course deviation indicator (CDI), electronic horizontal situation indicator (EHSI)) and/or a navigation map display. These must be used as primary flight instruments for aircraft navigation, for maneuver anticipation, and for failure/status/integrity indication.

Note: See paragraph 8-3g(2) for guidance on RNP systems with navigation computers using TO/TO navigation algorithms.

(a) The displays must be visible to the pilot and located in the primary field of view when looking forward along the flight path.

(b) The lateral deviation display scaling must agree with the RNP 0.3 alerting and annunciation limits.

(c) The lateral deviation display must have ±0.3 NM full-scale deflection based on the required total system accuracy.

(d) The display scaling may be set automatically by default logic; automatically to a value obtained from a navigation database; or manually by flight crew procedures. The full-scale deflection value must be known or must be available for display to the pilot commensurate with the required accuracy.

(e) The lateral deviation display must be automatically slaved to the RNP computed path. It is recommended that the course selector of the deviation display be automatically slewed to the RNP computed path.

Note: This does not apply for installations where an electronic map display contains a graphical display of the flight path and path deviation.

(f) As an alternate means, a navigation map display must give equivalent functionality to a lateral deviation display with appropriate map scales (scaling may be set manually by the pilot), and giving equivalent functionality to a lateral deviation display. To be approved as an alternative means, the navigation map display must be shown to meet the TSE criteria and be located in the primary field of view.

h. System Capabilities.

The following system capabilities must be provided, as a minimum, within any rotorcraft enroute RNP 0.3-capable equipment:

(1) The capability to continuously display to the pilot flying, on the primary flight instruments for navigation of the aircraft (primary navigation display), the RNP computed desired path and aircraft position relative to the path. For operations where the required minimum flight crew is two pilots, a means for the pilot not flying must also be provided to verify the desired path and the aircraft position relative to the path.

(2) A navigation database, containing current navigation data officially promulgated for civil aviation, which can be updated in accordance with the AIRAC cycle. The stored resolution of the data must be sufficient to achieve the required track keeping accuracy. The database must be protected against pilot modification of the stored data.

(3) The means to display the validity period of the navigation data to the pilot.

(4) The means to retrieve and display data stored in the navigation database relating to individual waypoints and navigation aids, so the pilot can verify the route to be flown.

(5) The capability to load from the database into the rotorcraft enroute RNP 0.3 system the entire segments of the procedures or routes to be flown. It is acceptable to manually load route waypoints from the database into a flight plan page and manually set the scaling and alerting.

> **Note:** Due to variability in systems, this document defines the segment from the first occurrence of a named waypoint, track, or course to the last occurrence of a named waypoint, track, or course. Heading legs prior to the first named waypoint or after the last named waypoint do not have to be loaded from the database.

(6) The means to display the following items, either in the pilot's primary field of view, or on a readily accessible display page:

(a) The active navigation sensor type;

(b) The identification of the active (To) waypoint;

(c) The ground speed or time to the active (To) waypoint; and

(d) The distance and bearing to the active (To) waypoint.

(7) The capability to execute RNP 0.3 routes using waypoints extracted from the onboard database including the capability to execute fly-by turns.

Note: The final waypoint used at the end of RNP 0.3 routes may designate a specific crossing point; that is, a fly-over waypoint. There is no intent to use fly-over turns on RNP 0.3 routes

(8) The capability to automatically execute leg transitions and maintain tracks consistent with the following ARINC 424 path terminators:

(a) Initial fix (IF);

(b) Course to fix (CF);

(c) Direct to fix (DF); and

(d) Track to fix (TF).

Note: Path terminators are defined in ARINC Specification 424, and their application is described in more detail in RTCA documents DO-236C Chg 1, DO-283B (as modified by TSO-C115d) and DO-201A.

(9) The capability to automatically or manually fly on a heading to intercept a course or to go direct to another fix after reaching a procedure-specified altitude. The system may use heading to altitude (VA), heading to manual (VM) and heading to intercept (VI) path terminators for automatic capability.

(10) The capability to automatically or manually permit the pilot to readily designate a waypoint and select a desired course to or from a designated waypoint. The system may use course to altitude (CA) and fix to manual termination (FM) path terminators for automatic capability.

(11) The capability to display an indication of the RNP 0.3 system failure in the pilot's primary field of view.

(12) The capability to indicate to the crew when the NSE alert limit is exceeded (alert provided by the "onboard performance monitoring and alerting function").

(13) The capability for the flight crew to build an enroute or offshore segment in the equipment flight plan function using individual waypoints from the database. This is similar to existing enroute capability.

Note: It is also acceptable for the navigation system to automatically load all route waypoints from the database by selecting the route name.

i. Flight Director/Autopilot.

For all rotorcraft enroute RNP 0.3 operations, the use of an autopilot and/or FD is an acceptable means of complying with the FTE assumption in paragraph 9-5.3.a(1). Any alternate means of FTE bounding, other than autopilot and/or FD, may require FTE substantiation through an airworthiness demonstration.

Note: Some rotorcraft may need a stability augmentation system to achieve 0.25 NM FTE during manual flight.

j. Database Integrity.

The navigation database suppliers must comply with AC 20-153(latest revision). The GPS/SBAS TSOA provides sufficient evidence for compliance to AC 20-153(latest revision), but GNSS operational approval for IFR use is based upon a database assurance process through a type 2 LOA (see paragraph 19-8).

9-5.4 Approval for Rotorcraft RNP 0.3 Operations.

a. The GPS/SBAS-enabled navigation system equipment manufacturer should provide an RNP capability statement that the equipment meets the performance and functional criteria in paragraph 9-5.3 for rotorcraft enroute RNP 0.3 operations. If provided, an RNP capability statement must include a description of the equipment procedures for pilots to select the rotorcraft enroute RNP 0.3 capability. The equipment manufacturer may provide the RNP capability statement through a service bulletin or equivalent document and list the GPS/SBAS equipment model(s) that meet the criteria in section 9-5 and are eligible for rotorcraft enroute RNP 0.3 operations.

b. The GPS/SBAS equipment must be installed according to a TC, ATC, or STC and any rotorcraft limitations required for IFR operations also apply to rotorcraft enroute RNP 0.3 capability. As an example to illustrate the point, a single-pilot rotorcraft could have a limitation to use an autopilot when conducting IFR operations. This limitation would also apply to rotorcraft enroute RNP 0.3 capability.

c. Applicants for new GPS/SBAS approvals should consider including rotorcraft enroute RNP 0.3 capability as part of their application and document the capability in the RFM(S). Doing so could benefit customers seeking operational approvals.

Chapter 10. Equipment Performance – RNP Oceanic

10-1. Introduction.

a. This chapter provides guidance for RNP 10 and RNP 4.0 equipment approvals in oceanic areas. RNP 10 supports 50 NM lateral and 50 NM longitudinal separations in oceanic or remote areas without reliance on ground-based navigation aids. Paragraph 10-2 describes the performance and system criteria equipment must meet for RNP 10 and reflects the criteria in the ICAO Performance-based Navigation (PBN) Manual.

b. RNP 4.0 supports 30 NM lateral and 30 NM longitudinal separations in oceanic areas. GNSS is the primary navigation sensor supporting RNP 4.0 operations either as a stand-alone system or part of a multi-sensor system. Paragraph 10-3 describes the performance and functional criteria equipment must meet for RNP 4.0 and reflects the criteria in the ICAO PBN Manual.

10-2. Aircraft and System Criteria for RNP 10.

Operational implementation of RNP 10 is an application of RNAV supporting 50 NM lateral and 50 NM longitudinal distance-based aircraft separation minima in oceanic or remote airspace. As an RNAV application, there is no requirement for onboard performance monitoring and alerting. Aircraft operating in RNP 10 oceanic and remote areas must be equipped with at least two independent and serviceable long-range navigation systems using INS/IRU and/or GNSS.

10-2.1 Performance Criteria.

a. Accuracy.

(1) During operations in airspace or on routes designated as RNP 10, the lateral TSE must be within ±10 NM for at least 95 per cent of the total flight time. The along-track error must also be within ±10 NM for at least 95 per cent of the total flight time.

(2) The navigational positioning error is the dominant contributor to cross-track and along-track error for aircraft capable of coupling the navigation system to the flight director or autopilot. A manufacturer or operator may consider FTE, path definition error, and display errors insignificant when obtaining an RNP 10 operations approval.

b. Integrity.

Malfunction of the aircraft's long-range navigation equipment without annunciation is a major failure condition (i.e., the probability of a malfunction with no annunciation must be less than 10^{-5} per hour).

c. Continuity.

Loss of function of the long-range navigation equipment is a major failure condition for oceanic and remote operations. Dual independent long-range navigation system equipage may satisfy the continuity criteria (excluding signal-in-space criteria).

d. Signal-In-Space.

If using GNSS, the aircraft long-range navigation equipment must provide an alert if the probability of signal-in-space errors causing a lateral position error greater than 20 NM exceeds 10^{-7} per hour.

10-2.2 System Criteria.

a. Aircraft Incorporating Two or More GNSSs.

(1) Paragraph 10-2.2.a provides an acceptable means of complying with RNP 10 criteria for aircraft using a GNSS-only installation; that is, no integration with other navigation sensors.

(2) Aircraft approved to use GNSS for oceanic and remote operations without reliance on other long-range navigation systems meet the RNP 10 criteria without the time limitations associated with INS/IRU equipment. However, using GNSS depends upon using an FDE availability prediction (see paragraph 10-2.2.a(3)).

(3) Dual GNSS installations with a TSOA qualify for RNP 10 when the operator uses an approved dispatch GNSS FDE availability prediction. The AFM(S) should also indicate if a particular GNSS installation meets the appropriate FAA criteria for oceanic and remote operations.

(a) When conducting GNSS pre-departure dispatch FDE predictions, the maximum allowable time for a predicted loss of GNSS FDE capability is 34 minutes. The 34 minute time limit must be a condition of the RNP 10 operations approval.

> **Note 1:** If a GNSS FDE prediction indicates a loss of FDE capability exceeding 34 minutes, the performance criteria for the intended RNP 10 operation cannot be met. The operator must reschedule the RNP 10 operation to a period when predicted FDE is available; or, select another route where predicted FDE capability is available.

> **Note 2:** The FAA's SAPT prediction program does not provide FDE predictions for oceanic operations.

(b) TSO-C145/TSO-C146(AR) and TSO-C196(AR) GNSS equipment supports oceanic and remote operation by virtue of the TSOA when used in conjunction with an approved GNSS FDE prediction program. No further evaluation is needed for TSO-C145/C146/C196 equipment.

(c) TSO-C129(AR) GPS equipment might not support oceanic and remote operations. Appendix 1 describes additional criteria defining an acceptable means of compliance for TSO-C129(AR) GPS equipment to support an operations approval for oceanic and remote operations. The AFM(S) should also indicate if a particular TSO-C129a GNSS installation meets the appendix 1 criteria for oceanic and remote operations.

(4) Multi-sensor navigation systems (i.e., FMSs) meet the RNP 10 criteria when integrating dual GNSS with FDE, and approved using the guidance contained in this AC.

b. Aircraft Incorporating a Single INS/IRU and a Single GNSS.

(1) Aircraft approved to use a single INS/IRU and a single GNSS for oceanic and remote operations meet the RNP 10 criteria without time limitations.

(2) The INS/IRU equipment must meet the standards of paragraph 10-2.1 and 10-2.2.c, but aircraft qualification only requires one INS/IRU.

(3) The GNSS equipment must meet the standards of paragraph 10-2.1 and 10-2.2.a, but aircraft qualification only requires one GNSS.

Note: If a GNSS FDE prediction indicates FDE unavailability exceeding 34 minutes, the performance criteria for the intended RNP 10 operation cannot be met using GNSS. The operator must predicate their RNP 10 operations on an INS/IRU for that portion of the flight.

c. Aircraft Incorporating a Single INS/IRU or a Single GNSS.

(1) Aircraft equipped with a single INS/IRU or a single GNSS are qualified for oceanic and remote navigation in the Houston oceanic control area/flight information region, the Gulf of Mexico portion of the Miami oceanic control area/flight information region, the Monterrey control area, and the Merida High control area within the Mexico flight information region/upper control area. Aircraft equipped with a single GNSS meet the RNP 10 performance criteria in this airspace without time limitations.

Note: Aircraft qualification in these regions is predicated on the air traffic surveillance provided in the Gulf of Mexico. Therefore, RNP 10 authorizations approved solely in accordance with this paragraph must clearly limit the RNP 10 operational approval to the Gulf of Mexico.

(2) The INS/IRU equipment must meet the standards of paragraph 10-2.1 and 10-2.2.c, but only one INS/IRU is required.

(3) The GNSS equipment must meet the standards of paragraph 10-2.1 and 10-2.2.a, but only one GNSS is required.

d. Aircraft Incorporating Two or more INS/IRUs – Standard Time Limit.

(1) Aircraft Equipped with Two or More INSs or IRUs Approved in Accordance with Part 121 Appendix G. Inertial systems approved in accordance with part 121 appendix G

meet RNP 10 performance criteria for up to 6.2 hours of flight time. This time starts when the flight crew places the INS/IRU system in the inertial navigation mode.

(a) If the flight crew updates the INS/IRU systems en route (through manual or automatic means), the flight crew must adjust the 6.2 hour RNP 10 time limit to account for the update's accuracy. The flight crew must base any adjustments to the time limit on the demonstrated capability of the updates stated in the aircraft's airworthiness approval documentation (i.e. the AFMS(S)).

(b) INS/IRU accuracy, reliability, training, and maintenance issues required by an airworthiness approval in compliance with part 121 appendix G are applicable to an RNP 10 operation, including any associated oceanic/remote navigation procedures. Except as authorized by the FAA Administrator, and in accordance with the applicable section of 14 CFR, RNP 10 operations based solely IRS/IRU requires at least dual equipage (i.e. two or more inertial systems). Refer to 14 CFR § 121.351, § 125.203, and § 135.165.

Note 1: The long-term inertial drift rate of 2.0 NM/hour (a 95 percent radial position error rate (circular error rate)) is the performance basis for the 6.2 hour time limit. This drift rate is statistically equivalent to an individual 95 percent cross-track and an individual 95 percent along-track position error rates (orthogonal error rates) of 1.6015 NM/hour each; and, a 95 percent cross-track and a 95 percent along-track position error limit of 10 NM each (e.g., 10 NM/1.6015 NM/hour=6.2 hours).

Note 2: The FAA has adopted the ICAO term "oceanic/remote" instead of Class II.

(2) Aircraft approved for North Atlantic minimum navigation performance specification operations or for RNAV operations in Australia meet RNP 10 criteria for up to 6.2 hours after the flight crew places the long-range navigation system in the inertial navigation mode.

e. Aircraft Incorporating Two or more INS/IRUs – Extended Time Limit.

The 6.2 hour time limit is the baseline for RNP 10 inertial systems performance, and the time limit begins when the flight crew places the long-range navigation system in the inertial navigation mode. However, this time limit may be extended by one of the following methods:

(1) Establishing an extended time limit during a formal RNP 10 airworthiness approval process (e.g., a new TC, ATC, or STC project).

(2) An existing airworthiness approval holder requests an extension for the installed inertial navigation system from the appropriate ACO based on justifying engineering data.

(3) An airworthiness applicant or existing airworthiness approval holder requests an extended time limit by showing how multiple navigation sensors that mix or average navigation position error justifies an extension (e.g., triple-mixed INSs). If the applicant requests an extended time limit based on mixing, then the availability of the mixing capability is a limitation for flight on RNP 10 routes. If the mixing or averaging function is not available, the operator must use a time limit that does not depend on mixing.

10-2.3 System Eligibility and Approval for RNP 10 Operations.

RNP 10 is an RNAV operational application supporting 50 NM lateral and 50 NM longitudinal distance-based aircraft separation minima in oceanic or remote airspace. As an RNAV application, there is no requirement for onboard performance monitoring and alerting. There are two methods to recognize aircraft and system eligibility for RNP 10 operations: 1) RNP 10 certification; and, 2) prior navigation system certification. In both cases, the aircraft must be equipped with at least two independent and serviceable long-range navigation systems using GNSS and/or INS/IRU.

RNP 10 Aircraft Certification.

a. RNP 10 aircraft qualification is typically documented in the AFM(S) for aircraft with a formal airworthiness approval for RNP operations. RNP operations approval is not typically limited to just RNP 10. The AFM(S) should document the demonstrated RNP accuracy values the aircraft supports along with any limitations (e.g., navigation aid sensor requirements for present position updating). Implementing States may base operational approval on the stated performance in the AFM(S).

> **Note:** Aircraft qualified for RNP 4.0 operations automatically qualify for RNP 10 operations.

b. An applicant may obtain an airworthiness approval specific to RNP 10 aircraft qualification. The following example AFM(S) wording (or equivalent) is used when RNP 10 is granted for a change in, or new demonstration of, the INS/IRU certified performance:

> "The <*insert name*> navigation system meets the aircraft qualification criteria of AC 20-138 <*insert latest revision*> as a primary means of navigation for flights up to XXX hours in duration without present position updating. Determining the flight duration starts when the flight crew places the long-range navigation system in the inertial navigation mode."

> **Note:** The "XXX hours" specified in the AFM(S) for INS/IRU systems do not include credit for present position updating.

(1) For long-range navigation systems capable of updating the aircraft's present position while airborne, the airworthiness approval must address the impact present position updating has on position accuracy and any impact on time limits for RNP 10 operations. The approval should clarify the role of ground-based navigation facilities in present position

updating (if any), clarify the role of GNSS present position updating (if equipped), and define any requisite flight crew procedures necessary to initiate and terminate present position updating. The credit received for present position updating can be applied to the "XXX hours" specified in the AFM(S) for INS/IRU systems.

(2) Demonstration of aircraft performance in accordance with this AC does not constitute operations approval to conduct RNP operations.

(3) The demonstration of inertial performance to FAA Aircraft Certification Service (AIR) forms the basis for the suggested AFM(S) wording above, but is only one element of the approval process. Aircraft that have this wording in their flight manual will be eligible for operational approval through issuance of OpSpecs/MSpecs or an LOA (as applicable) when the operator and aircraft meet all other RNP 10 qualification criteria.

Prior Navigation System Certification.

Manufacturers and operators may use their prior navigation system certification to recognize an aircraft whose performance under criteria of another RNP specification equates to or exceeds the RNP 10 performance criteria listed in this AC. Manufacturers and operators may also use other navigation specifications standards when they are sufficient to ensure compliance with RNP 10 performance criteria.

10-3. Aircraft and System Criteria for RNP 4.0.

Aircraft operating in RNP 4.0 oceanic and remote areas must be equipped with at least two independent and serviceable long-range navigation systems. GNSS must be used as either a stand-alone navigation system, as one of the sensors in a multi-sensor system, or as part of an integrated GNSS/inertial system.

10-3.1 Performance and Functional Criteria for RNP 4.0.

a. Accuracy.

(1) The lateral TSE must be within ±4 NM for at least 95 per cent of the total flight time. The along-track error must also be within ±4 NM for at least 95 percent of the total flight time.

(2) Table 9 in chapter 17 indicates allowable "FTE credit" for various RNP operations when using autopilot, flight director, or manual flight control. Applicants may use these FTE values toward meeting TSE for the desired RNP operation without further demonstration or evaluation.

b. Integrity.

Malfunction of the aircraft navigation equipment that causes the TSE to exceed 2 times the RNP value without annunciation is classified as a Major failure condition under airworthiness regulations (i.e., 10^{-5} per hour).

c. Continuity.

Loss of function is classified as a major failure condition for oceanic and remote navigation. The continuity criteria is satisfied by the carriage of dual independent long-range navigation systems (excluding SIS).

d. Performance Monitoring and Alerting.

(1) The RNP system must provide an alert if the accuracy criteria is not met, or if the probability that the lateral TSE exceeds 8 NM is greater than 10^{-5}.

(2) On-board performance monitoring and alerting compliance does not imply an automatic monitor of FTE. The on-board monitoring and alerting function should at least consist of an NSE monitoring and alerting algorithm and a lateral deviation display enabling the crew to monitor the FTE.

(3) Path definition error is considered negligible.

e. Signal-in-Space.

When using GNSS, the aircraft navigation system must provide an alert if the probability of signal-in-space errors causing a lateral position error greater than 8 NM exceeds 10^{-7} per hour.

f. Functional Criteria of Navigation Data Displays.

(1) The RNP system must have the following navigation displays and functions installed in accordance with this AC.

(2) Navigation data, including a TO/FROM indication and a failure indicator, must be displayed on a lateral deviation display (CDI, EHSI) and/or a navigation map display. These must be used as primary flight instruments for aircraft navigation, for maneuver anticipation, and for failure/status/integrity indication. A non-numeric lateral deviation display (for example, CDI, EHSI), with a TO/FROM indication and a failure annunciation, used as primary flight instruments for aircraft navigation, for maneuver anticipation, and for failure/status/integrity indication, should have the following attributes:

> **Note:** See paragraph 8-3.g(2) for TO/TO navigation computer displays.

(a) The displays must be visible to the pilot and located in the primary field of view when looking forward along the flight path.

(b) The lateral deviation display scaling must agree with any alerting and annunciation limits. The display scaling may be set automatically by default logic or set to a value obtained from the navigation database.

(c) The lateral deviation display must be automatically slaved to the RNP computed path and must have a full-scale deflection suitable for the current phase of flight. It is recommended that the course selector of the deviation display be automatically slewed to the RNP computed path.

Note: This does not apply for installations where an electronic map display contains a graphical display of the flight path and path deviation.

(3) As an alternate means, a navigation map display may be used. The navigation map display must give equivalent functionality to a lateral deviation display with appropriate map scales (scaling may be set manually by the pilot). To be approved as an alternative means, the navigation map display must be shown to meet the TSE criteria and be located in the primary field of view.

(4) It is not necessary for navigation displays, particularly primary flight displays, to include an actual navigation performance (ANP) or RNP accuracy value. The displays only need to provide an alert if the RNP for the operation cannot be met.

g. System Capabilities.

The following are the minimum system capabilities needed in RNP 4.0 equipment:

(1) The capability to continuously display to the pilot flying, on the primary flight instruments for navigation of the aircraft (primary navigation display), the RNP computed desired path and aircraft position relative to the path. For operations where the required minimum flight crew is two pilots, a means for the pilot not flying must also be provided to verify the desired path and the aircraft position relative to the path.

(2) A navigation database, containing current navigation data officially promulgated for civil aviation, which can be updated in accordance with the AIRAC cycle. The stored resolution of the data must be sufficient to achieve the required track keeping accuracy. The database must be protected against pilot modification of the stored data.

(3) The means to display the validity period of the navigation data to the pilot.

(4) The means to retrieve and display data stored in the navigation database relating to individual waypoints and navigation aids, so the pilot can verify the route to be flown.

(5) A means for the crew to create, review, and activate a flight plan. The system must incorporate a means for the crew to verify flight plan entries or changes before they are activated. The guidance output must not be affected until the flight plan or flight plan changes are activated.

(6) The capability to automatically sequence fixes.

(7) The means to display the following items, either in the pilot’s primary field of view, or on a readily accessible display page:

(a) The active navigation sensor type;

(b) The identification of the active (To) waypoint;

(c) The ground speed or time to the active (To) waypoint; and

(d) The distance and bearing to the active (To) waypoint.

(8) The capability to execute a “Direct to” function.

(9) The capability for automatic leg sequencing with display to the pilots.

(10) The system must have the capability to automatically execute leg transitions and maintain tracks consistent with the following ARINC 424 path terminators:

(a) Course to fix (CF);

(b) Direct to fix (DF); and

(c) Track to fix (TF).

Note: Path terminators are defined in ARINC Specification 424, and their application is described in more detail in RTCA documents DO-236C Chg 1, DO-283B and DO-201A.

(11) The capability to display an indication of the RNP system failure in the pilot’s primary field of view.

(12) The capability to indicate to the crew when the NSE alert limit is exceeded (i.e., the alert provided by the “onboard performance monitoring and alerting function”).

(13) The capability to fly parallel tracks at a selected offset distance. When executing a parallel offset, the navigation accuracy and all performance criteria of the original route in the active flight plan must be applicable to the offset route.

(a) The system must provide for entry of offset distances in increments of 1 NM, left or right of course. The system must be capable of offsets of at least 20 NM.

(b) System offset mode operation must be clearly indicated to the pilot. When in offset mode, the system must provide reference parameters (e.g. cross-track deviation, distance-to-go, time-to-go) relative to the offset path and offset reference points.

(c) An offset must not be propagated through route discontinuities, unreasonable path geometries, or beyond the IAF.

(d) The system must annunciation prior to the end of the offset path, with sufficient time to return to the original path.

(e) Once a parallel offset is activated, the offset must remain active for all flight plan route segments until removed automatically, until the pilot enters a direct-to routing, or until pilot (manual) cancellation.

(f) The parallel offset function must be available for en-route TF and the geodesic portion of DF leg types.

Note 1: Systems compliant with parallel offset requirements in RTCA/DO-236B (or later revision) and RTCA/DO-283A (or later revision) meet the parallel offset criteria for RNP 4.0.

Note 2: RTCA/DO-236C and RTCA/DO-283B require increments of 0.1 nm to support parallel offsets in terminal areas. Using these smaller increments is also acceptable for RNP 4.0 operations.

(14) The system must have the capability to perform fly-by transitions.

(a) Fly-by transitions must be the default when a transition type is not specified.

(b) Navigation systems should be designed to keep aircraft within the theoretical transition area.

(c) Fly-by theoretical transition areas are based upon the following assumptions:

- Course changes do not exceed 120 degrees for low altitude transitions (aircraft barometric altitude is less than FL 195); and,
- Course changes do not exceed 70 degrees for high altitude transitions (aircraft barometric altitude is equal to or greater than FL 195).

Note: Systems compliant with the fly-by transition requirements in RTCA/DO-236B (or later revision), RTCA/DO-283A (or later revision) and RTCA/DO-229C (or later revision) meet the fly-by transition criteria for RNP 4.0.

10-3.2 System Eligibility and Approval for RNP 4.0 Operations.

There are two methods to recognize aircraft and system eligibility for RNP 4.0 operations: 1) RNP certification; and, 2) prior navigation system certification. In both cases, the aircraft must be equipped with at least two independent and serviceable long-range navigation systems; at least one of which must be GNSS.

a. RNP Certification.

RNP certification is typically documented in the AFM(S) for aircraft that have been formally certificated and approved for RNP operations and typically is not limited to RNP 4.0. The AFM(S) addresses RNP levels that have been demonstrated to meet the certification criteria and any related provisions applicable to their use (e.g., navigation aid sensor requirements). Operational approval is based upon the performance stated in the AFM(S). This method also applies in cases where certification is received through an STC issued to retrofit equipment, such as GNSS receivers, to enable the aircraft to meet RNP 4.0 performance criteria in oceanic and remote area airspace.

b. Prior Navigation System Certification.

(1) This method is used to approve aircraft whose level of performance under previous standards equates to the RNP 4.0 criteria listed in this AC. The AFM(S) must indicate the aircraft is equipped with GNSS approved as a long-range navigation system for oceanic and remote airspace operations.

(2) RNP 4.0 operations using only GNSS is based upon a pre-departure FDE availability prediction program. 25 minutes is the maximum allowable time for which FDE capability is projected to be unavailable on any one event. This maximum outage time must be included as a condition of the RNP 4.0 operational approval. If predictions indicate that the maximum allowable FDE outage will be exceeded, the operation must be rescheduled to a time when FDE is available.

> **Note:** The FAA's SAPT prediction program does not provide FDE predictions for oceanic operations.

(a) Aircraft with TSO-C129(AR) equipment must also document the equipment is approval for oceanic operations according to appendix 1 in this AC.

(b) TSO-C115b (or later revision) is acceptable for multi-sensor systems incorporating GNSS sensors.

(3) Multi-sensor systems incorporating an approved INS/IRU can extend the maximum FDE unavailability time based upon the amount of time the system can maintain RNP 4.0 coasting performance without a position update. The approval must indicate the maximum GNSS FDE unavailability time.

Chapter 11. Equipment Performance - Baro-VNAV.

11-1. General Limitations for Operations under IFR.

a. A baro-VNAV system may be approved for enroute, terminal, and approach use within the contiguous U.S., Alaska, and Hawaii. VNAV equipment may be used to provide advisory vertical path guidance to aid in more efficient and precise operation of the aircraft. However, unless compensated for temperature, baro-VNAV equipment can only be used within the limitations for temperature published on approach procedure charts. **The barometric altimeter must always be the primary altitude reference for <u>all</u> flight operations** (see paragraphs 12-7, 18-2.b and 23-3.1).

b. Systems providing automatic temperature compensation to the baro-VNAV guidance must comply with RTCA/DO-283B, appendix H. This enables baro-VNAV operations outside of the temperature limits published on approach procedure charts.

(1) Equipment manufacturers may include compensation for temperatures above and below the limits published on approach charts.

> **Note:** Any equipment limitations must be documented in the installation manual.

(2) Temperature compensation may be provided on segments other than the final approach and missed approach (i.e., the segments prescribed by RTCA/DO-283B, appendix H) if the equipment includes a method for the flight crew to inhibit the compensation function. Equipment manufacturers providing baro-VNAV temperature compensation on other segments must specify language in the installation instructions/manual for an AFM(S)/RFM(S) caution that the flight crew/pilot must coordinate use of temperature compensation with ATC prior to employing this function. The reason for an AFM(S)/RFM(S) caution is to ensure there is no loss of separation between an aircraft employing temperature compensation and an aircraft not employing this function.

> **Note:** Aviation authorities in different countries may or may not authorize temperature compensation outside the final approach segment.

c. Procedures for manual altitude corrections must be established for systems that do not provide automatic temperature compensation. A pilot workload evaluation must be performed for all segments in the approach, including the missed approach holding waypoint.

d. Baro-VNAV equipment may also be used to provide advisory vertical guidance to aid in more efficient and precise operation of the aircraft for enroute, terminal, and/or approach operations (see chapter 4). The primary barometric altimeter will be the primary altitude reference for all flight operations.

e. Baro-VNAV performance is not adequate for vertical guidance on LPV or GLS approaches.

11-2. Baro-VNAV Equipment Performance for Operations under IFR.

a. The initial certification of a baro-VNAV system requires an engineering evaluation because of the need to verify performance, failure indications, environmental qualifications, etc. Subsequent installations of the same baro-VNAV equipment system in other aircraft may require additional engineering evaluation, depending upon the degree of integration with other aircraft systems, in particular autopilot and FD systems.

b. For enroute, terminal, and approach IFR operations, the airborne baro-VNAV system must have TSE components in the vertical direction that are less than those shown in Table 6 below, 99.7 % of the flying time (reference RTCA/DO-283B, paragraph 2.2.2.6.1). Misleading guidance during LNAV/VNAV approach operations is considered a major failure condition (see Table 8). A baro-VNAV system providing vertical guidance during the final approach segment of an LNAV/VNAV approach operation must meet the design error and failure mode probability requirements that satisfy a major failure condition (see paragraph 12-2).

> **Note 1:** Baro-VNAV vertical guidance is independent from the lateral guidance. Loss of baro-VNAV guidance during an LNAV/VNAV approach results in a fail-down to LNAV or a missed approach. Therefore, loss of navigation for baro-VNAV is considered a minor failure condition.

> **Note 2:** Baro-VNAV systems certified before 11/20/1989 may have been certified to a lesser standard that is not consistent with a major failure condition. Operators of these aircraft should apply the final approach segment step-down fix to the LNAV/VNAV line of minima and should use the primary barometric altimeter to ensure meeting the step-down fix altitude constraint.

(1) Baro-VNAV TSE includes all errors (except horizontal coupling error and the effects of temperature) resulting from the vertical guidance equipment installation. This includes altimeter system errors.

(2) During the final approach segment only (i.e., from the final approach fix to the missed approach point) baro-VNAV TSE must also include horizontal coupling error.

> **Note:** GPS/SBAS Class 2 and Class 3 as well as GPS/GBAS vertical positioning performance exceeds the accuracy requirements of a barometric sensor used for final approach VNAV. The GPS/SBAS 50m Vertical Alert Limit (VAL) used for LNAV/VNAV is consistent with baro-VNAV and may also be used to comply with RNP approach.

c. Table 6 is a means to identify the degradation in altimeter performance as altitude increases. But Table 6 is not intended as an exact representation of expected performance characteristics with distinct steps. Instead, altimeter performance degradation is curvilinear as altitude increases. Therefore, to qualify a baro-VNAV system, the 99.7% aircraft altimetry system error for the aircraft (assuming International Standard Atmosphere temperature and lapse rates) must be less than or equal to the following:

$$ASE = -8.8 * 10^{-8} * H^2 + 6.5 * 10^{-3} * H + 50 \text{ (ft)}$$

where H is the true altitude of the aircraft.

Altitude Region (MSL)	Level Flight Segments	Flight Along Specified Vertical Profile
At or below 5000 ft.	150 ft.	160 ft.
5000 ft. to 10000 ft	200 ft.	210 ft.
10000 ft. to 29,000 ft	200 ft.	210 ft.
Above 29,000 ft to 41,000 ft	200 ft. (See Notes 1 and 2)	260 ft.

Table 6. Vertical Path Performance Limit for Baro-VNAV

Note 1: These requirements are based upon airborne altimetry and avionics systems that provide performance consistent with reduced vertical separation minimums (RVSM) requirements. Aircraft meeting RVSM requirements provide acceptable vertical total system error in level flight for the last row in table 6. No additional demonstration or compliance evaluation is required. However, the altimetry system error cannot be extrapolated to the other altitude blocks.

Note 2: For aircraft type designs prior to April 9, 1997, the value is 200 ft in the cruise flight envelope and is not to exceed 250 ft over the full aircraft operating envelope. Basic height-keeping parameters for 1000 ft. vertical separation minimum between flight levels 290 and 410 are in ICAO Document 9574, *Manual on Implementation of 1000 ft. Vertical Separation Minimum between FL 290-FL410 Inclusive*.

Note 3: Table 6 does not address altitudes above FL 410 because current altimetry and baro-VNAV systems are adequate for the 2,000 ft air traffic control vertical separation criteria.

d. Flight crew Inputs.

(1) The altitude associated with the active waypoint should be to the nearest 100 feet for enroute and terminal flight phases, and nearest 10 feet for the approach phase. If provided, waypoint horizontal position should be in increments not greater than 0.1 nautical miles.

(2) The ascent or decent angle should be to at least the nearest 0.1 degree for equipment that specifies gradient angles.

(3) The station elevation, if necessary for equipment employing slant range error correction, should be at least to the nearest 1,000 feet for enroute and terminal flight phases, and to the nearest 100 feet for the approach phase.

(4) For terminal and approach operations, the ability to enter the altitude associated with at least eight (for TO-FROM equipment) or nine (for TO-TO equipment) successive waypoints.

(5) A means to confirm input data correctness prior to the system using the new data.

e. System Displays.

(1) There should be a continuous display of vertical path deviation with the performance indicated in Table 7 below.

	Enroute/Terminal (feet)	**Approach (feet)**
Full-Scale Deflection (see note 1)	≤ 500	150 (see note 2)
Readability	≤ 100	≤ 30
Minimum Discernable Movement	≤ 10	≤ 5

Table 7. Vertical Path Deviations

Note 1: This is the minimum standard for vertical deviation display scaling and does not preclude using a scale of other than the values listed (e.g. large PFD display) provided that the scaling is suitable to control the aircraft on the intended path.

Note 2: Other values of full-scale deflection for approach may be acceptable provided the proposed value is found satisfactory by an engineering evaluation.

(2) The vertical guidance presentation should be compatible with the aircraft's flight instrumentation such that the pilot is continuously furnished the aircraft's vertical deviation with respect to the pre-programmed ascent/descent or level flight profile.

(3) Scale change for the final approach must be done in a manner that supports operational suitability for transitioning onto the final approach segment.

(4) Baro VNAV systems using angular vertical scaling must meet the following:

(a) The deviation scaling supports the FTE monitoring and bounding (75 ft deviation below path).

Note: This may require limiting the length of the approach to exclude operating where the angular deviations no longer support FTE monitoring and bounding.

(b) The deviation limits are equivalent to the operational limits for glideslope deviations during an ILS approach.

f. Alert Indications.

Alert indications for the system should be located on or near the vertical path deviation indicator and should provide a readily discernible annunciation to the pilot(s) for any of the following:

(1) Inadequate or invalid navigation signals or sources;

(2) Absence of primary power;

(3) Inadequate or invalid navigation displays or output sources; and

(4) Equipment failures.

Note: These failure/status indications must occur independently of any operator action. Power or navigation equipment failures may be indicated in a common manner. In the approach mode, the lack of adequate navigation signals or sources will be annunciated by means of a flag displayed on the primary vertical navigation display. In other modes, an appropriately located annunciator may be used.

g. Additional Constraints.

(1) The baro-VNAV equipment should indicate the aircraft vertical path position to the accuracy specified in paragraph 11-2.b within five seconds after any maneuvering or changes in attitude encountered in normal operations.

(2) The system should be capable of providing navigation guidance to the accuracy specified in paragraph 11-2.b within 20 seconds after input of the desired vertical track information (assuming sensor outputs are available).

(3) Navigation guidance should be available within five seconds of waypoint data input.

(4) The equipment should have the capability to meet the criteria outlined in paragraph 11-2 throughout the range of environmental conditions that will be encountered in actual service. Exposing the equipment to the environmental test conditions of TSO-C115b (or later revision) may be used to demonstrate this capability. The environmental test conditions contained in RTCA/DO-160F may be used to demonstrate this ability for baro-VNAV systems certified independent of a multi-sensor RNAV system.

> **Note:** Previously certified baro-VNAV systems may have used an earlier RTCA/DO-160 revision. This equipment may still be installed within the provisions of its original certification.

(5) The equipment should provide a means for the flight crew to determine system status prior to flight.

(6) The equipment should provide the navigation accuracy specified in paragraph 11-2.b for all groundspeeds up to a maximum value, and for all ascent (if applicable) and descent rates up to a maximum value to be set by the applicant.

(7) The equipment should provide a means to alert the flight crew prior to arrival at a waypoint for anticipating necessary vertical maneuvering. This indication should be located on or near the vertical path indicator. A procedural means based on a continuous and properly located distance to waypoint display may be used for vertical maneuver anticipation for baro-VNAV equipment that is not coupled to a FD or autopilot.

(a) Systems that provide steering signals for FDs or autopilots should provide automatic vertical maneuver anticipation and a waypoint alert that occurs prior to the initiation of the vertical maneuver. Systems that are coupled to the automatic guidance/control system(s) should not cause the aircraft to depart an assigned altitude until the impending altitude change is indicated to the crew within the pilot's primary field of view, then acknowledged by timely crew action unless the system is mechanized to the altitude selector in such a manner that a transition to descent or climb will not occur unless the altitude selector has been reset by the flight crew to the new altitude.

(b) Acceptance of the acknowledgment should not precede the indication if this acknowledgement is stored by the equipment. The acknowledgement timing of an impending vertical path change depends on operational procedures and aircraft/equipment design; however, past practice has shown that this acknowledgment should not occur more than five minutes prior to the impending vertical path change.

(8) If parallel offset track capability is provided, waypoint alerting and vertical maneuver anticipation should be provided prior to arrival at the point where the offset track intersects the angle bisector of the parent track. These functions should operate as described above in paragraph 11-2.d(7).

(9) The equipment should be capable of providing correct vertical path guidance when interfaced with lateral navigation equipment providing turn anticipation. The baro-VNAV equipment should recognize the angle bisector of the lateral track change as the "zero distance to waypoint" location.

h. The software should be verified and validated to at least level C as defined in RTCA/DO-178B or 'C' for baro-VNAV equipment that uses a digital computer.

Chapter 12. General Installation Considerations.

12-1. Introduction.

The following information applies to the installation of all positioning and navigation equipment intended for IFR use.

12-2. Failure Classification.

a. From enroute through Category I precision approach, the loss of navigation function 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). Other aircraft navigation systems should be considered when determining GNSS loss of navigation, which could be major (no other navigation systems) or minor (other applicable navigation systems). Navigation data is considered to be misleading when un-annunciated position errors exist. For enroute, terminal, LNAV, and LNAV/VNAV approaches, presenting misleading information to the flight crew is considered to be a major failure condition for the aircraft. For LP/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 Table 8.

	Advisory Vertical Guidance	Enroute/ Terminal Area/ Non-precision Approach (LNAV or RNP 0.3)	Non-precision Approach with Vertical Guidance (LNAV/VNAV)	LP/LPV Approach	GLS Approach
Loss of Navigation	No Effect	Major	Major	Major	Major
Misleading Information	Minor	Major	Major	Hazardous	Hazardous

Table 8. Typical Hazard Classifications

Note 1: For RNP values less than 0.3, losing RNP capability constitutes loss of navigation. Refer to appendix 2 for further RNP AR airworthiness information and AC 90-101 (latest revision) for complete guidance on RNP AR operations.

Note 2: Baro-VNAV vertical guidance is independent from the lateral guidance. Loss of baro-VNAV guidance during an LNAV/VNAV approach results in a fail-down to LNAV or missed approach. Therefore, loss of navigation for baro-VNAV is considered a minor failure condition.

b. The applicant must conduct a safety assessment of the positioning/navigation equipment installation to verify that design errors and failure modes meet the probability requirements for that failure class. AC 23.1309-1, AC 25.1309-1, AC 27-1, or AC 29-2, per the latest revision levels, provide an acceptable means for showing that the hardware complies with pertinent airworthiness requirements. See paragraph 15-2.a for GPS/SBAS and GPS/GBAS retrofit installation guidance related to navigation displays previously approved for ILS.

c. Any probable failure of the positioning/navigation equipment must not degrade or adversely affect the normal operation and performance of other required equipment or create a flight hazard. The interfaces with other aircraft equipment must be designed such that normal or abnormal positioning/navigation equipment operation must not adversely affect the operation of other equipment nor must operation of other equipment adversely affect the positioning/navigation equipment operation.

12-3. Software Considerations.

a. In December 2011, RTCA published RTCA/DO-178C, *Software Considerations in Airborne Systems and Equipment Certification*. AC 20-115C *Airborne Software Assurance*, defines an acceptable means of qualifying software and provides guidance for applicants with software qualified to previous RTCA/DO-178 revisions. Applicants may choose to use RTCA/DO-178C instead of RTCA/DO-178B provided they declare their intention to the applicable aircraft certification office for the project.

b. 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 determining software levels. Software certification is normally addressed during the design approval for positioning/navigation equipment, but should be confirmed at installation to ensure the certification level is appropriate for the installation intended function.

> **Note:** It may be possible to obtain approval for navigation functions that have hazardous level effects with FMS software developed to RTCA/DO-178B or 'C' level C criteria. AC 20-174, *Development of Civil Aircraft and Systems* provides an acceptable method for establishing design assurance levels. This guidance may be helpful for navigation architectures containing independent functions.

12-4. Hardware Considerations.

AC 20-152 (latest revision) *RTCA, Inc., Document RTCA/DO-254, Design Assurance Guidance for Airborne Electronic Hardware*, defines an acceptable means of qualifying complex electronic hardware devices. The applicant is encouraged to submit the Plan for Hardware Aspects of Certification (PHAC) early in the development process. Hardware certification is normally addressed during the design approval for positioning/navigation equipment; but, should be confirmed at installation to ensure the certification level is appropriate for the installation intended function.

12-5. Installed Equipment Compatibility.

There is no one, single, standardized interface for positioning and navigation equipment to other equipment on-board the aircraft such as displays, autopilots, terrain warning, etc. Positioning and navigation equipment manufacturer's installation manuals/instructions should define what other equipment is compatible with the positioning and navigation system. Equipment manufacturers are encouraged to develop compatible equipment lists and/or detailed interface requirements for their installation manuals/instructions. The installer must ensure that other on-board equipment interfaced with the positioning and navigation systems is compatible, and the airworthiness approval holder is ultimately responsible for defining the installation. But the installation burden is greatly eased when equipment manufacturers define compatible systems in their installation manual/instructions, including software version and/or part number if necessary.

12-6. Installation Instructions.

a. The equipment must be installed in accordance with the instructions and limitations provided by the positioning and navigation equipment manufacturer. The airworthiness approval will address any additional installation specifics.

b. Equipment should be installed with separation between wires of redundant equipment (see AC 43.13-1 latest revision). Wire separation will mitigate the possibility of loss of navigation due to a single event. During installation approval of the system, when wire separation cannot be achieved, the following questions must be evaluated and the potential for single event upsets minimized:

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

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

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

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

12-7. Equipment Capability and Installed Limitations.

a. Positioning and navigation avionics might have optional TSO functions that are not supported at the aircraft level after installation. The avionics must have the functions inhibited through configuration settings (e.g., strapping, software, etc.) or through database management processes if the aircraft is not qualified to perform those functions. The AFM(S)/RFM(S) must contain an appropriate entry for any limitations. An example to illustrate the point is avionics with the capability to perform RF legs. The installed avionics may have approved RF leg capability, but the aircraft lacks one or more necessary capabilities such as a roll-steering autopilot or displays able to depict RF legs. For this installation, the avionics would need to have the RF leg capability inhibited.

b. Airworthiness approval holders should include a comprehensive PBN statement of capabilities and qualification in the AFM(S)/RFM(S) describing the aircraft's PBN capabilities and operations limitations as an easy reference for flightcrews and authorities that grant operations approvals (see appendix 5 for an example). Doing so can greatly ease the process for operators that need operations approvals and enhance flightcrew awareness of the aircraft's PBN capability.

12-8. Final Approach Segment Step-Down Fixes in Navigation Databases.

a. In the U.S. when RNAV (GPS) approach procedures are produced or updated, the procedure designer names the final approach segment (between the final approach fix and missed approach point) step-down fixes applicable to the LNAV and LP lines of minima. But, some previously published RNAV (GPS) approach procedures still contain unnamed final approach segment step-down fixes, meaning there will be a mix of named and unnamed step-down fixes published with RNAV (GPS) approach procedures until all the procedures receive their periodic update. ARINC 424 specifications provide data elements for encoding both named and unnamed step-down fixes in a navigation database. Including final approach segment step-down fixes in the aircraft's onboard navigation database is entirely optional. However, the database must include all named waypoints that make up the instrument approach procedure except for final approach segment step-down fixes. Showing step-down fixes on a vertical profile display can enhance flight crew situation awareness, but can also complicate installation issues (see paragraphs 12-8.b through 12-8.d). Airworthiness approval applicants should contact their ACO early when seeking an approval for equipment with step-down fixes in the onboard navigation database.

> **Note 1:** Final approach segment step-down fixes are commonly used on U.S. RNAV (GPS) approach procedures to support an LP or LNAV line of minima.

> **Note 2:** Pilots are expected to use distance information to comply with step-down fixes when they are not included in the equipment database.

> **Note 3:** ARINC 424 is not specified by any positioning or navigation TSO. Nor is there any TSO requirement to include final approach segment or unnamed step-down fixes prior to the final approach fix in navigation databases for approach procedures.

b. Equipment manufacturers providing final approach segment step-down fixes in their onboard navigation databases for RNAV (GPS) approach procedures must either provide a method to remove them or provide an installation limitation for cockpit configurations that cannot properly support them (i.e., define the requirements in the installation instructions/manual). If removing final approach segment step-down fixes, manufacturers may choose to employ installation-specific configurations (i.e., software, strapping, etc.), or they may offer a navigation database solution (i.e. a database with final approach segment step-down fixes and a database without final approach segment step-down fixes).

c. Many U.S. RNAV (GPS) approach procedures include LNAV, LNAV/VNAV, and LPV lines of minima. However, a final approach segment step-down fix **does not apply to the LNAV/VNAV or LPV minima**. The airworthiness applicant must ensure the displayed RNAV(GPS) approach is in the primary field of view, in the proper sequence, unambiguous, and does not create detrimental clutter.

> **Note:** For LPV, some ICAO States may prohibit displaying step-down fix information from the onboard navigation database. Navigation system manufacturers should take this into consideration during their navigation system design and airworthiness applicants should consider this during equipment installation.

(1) The cockpit design and layout can greatly influence an airworthiness approval when it comes to displaying final approach segment step-down fixes. Integrating an RNAV (GPS) approach with LNAV/VNAV or LPV capability in an older cockpit design can be challenging when the onboard navigation database includes final approach segment step-down fixes due to limited display capability and little or no labeling flexibility.

(2) When installing equipment with final approach segment step-down fixes in the onboard navigation database, the display integration must:

- Be accessible and readable by all required flight crewmembers;
- Cleary depict and label the aircraft's track;
- Clearly label displayed waypoints, fixes and numeric information with sufficient detail to enable a pilot to discern a step-down fix from other fixes on a procedure; and,
- Clearly display distance/bearing/track to the landing threshold point/fictitious threshold point (LTP/FTP) during the final approach segment of an LPV approach.

(3) The suggested optimum implementation is showing final approach segment step-down fixes for LNAV and LP approaches, but not showing final approach segment step-down fixes during an LNAV/VNAV or LPV approach. When displaying distance/bearing/track to a step-down fix on the LPV final approach segment (i.e., after crossing the final approach fix), the equipment must also provide a readily available, clear, unambiguous indication of distance/bearing/track to the LTP/FTP. Due consideration should be given to the cockpit configuration and display capabilities during the airworthiness approval process. Additionally, equipment manufacturers must ensure final approach segment step-down fixes do not interfere with LPV path construction via the FAS datablock.

d. When using **any** advisory vertical guidance during an approach to LNAV or LP minimums, or when using GPS substitution on a conventional approach procedure, the flight crew must use the primary barometric altimeter to ensure compliance with any altitude restrictions. RNAV(GPS) procedure design criteria puts final approach segment step-down fixes on or below the VNAV path to provide an opportunity for a continuous descent final approach to the landing runway. However, for any approach other than LNAV/VNAV, LPV, or ILS there is no guarantee the VNAV path guidance will always clear the final approach segment step-down fix altitude restriction(s). Therefore, airworthiness applicants must include language for a limitation in the AFM(S)/RFM(S) (or equivalent documentation) requiring the flight crew to use the primary barometric altimeter to comply with a final approach segment step-down fix altitude restriction during an LNAV, LP, or non-ILS conventional approach. Equipment manufacturers should also include a limitation in the equipment operating instructions or flight crew operating manual.

Note 1: The intent of paragraph 12-8.d is to ensure the flight crew does not rely solely on the advisory VNAV guidance deviations for compliance with a step-down fix altitude restriction. The limitation must make it clear that it is unacceptable to follow VNAV path guidance below a step-down fix altitude restriction.

Note 2: Baro-VNAV systems certified before 11/20/1989 may have been certified to a lesser standard that is not consistent with a major failure condition. Operators of these aircraft should apply the final approach segment step-down fix to the LNAV/VNAV line of minima and should use the primary barometric altimeter to ensure meeting the step-down fix altitude constraint.

12-9. Magnetic Variation Data and Onboard Database.

a. Avionics typically convert true heading references to magnetic heading references by using worldwide magnetic variation data contained in an on-board magnetic variation database and a set of software algorithms. The algorithms convert the data into a specific magnetic heading reference for a specific geographic reference point. However, since the Earth’s magnetic fields constantly change, magnetic variation databases need periodic updates to provide accurate magnetic heading references. The National Oceanic and Atmospheric Administration (NOAA) offers the World Magnetic Model, available at http://www.ngdc.noaa.gov/geomag/geomag.shtml, and this product is an acceptable source for updating an aircraft magnetic variation database. NOAA updates the model on a five-year cycle, and magnetic variation databases should be re-assessed consistent with this cycle to make sure they continue to meet their stated performance.

Note: If the magnetic variation database is not kept current, the navigation systems no longer support their intended functions for use during flights conducted under IFR. Failure to maintain and update the magnetic variation database can result in presentation of misleading magnetic heading references that can place the aircraft outside the terrain and obstacle protection provided in instrument procedure and route designs.

b. Equipment design approval holders should identify any operating limitations in their equipment associated with application of the magnetic variation data (e.g., operations using magnetic heading references may only be valid between 82° north latitude and 82° south latitude) to ensure accurate magnetic heading references are presented and used in the aircraft. Since the earth's magnetic field is not static, equipment design approval holders should periodically re-evaluate their performance claims. Appropriate evaluation periods will depend on operating limitations, performance expected, and avionics intended function. The equipment design approval holders should also define a continuing airworthiness requirement to update the magnetic variation database and, if applicable, conversion algorithms or hardware when the periodic updates become available. This requirement should also define the maintenance procedures necessary to update the on-board magnetic variation database for their avionics.

12-10. Environmental Considerations.

a. Most equipment will have been tested by the equipment manufacturer to the environmental categories described in RTCA/DO-160 (applicable revision), with results described in an environmental qualification form. The airworthiness approval applicant must ensure the environmental categories (or criteria) to which the equipment has been tested are compatible with the aircraft environment in which the positioning and navigation equipment is installed. See AC 21-16F (or later revision) *RTCA Document DO-160 versions D, E, and F, Environmental Conditions and Test Procedures for Airborne Equipment*, for guidance on differences among RTCA/DO-160 versions D, E, and F.

b. For equipment that has not been tested to the environmental categories described in RTCA/DO-160 (applicable revision), either the equipment manufacturer or airworthiness applicant must thoroughly define the intended aircraft environment and conduct comparable normal and abnormal environment testing.

12-11. General Human Factors Considerations.

a. Control Accessibility.

(1) Controls installed for in-flight operation should be readily accessible from the flight crew'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) The equipment should be designed so that controls intended for use during flight cannot be operated in any position, combination, or sequence that would result in a condition detrimental to the operation of the aircraft or the reliability of the equipment.

(3) Controls should provide feedback (e.g., tactile, visual) when operated.

(4) Control operating force should be appropriate for its intended function.

Note: Low forces might provide insufficient feedback, while high forces might impede intentional rapid use.

(5) Controls should be resistant to inadvertent activation. Common and acceptable means of reducing the likelihood of inadvertent operation through design include the following:

(a) Placing fences between closely spaced adjacent controls.

(b) Concave upper surface of keys to reduce slippage.

(c) Size of control surface sufficient to provide for accurate selection.

(d) Placing guards over controls.

(e) Providing appropriate sensory feedback, or explicit confirmation of activation.

(6) The function for each control should be indicated, unless obvious. Pilots should be able to quickly and accurately determine the function of the control with minimal experience or training. If a control can be used for multiple functions, the current and inactive functions should be distinguishable.

(7) Controls/input devices should be organized according to the following principles, when feasible:

(a) Controls should be organized in logical groups according to function and frequency of use.

(b) Controls should be easily associated with the related elements (e.g., displays and labels) that identify their function. For example, line select function keys should align with adjacent text.

(c) Controls used most frequently should be the most accessible.

(d) Dedicated controls should be used for frequently used functions.

(e) Line select function keys should align with adjacent text.

(8) Use of two or more controls simultaneously (e.g., pushing two buttons at once) in flight should not be required to perform a function.

(9) Controls that do not require adjustment by the flight crew (e.g., maintenance functions) should not be readily accessible to the flight crew.

(10) Controls and their labels should be identifiable during all normally expected ambient light conditions, including direct sunlight and nighttime.

(11) Control identifiers and other information should not be obstructed by the control input devices.

b. Display Visibility.

(1) Each display element, used as a primary flight instrument in the guidance and control of the aircraft, should be located where it is clearly visible to the pilot with the least practicable deviation from the pilot's normal position and line of vision when looking forward along the flight path (i.e., within the primary optimum field of view).

> **Note 1:** CDI displays contained in the Control Display Unit (CDU) will most likely not be acceptable for IFR operations.
>
> **Note 2:** FTE can be reduced when numeric display information is integrated with the non-numeric display or is located within the pilot's primary field of view. Both digital cross-track and track angle error have been shown to reduce FTE. This information should be displayed together (either within the CDU or remotely displayed near the non-numeric display) for better tracking performance. Using non-numeric cross track data integrated with non-numeric track angle error data into one display may provide the optimum situation and control information for the best overall tracking performance.
>
> **Note 3:** The General Aviation Manufacturers Association with FAA collaboration published Publication Number 10 that has recommended guidelines for Part 23 cockpit/flight deck design. Applicants may apply these guidelines for their Part 23 installations. Additional guidance can be found in FAA Human Factors Design Guide. DOT/FAA/CT-96/1.

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

(3) Connection to external displays (CDI, horizontal situation indicator (HSI), moving map, annunciator panel, etc.) should be consistent with the equipment installation instructions.

(4) The horizontal (and vertical) deviation(s), display(s), and failure annunciations should be located within the pilot's primary field of view, as should any indication requiring immediate aircrew action.

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

c. Lighting Conditions.

(1) 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).

(2) Night lighting provisions must be compatible with other cockpit lighting, particularly if night vision goggle compatibility is desired.

12-12. Path Definition and Collocated Navigation Aids.

a. ICAO SARPS in Annex 10 permits definition of geographically separated VOR and DME conventional navigation facilities as “collocated” when terminal approach procedures use the facilities and the separation between the facilities’ antennas is no more than 260 feet (80 meters). For other operations, such as en route operations, the SARPS define the facilities as collocated when the separation between the VOR and DME antennas does not exceed 2,000 feet (600 meters). The U.S. identifies these collocated facilities as a “VOR/DME” or “VORTAC” (when the facilities include a tactical air navigation (TACAN) system), and the facilities will share a common 3-letter alphanumeric identifier. For example, despite the VOR and TACAN antennas being geographically separated by nearly 300 feet, the U.S. considers the Battle Ground VORTAC in Oregon a collocated facility with “BTG” as the three-letter identifier for both the VOR and TACAN.

b. RNAV and RNP routes and terminal procedures, including RNP approach procedures, may use a collocated conventional navigation aid, such as a VOR/DME or a VORTAC, as a waypoint in their path definition. When this occurs, the navigation system must use the location the State provides in the route or terminal procedure path definition for the waypoint’s location in the onboard navigation database. This will ensure the navigation system provides the correct path definition for the aircraft. Failure to use the procedural definition for the waypoint can create misleading guidance for the flight crew.

c. Some multi-sensor navigation systems also use DME facilities as aids in creating a filtered position solution for both RNAV and RNP operations. Other navigation systems use DME-DME positioning when GNSS is lost or unavailable. When using DME facilities to create a position solution for an RNAV or RNP route or procedure, and the route or procedure uses a collocated navigation aid as a waypoint, the navigation system must not use the DME’s latitude/longitude as the default position of the collocated navigation aid. The onboard navigation database definition for the waypoint and the navigation system’s path definition must both match the State’s route or procedure definition.

d. FAA AC 90-108 (latest revision), *Use of Suitable Area Navigation (RNAV) Systems on Conventional Routes and Procedures,* permits flight crews to use some RNAV systems to overfly routes and terminal procedures defined by conventional navigation aids. The AC also permits some RNAV systems to substitute for a conventional navigation aid when the facility is out-of-service. When the RNAV system overflies a conventional route or procedure, or when the RNAV system substitutes an RNAV position solution for the location of an out-of-service conventional navigation facility, the path definition the RNAV system uses and extracts from the onboard navigation database must match the State’s definition of the conventional route or procedure. For example, when a collocated VOR/DME facility is part of a conventional route or procedure, and the procedural path definition overflies the collocated facility, the RNAV system must use the VOR's location (i.e. the VOR's latitude and longitude) in the path definition.

12-13. Runway Position Monitoring.

RTCA/DO-283B, implemented by TSO-C115d, has an option for including a runway position monitoring function in section 2.2.1.4.14. If this option has not been implemented within the FMS installed on transport category airplanes, the FAA recommends implementing the function on the airplane through another on-board system or combination of systems. The intent is to provide a function that detects a discrepancy between the aircraft position/orientation and the runway entered into the positioning/navigation system for departure. When the discrepancy is detected an alert must be annunciated to the flight crew.

Chapter 13. General Installation Considerations - Antennas.

13-1. Antenna Placement.

13-1.1 GNSS-Specific Considerations.

a. Typically, a GNSS antenna is located forward or aft of the wings on the top of the fuselage. GNSS antennas must be installed to provide the widest, unobstructed field of view to the satellites. The antenna installation instructions should provide information on how to determine a location that minimizes the potential for signal blockage by any portion of the aircraft. Consideration should be given to the following items when choosing an antenna location on the aircraft.

(1) The GNSS antenna placement on the airframe should be optimized to ensure the receiver can take full advantage of a 5 degree mask angle (or lower if the receiver installation instructions identify the equipment is certified to a lower mask angle).

(2) Shadowing by aircraft structure (and in some cases by rotorcraft blades) can adversely affect the operation of the GNSS equipment. Antenna location should minimize blockage from airframe components, airframe structures, engine components, or other antennas with the aircraft at typical level cruising attitude.

(3) The antenna should also be located to minimize the effects of aircraft shadowing during typical maneuvers.

(4) Avoid locations that could subject the antenna to engine exhaust contamination.

(5) Antenna shadowing and engine exhaust can present unique problems on rotorcraft. One possible ground-based method to aid in selecting an optimum location is to temporarily attach the antenna at various places and compare the signal strength. If using this method, it is important to perform the check with the rotors turning since they can be a source of shadowing. But, this method does not remove the need to do functional flight checks to ensure the antenna location is suitable (see paragraphs 13-1.1.c and 13-1.2.a).

(6) It is desirable to minimize the cable length between the antenna and receiver to reduce signal loss. In general, a shorter cable length improves signal strength to the GNSS receiver.

(7) Attempt to place the antenna on the aircraft's centerline (i.e., symmetrically on the airframe). This is particularly important on metal aircraft as symmetry can potentially affect antenna gain patterns.

b. 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 RTCA/DO-253C, paragraph 2.2.9.1.

c. The GNSS multi-path error model specified in RTCA/DO-229D and RTCA/DO-253C was developed and validated using flight test data collected on a variety of large, fixed-wing aircraft. Further validation was done using computer modeling of large, fixed-wing aircraft. For installations on rotorcraft, antenna location should consider the compatibility of the resulting multi-path errors with this model. This may require additional equipment functional flight evaluation or analytical evaluation to confirm the antenna location is suitable.

13-1.2 General Considerations.

a. In general, the effects of the rotor blades on antenna performance should be considered for any antenna installations on rotorcraft. This may require additional equipment functional flight evaluation or analytical evaluation to confirm the antenna location is suitable.

b. For multiple-sensor installations, the installer should reduce the likelihood that a single lightning strike affects all the sensors (i.e., do not place them in a straight line from the front to the rear of the fuselage).

13-2. 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 possibly ingesting accumulated ice into the engine or degradation in aerodynamic performance. The effects of ice accumulation on the antenna, if any, can be found in the equipment manufacturer's installation instructions/ manual. See the latest revisions of ACs 23.1419-2 and AC 25.1419-1 for additional fixed-wing aircraft guidance. For additional rotorcraft guidance, AC 27.1419 is contained in the latest revision of AC 27-1 and AC 29.1419 is contained in the latest revision of AC 29-2.

13-3. Antenna Cables.

Double shielded cables should be used to prevent interference coupling into the cable. GNSS equipment manufacturers should indicate the type of cable to use in their installation instructions/manual to minimize insertion losses that could result in reduced performance. GNSS installations should use the equipment manufacturer-specified cable. However, if the equipment manufacturer did not specify a particular cable, the installation should use high quality coax and connectors because of the high frequency signals and sensitivity to cable losses.

13-4. Structure.

Any modifications to the aircraft to install a new antenna need to be evaluated as part of the airworthiness approval for their impact on aircraft structure. Examples are evaluating and testing antenna installations for buffet and vibration (compliance with 14 CFR part XX.251), or when modifying pressurized structures (compliance with 14 CFR part XX.841 and XX.843). For specific guidance relating to modifications in the fuselage structure, see AC 43.13-2 (latest revision). Additional guidance information related to structures can be found in the latest revisions of ACs 20-107, 23-13, and 25.1529-1.

13-5. Additional Guidance.

Further information on antenna installation considerations, and good avionics installation practices in general, can be found in AC 43.13-1 (latest revision), *Acceptable Methods, Techniques and Practices – Aircraft Inspection and Repair* and AC 43.13-2 (latest revision), *Acceptable Methods, Techniques and Practices – Aircraft Alterations*.

Chapter 14. General Installation Considerations - Sensors.

14-1. Introduction.

This chapter provides guidance related to positioning/navigation sensor installation. This chapter also applies to stand-alone navigation equipment installation, since that equipment has an embedded sensor. This guidance applies to all installations, but is only expected to be specifically evaluated as part of the initial airworthiness approval (i.e., initial airworthiness approval may provide sufficient substantiation for follow-on installations).

14-2. Positioning and Navigation Configuration Strapping.

Often, positioning and navigation equipment uses software configuration straps or installation set parameters entered either manually by the installer or by using an aircraft personality module. These software configuration straps or parameters disable/enable functionality; configure the input/output formats; determine the displayed units of measure; etc. The software configuration programming documentation must become a part of the installation package and should be included in the master drawing list. When using an STC-AML (see paragraph 2-3), approved multiple configurations may be specified.

14-3. Navigation Source Selection.

a. For installations where positioning and navigation outputs can drive a display that is shared with other navigation equipment (e.g., VOR/DME, ILS, GPS/SBAS, baro-VNAV), the pilot must be able to select the source of guidance, and the selected source must be clearly annunciated to the flight crew on or near the affected display.

b. There are many possible navigation source and service level combinations and permutations given the variety of sensors and capabilities that can be integrated into the aircraft. Some of the capabilities are very similar, but have subtle differences that are very significant. The aircrew must have a clear, unambiguous annunciation of what capability is being provided by the navigation system. This can either be accomplished by multiple annunciation indicators, or by removing some navigation capabilities when others are added to reduce the annunciator complexity.

c. GNSS-based navigation (GPS, GPS/SBAS, GPS/GBAS) might not require differentiation unless integration complexity requires it for clear, unambiguous indication of selected capability to the flight crew. For example, oceanic, enroute, or terminal RNAV modes or LNAV-only approach capability may not require differentiation.

d. When applicable, annunciation of the selected source should be driven by the same relay switch to preclude erroneous information in case of switch failure.

e. Autopilot navigation modes related to the navigation source should be inhibited if the displayed source is not the same as the source driving the autopilot. This is particularly critical for approach operations (i.e., autopilot in approach mode). One possible method is to consider integrations that do not permit separate display source and autopilot source navigation selection.

f. Navigation source annunciations included in the optimum primary field of view do not also have to be shown on a heads-up display.

14-4. Dual Positioning and Navigation Installations.

a. Paragraph 14-4 describes guidelines for synchronizing dual positioning and navigation equipment installations. Synchronization refers to the ability for control inputs to one positioning and navigation equipment set to automatically update the other equipment set. 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 functional hazard assessment requires dual positioning and navigation equipment or is operationally required, then synchronization is required.

b. If the navigation equipment is not synchronized, then the following issues should be evaluated:

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

(2) The pilot workload associated with manually updating both equipment sets to maintain consistency between the equipment sets.

(3) There should be no possible confusion as to which equipment is driving the autopilot and navigation displays.

(4) Controls, displays and annunciations must not result in misleading information, pilot confusion or unacceptable workload due to possible inconsistencies from differences in the equipment (e.g., different flight plans making one unit go into approach mode while the other does not). Evaluations for these types of inconsistencies are of particular concern when the cockpit architecture enables cross coupling (e.g., GNSS-2 switched to drive side 1 displays).

14-5. Intermixing RNAV equipment.

a. Where multiple RNAV systems are intended to be used simultaneously (typically in two-pilot aircraft), installing area navigation equipment with different crew interfaces can be very confusing and could 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.

b. At a minimum, consideration should be given to the following potential incompatibilities, particularly when the cockpit architecture allows for cross coupling (e.g., RNAV-2 switched to drive side 1 displays):

(1) Data entry.

The two units must have consistent methods of data entry and similar pilot procedures for accomplishing common tasks. Workload should be acceptable, and it should be easy for pilots to identify and recover from data entry mistakes.

(2) CDI scaling.

CDI scaling sensitivity must be consistent across different equipment or labeled.

(3) Display symbology and mode annunciations.

There must be no conflicting symbols or annunciations (e.g., a common symbol used for two different purposes), and differences should be specifically highlighted during the evaluation for any potential confusion they may cause.

(4) Mode logic.

The modes internal to the equipment and interfaced to the rest of the aircraft should be consistent across RNAV units.

(5) Equipment failure.

The effect of failure of one RNAV unit must not result in misleading information or failures in the other unit.

(6) Displayed data.

The display of primary navigation parameters must use consistent units and a consistent notation across multiple RNAV units. Industry standard labels and nomenclature should be used.

(7) Database differences.

Intermixed RNAV units must use the same navigation database to prevent conflicting information among the equipment.

14-6. Interface to FGS.

a. Paragraph 14-6 describes guidelines for interfacing the positioning and navigation equipment with a FGS. When used in paragraph 14-6, the word “consistent” means the installation does not alter the positioning and navigation equipment’s intended function, nor does it alter the cockpit design philosophy.

b. Connection to the autopilot must be consistent with the autopilot installation instructions and the positioning and navigation installation instructions. The positioning and navigation system manufacturer should provide instructions on connection with specific autopilots to which they have shown compatibility. Interfacing digital positioning and navigation systems with an analog FGS (for example, autopilots) may present potential hazards and is not recommended. However, applicants that desire to integrate these systems in legacy aircraft will need to perform a thorough engineering evaluation to ensure compatibility. The AFM(S)/RFM(S) must reflect any limitations resulting from the installation.

c. Operational compatibility should be verified between the positioning and navigation equipment and the FGS. Protection should exist in the positioning and navigation equipment or the FGS to keep the aircraft within the approved operational envelope (e.g., roll, pitch, speed, and altitude). See the relevant guidelines for the particular aircraft (e.g., the latest revision of AC 23-17, AC 25.1329-1, AC 27.1329 contained in AC 27-1, and AC 29.1329 contained in AC 29-2).

d. A continuous and unambiguous indication must be provided of the FGS modes actually in operation, as well as those that are armed or enabled. This includes a clear indication whenever the mode has been armed either manually by the flight crew, or automatically by the system.

e. The positioning and navigation equipment must be compatible with the FGS modes of operation. For example, the arm, engage, and disengage sequence of the positioning and navigation equipment should be consistent in the annunciation and engage/disengage timing of the FGS. This is particularly important during GPS/SBAS-augmented GNSS approaches that include different levels of service.

f. If the positioning and navigation equipment is connected to a reduced bank selector, the equipment bank angle, like the FGS, must not be limited by this switch selection during approach. Consistency in the operation must be maintained.

g. 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 positioning and navigation equipment can automatically sequence waypoints and initiate turn maneuvers that may or may not have the pilot’s attention. If buffet protection is not automatically provided in the positioning and navigation equipment or FGS (e.g., bank angle limiting, or cruise altitude limiting based upon buffet margin), an AFMS/RFMS limitation should be added to the performance section, prohibiting cruise operation at weight/altitude combinations that result in buffet margins less than 1.4g.

h. For those aircraft that have incorporated bank angle limiting, consideration should be given to whether the positioning and navigation equipment is defining a path that cannot be flown or does not conform to the published procedure.

i. If the aircraft includes a synthetic vision system (SVS) or enhanced vision system (EVS) displaying flight guidance, the positioning and navigation output to the SVS or EVS function should meet the appropriate system performance criteria in this AC. The latest revision of AC 20-167, *Airworthiness Approval of Enhanced Vision System, Synthetic Vision System, Combined Vision System, and Enhanced Flight Vision System Equipment* provides additional guidance for these systems.

14-7. Interface to Magnetic/True Switch.

If a magnetic/true heading reference switch is installed in the aircraft, the positioning and navigation equipment should be driven by the same switch to maintain consistency in the displays and operation for both manual and automatic heading reference changes. Magnetic heading is the primary heading reference.

> **Note:** Magnetic heading is the primary heading reference in the U.S. However, aviation authorities in other countries do use true heading as the primary heading reference in areas of extreme latitude.

14-8. Interface to Air Data and Inertial Reference Systems.

a. 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 positioning and navigation equipment. This becomes important for GNSS barometric-aided FDE since erroneous altitude inputs to the FDE algorithm could lead to improper satellite FDE.

b. If there is an inertial source select switch, when the pilot de-selects an inertial source, the de-selected source must no longer be used by the positioning and navigation equipment.

c. If the positioning and navigation equipment requires barometric corrected (or pressure) altitude data for certain operations (identified in the equipment manufacturer's installation manual/instructions), the installation should provide an automatic altitude input from the air data system to the positioning and navigation equipment such that additional pilot actions are not required.

d. If barometric corrected altitude is required by the positioning and navigation equipment and 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 equipment. If the equipment requires multiple entries to enter the correction, the workload should be evaluated during an approach.

14-9. Antenna/Sensor Compatibility.

a. Using the guidelines in the equipment manufacturer's installation manual/instructions, verify the antenna installation is compatible with the positioning and navigation equipment. This may be accomplished by one of the following:

(1) The antenna (part number) is identified in the positioning/navigation equipment manufacturer's installation manual/instructions as compatible.

(2) The positioning/navigation equipment manufacturer's installation manual/instructions state that the equipment is compatible with an appropriate antenna that has a TSOA/LODA (refer to Table 2 for GNSS antennas). Compare the RTCA/DO-160 (appropriate revision) category for lightning-induced transients specified in the antenna

installation instructions with the category defined in the receiver installation instructions. Also, for active GNSS antennas, a signal power budget must be defined that takes the output power at the low-noise amplifier (pre-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).

b. Use the guidelines in the equipment manufacturer's installation manual/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.

c. Ensure antenna and positioning/navigation equipment compatibility for aircraft equipped with SATCOM. Some equipment may have been qualified to less stringent interference levels intended for aircraft installations without SATCOM.

14-10. Interference - Electromagnetic Compatibility (EMC).

a. 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.

b. Proper sensor equipment grounding is essential to ensuring EMC.

c. When possible, do not install positioning/navigation sensor(s) near a VHF radio.

d. The following paragraphs identify potential sources of interference and means of mitigating that interference:

(1) VHF communications harmonic, spurious, and local oscillator harmonics can cause interference. VHF 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, or the installed VHF transceiver performance will have to be re-evaluated.

(b) Installing the positioning/navigation equipment as far away as feasible from any VHF transmitter equipment (to prevent case-to-case interference).

(c) Replacing the VHF equipment.

(2) An emergency locator transmitter (ELT) can re-radiate DME or VHF signals that can interfere with GNSS. Notch filters on the ELT antenna cable or replacing the ELT can eliminate this problem.

(3) DME has been known to cause interference to GNSS. Replacing the DME transceiver can eliminate the problem for some equipment.

(4) Direction finding equipment may cause interference. Moving the direction finding antenna to the belly of the aircraft has been found to eliminate this problem.

14-11. Interface Requirements.

a. Ensure sensor compatibility for aircraft systems using the position output (e.g., FMS, automatic dependent surveillance system, etc.). Systems should use the same bus standard (e.g., ARINC 429 with ARINC 743 data, RS-232 as applicable).

b. Operation of the positioning/navigation equipment must not adversely affect the performance of, or interfere with, other installed aircraft equipment.

c. Some applications will require the positioning/navigation sensors to provide a position output at a 5 Hz rate. However, sensors with a 1 Hz rate augmented by inertial aiding can be considered for use in applications requiring 5 Hz output.

d. Positioning/navigation equipment (particularly installations that use GNSS sensors) may provide output to a variety of applications, including TAWS/HTAWS, automatic dependent surveillance, and moving map displays. Output of navigation position, velocity and time must support the intended function for which it is used under any foreseeable operating condition. It is important to note for ground based navigation aids that the airworthiness approval alone does not guarantee performance since it is dependent upon the operational environment. This is significant when interfacing the positioning and navigation equipment to systems dependent upon the navigation accuracy and integrity statements.

e. The guidance material in this AC for sensors applies to all of these interfaces, and should be used in conjunction with the guidance material for the application. For specific information relating to:

(1) TAWS equipment, see TSO-C151(latest revision) and the latest revisions of AC 23-18, and AC 25-23.

(2) HTAWS equipment, see TSO-C194(latest revision) and Miscellaneous Guidance 18 in the latest revisions of AC 27-1 and AC 29-2.

(3) Electronic map displays, see TSO-C165(latest revision) and the latest revisions of AC 20-159, AC 23.1311-1, and AC 25-11.

(4) ADS-B equipment, see TSO-C166b, RTCA/DO-260B for 1090 Extended Squitter; and, TSO-C154c and RTCA/DO-282B for Universal Access Transceiver. AC 20-165 provides guidance information on ADS-B.

Chapter 15. Installation Considerations - GNSS.

15-1. Introduction.

a. GNSS equipment is particularly susceptible to out-of-band SATCOM emissions and in-band inter-modulation between multiple channel SATCOM installations. 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; this should be noted in the equipment manufacturer's installation manual/instructions.

b. In addition, improperly used or installed GNSS re-radiators can present misleading information to GNSS equipment. Equipment manufacturers may provide mitigation against the use of erroneous data for GNSS position and navigation solutions. Possible measures include: implementing or enabling cross-checks of GNSS sensor data against independent position sources and/or other detection monitors using GNSS signal metrics or data. It is incumbent upon airworthiness approval applicants to determine the method chosen by the equipment manufacturer and its adequacy for the aircraft integration.

15-2. Navigation Displays.

a. Navigation Display(s) for Retrofit Installations.

This guidance reflects the AC 20-138A clarification policy memorandum signed on July 30, 2007 and replaces that memorandum.

(1) Table 8 in paragraph 12-2.a classifies misleading information during GNSS CAT I and LP/LPV approaches as a hazardous failure condition; and paragraph 12-2.b states applicants must conduct a safety assessment of the installation to verify that design errors and failure modes meet the probability requirements for that failure class. The guidance in paragraph 15-2.a only applies when installing retrofit GPS/SBAS LP/LPV or GPS/GBAS CAT I GNSS landing system capability in aircraft that have a previously certified horizontal/vertical course deviation indicator(s) or an electronic display (or displays) approved for ILS approaches. The intent is to apply this guidance when introducing GPS/SBAS LP/LPV or GPS/GBAS GLS capability into aircraft equipped with ILS course deviation indicator(s) or display(s) that were approved (TSOA/LODA, STC/PMA or type approval (TC/amended TC)) on or before July 30, 2007.

(2) Applicants may use the existing display(s) or course deviation indicator(s) for GPS/SBAS LP/LPV or GPS/GBAS GLS course deviations and annunciation data when adding GPS/SBAS LP/LPV or GPS/GBAS GLS capability into existing approved aircraft type designs, either by retrofit (STC, Form 337) or forward fit in the factory (amended TC), that were previously approved with ILS. It is not necessary to demonstrate compliance with the end-to-end design assurance levels of a 'hazardous' failure condition for the mechanical or electronic course deviation displays. Using the same path and device that was previously used to display ILS data for displaying GPS/SBAS LP/LPV or GPS/GBAS GLS data yields an equivalent level of safety to the original ILS certification basis. This equivalency provides

relief from paragraphs 12-2.a, 12-2.b, and data submittal requirements related to a 'hazardous' failure condition during LP/LPV or GLS approaches for the existing display(s) or course deviation indicator(s).

(3) This guidance may be applied to aircraft equipped with a single or dual horizontal/vertical course deviation indicator, or electronic display(s) with level C software. However, this guidance cannot be applied to the equipment that computes and outputs the GPS/SBAS LP/LPV or GPS/GBAS GLS deviation data, as GPS/SBAS and GPS/GBAS do not have the same failure modes as ILS in generating the deviations. The installation is considered 'not significant' with respect to 14 CFR 21.101 when installing GPS/SBAS LP/LPV or GPS/GBAS GLS capability per this guidance.

b. Displays used for waypoint sequencing, start of a turn, turn anticipation, active waypoint, distance to active waypoint, desired track and actual track (track angle error), and automatic mode switching should be located within the pilot's primary field of view, or on a readily accessible display page.

(1) Displays used for loss of integrity monitoring, TO/FROM indication, and approach mode annunciation should be located within the pilot's primary field of view.

(2) Traditionally, 14 CFR part 23 airplanes with "classic" analog instrumentation in the "basic T" arrangement have included the center radio stack within the allowable field of view to satisfy this guidance. There is no intent for this AC to change that long-standing guidance.

> **Note:** Primary field of view is being incorporated as a standardized term across all documents. The primary field of view definition should be broad enough to include the center radio stack on 14 CFR part 23 airplanes with "classic", basic 'T' instrumentation.

c. For some "stand-alone" equipment, the display can be remote from the navigation computer and GNSS sensor. These displays must be compatible with expected outputs from the navigation computer to provide the proper deviation indications to the pilot. Both GNSS and display manufacturers are encouraged to provide a list of compatible GNSS/display equipment, as appropriate, in their installation manuals as this has been shown to greatly aid installation approvals. The installation instructions approved as part of the STC or the installation manual approved by the TSOA for GNSS equipment and displays should provide appropriate equipment compatibility lists and/or compatibility standards. Additional combinations can be established later through a simple amendment to the STC installation instructions or TSOA installation manual.

> **Note:** In addition to or instead of compatibility lists, equipment manufacturers may decide to provide detailed compatibility standards information on their equipment's interface characteristics.

15-3. Failure Indications.

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

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

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

d. A unique annunciation of the loss of integrity monitoring should be provided. Consideration may be given to the aircraft's overall cockpit alerting philosophy to reduce the number of independent indicators.

> **Note:** Paragraph 15-3.d does not apply to GPS/SBAS Class Delta-4 LPV operations because this equipment only functions during the final approach segment (or its extension) where loss of integrity monitoring is defined as a loss of navigation. A normal loss of navigation indication is sufficient.

15-4. Documenting Effects of GNSS Outage.

a. GNSS outages are a normal operating condition in areas with routine interference testing, and can occur anywhere in the NAS due to unintentional interference. The aircraft-level effect from losing GNSS positioning, velocity, and timing is a complex problem that depends on the GNSS equipment design, the degree of integration with other systems, and where the installations take place. GNSS outputs are being integrated into a variety of functions beyond traditional navigation data. For example, GNSS PVT is being used for TAWS/HTAWS, synthetic vision systems, ADS-B, and micro-electro-mechanical system (MEMS) accelerometers/sensors in air data attitude heading reference system (ADAHRS) inputs to electronic primary flight displays. There are a wide range of integrations from legacy aircraft with self-contained GNSS navigation units and a simple autopilot interface to new production aircraft with digital cockpits using integrated modular avionics providing the advanced functions mentioned above and more (including potential GNSS time applications).

b. TC and STC applicants must document, in the AFM(S)/RFM(S) normal section, the aircraft-level effects if GNSS PVT is not available or the outputs are disrupted. The AFM(S)/RFM(S) must describe the effects on any affected system from losing GNSS outputs; the indications that should be expected if GNSS outputs are disrupted; and the flight crew or pilot procedures. TC and STC applicants should not use GNSS for both primary and back-up critical systems that would result in a single point of failure due to a GNSS outage. Additionally, installers should be alert for equipment upgrade combinations that may result in GNSS as a single point of failure.

c. TSOA applicants must include, in their required operating guide, a description of the effects of GNSS outage on the functions in the article. The installation instructions must include a description of the GNSS outage effects on the outputs from the article so the installer can evaluate the effects at the aircraft level.

15-5. Installed Performance Capability.

a. It is essential that procedures or optional functions an aircraft is not capable of performing are either removed from the GNSS equipment database, or otherwise inhibited, even if the avionics do support the function (RNP AR procedures or procedures with RF legs for example). The AFM(S)/RFM(S) must contain an appropriate entry for any limitations (see paragraph 12-7 and 12-8).

b. Helicopter-specific RNAV(GPS) approach procedures to LNAV, LNAV/VNAV, LP, or LPV minima can have unique characteristics. For the most part, helicopter-specific RNAV(GPS) procedures that contain unique features are published as Special Instrument Approach Procedures. Examples of unique criteria are: steep descent gradients, speed restrictions, and turns at the FAF greater than allowed in public approach procedures. The GNSS equipment standards generally support the TERPs criteria for helicopter-specific RNAV(GPS) procedures, but that does not ensure installed performance. It is incumbent upon the airworthiness approval applicant to demonstrate the rotorcraft GNSS integration is capable of meeting the desired performance for the intended function, or provide appropriate RFM(S) limitations. Particular attention should be directed toward the autopilot integration and whether or not the autopilot, coupled to all flight axes, is able to support the intended function.

c. Data Quality Requirements (DQRs) for installed databases are normally addressed at the equipment design level. The DQRs applicable to the intended function must be confirmed at the aircraft level during airworthiness approval. A Type 2 LOA may be used to ensure the database requirements, including tool qualification, is appropriate for the intended function of the installed equipment. A Type 2 LOA also provides evidence the data quality characteristics are described and valid for the compatible equipment listed on the LOA (see paragraph 19-8).

15-6. GPS Equipment.

a. GPS equipment only uses a RAIM algorithm to provide integrity and has reduced availability of an integrity-assured position solution at the minimum, guaranteed satellite constellation configuration compared to equipment using GPS/SBAS or GPS/GBAS augmentation.

b. When installing GPS equipment that uses RAIM for integrity during instrument meteorological conditions (IMC), there must be a performance limitation in the installation manual (or equivalent installation documentation) for inclusion as a limitation in the AFM(S)/RFM(S). The limitation is to have other navigation equipment available appropriate to the operation.

c. There must also be a flight planning performance limitation in the installation instructions (or equivalent installation documentation) for inclusion as a limitation in the AFMS/RFMS. This limitation must indicate the equipment has a performance limitation necessitating an alternate airport flight planning operational mitigation (see appendix 5 for an example). The Aeronautical Information Manual provides some operational flexibility regarding the flight planning operational mitigation for equipment that has FDE capability. Refer to paragraphs 1-1-17b.5 and 1-2-3d in the Aeronautical Information Manual for specific operational guidance.

d. The limitation language can provide further reference to the Aeronautical Information Manual for additional information.

> **Note 1:** See appendix 1 for methods to remove the limitation for other navigation equipment in oceanic and remote areas.

> **Note 2:** The performance limitations in paragraphs 15-6.b and 15-6.c do not have to use the specific language above or the example in appendix 5. The intent is to indicate the equipment has a performance limitation and adequately capture that limitation in the AFM(S)/RFM(S).

15-7. GPS/SBAS Equipment.

This paragraph provides guidance related to the installation of GPS/SBAS equipment supporting LP/LPV approaches. This guidance applies to all installations, but is only expected to be specifically evaluated as part of the initial airworthiness approval (i.e., initial airworthiness approval may provide sufficient substantiation for follow-on installations).

15-7.1 Limitations.

a. When installing equipment that uses GPS/SBAS for integrity during instrument meteorological conditions, there must be a performance limitation in the installation instructions (or equivalent installation documentation) for inclusion as a limitation in the AFMS/RFMS. This limitation must indicate the equipment has a performance limitation necessitating an alternate airport flight planning operational mitigation (see appendix 5 for an example). The Aeronautical Information Manual provides some operational flexibility regarding the flight planning operational mitigation for operators that also have baro-VNAV capability. Refer to paragraphs 1-1-18c.9 and 5-4-5m.7(h) in the Aeronautical Information Manual for specific operational guidance.

> **Note:** The performance limitation in 15-7.1a does not have to use the specific language above or the example in appendix 5. The intent is to indicate the equipment has a performance limitation and adequately capture that limitation in the AFMS/RFMS.

b. The limitation above can provide further reference to the Aeronautical Information Manual for additional information.

15-7.2 LP Approach.

a. It is not acceptable to install TSO-C145a/C146a equipment that hasn't been certified with LP capability in such a way as to make the equipment perform LP approaches. To do so is forcing the equipment to perform an unintended, non-certified function that is a violation of the original certification basis.

b. TSO-C145a/C146a equipment manufacturers may provide LP capability through software changes. The guidance above in paragraph 15-7.2a is not intended for equipment updated by the manufacturer.

c. GPS/SBAS installations of Class 3 or Class 4 equipment that complies with TSO revision 'b' or later with a deviation to not include LP capability must have an appropriate limitation included in the AFM(S)/RFM(S).

d. There are no unique LP flight testing requirements for airworthiness applicants that have performed LPV flight testing. LP uses the same signal and horizontal performance capability that GPS/SBAS provides during LPV. Airworthiness applicants with LPV data may use similarity or analysis as the basis for approving LP capability on the aircraft. The only installation considerations are that LP is clearly and unambiguously annunciated, and the FGS is able to accept horizontal-only approach guidance inputs (see paragraph 21-2.2.f).

> **Note:** An LP approach is somewhat analogous to a localizer-only approach in that localizer-only uses the horizontal ILS component to provide horizontal guidance. However, LP and Localizer are not operationally similar because LP is not published on the same approach chart as LPV.

15-7.3 Update Rate.

For sensors and stand-alone equipment that support an LP/LPV approach capability (Class 3 equipment of TSO-C145(AR), Class 3 and 4 equipment of TSO-C146(AR)), the position used for the approach should be computed and output at a minimum 5 Hz rate per the requirements in RTCA/DO-229D, Change 1. If the equipment provides a 1 Hz output, the installation must use inertial aiding or some other equivalent method to obtain deviations at a minimum 5 Hz rate.

15-7.4 Performance Monitoring.

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

a. Unambiguous indication of the intended path for the approach (e.g., LP/LPV approach type, approach identifier, active waypoint); and

b. Unambiguous indication of the position of the aircraft with respect to the intended path (e.g., cross track and vertical deviation information).

15-7.5 System Status.

The flight crew must have a means to evaluate the aircraft equipment's capability to accomplish the approach operation. The flight crew must be advised of failed aircraft systems or equipment affecting the decision to continue to the destination or divert to an alternate.

> **Note:** System status considerations also apply to IFR departure operations such as standard instrument departures. The flight crew must be advised of failed aircraft systems or equipment affecting the decision to depart.

15-7.6 Annunciations.

a. For installations containing more than one approach navigation source, the navigation source (for example, ILS, GPS/SBAS, baro-VNAV, etc.) selected for the approach must be positively indicated in the primary field of view. Consideration should be given to the overall aircraft-level annunciation philosophy.

> **Note:** Aircraft requiring two pilots must have this annunciation at each pilot station.

b. The approach type (LP/LPV, LNAV/VNAV, LNAV) must be clearly annunciated to the pilot prior to and throughout the entire approach in the primary field of view.

(1) It is acceptable for a primary flight display to annunciate localizer/glideslope using an abbreviation such as LOC/GS when the aircraft integration includes GPS/SBAS LPV, GBAS GLS Category I, and ILS. There must be an unambiguous indication the navigation source is provided by GPS/SBAS, GPS/GBAS, or ILS, as appropriate, in the primary field of view.

(a) LNAV/VNAV and LNAV approach types must still be annunciated, when applicable, if the applicant uses LOC/GS for LPV, or GLS Category I, or ILS.

(2) It is acceptable for the primary flight display to annunciate azimuth/elevation using an abbreviation such as AZ/EL when the aircraft integration includes GPS/SBAS LPV, GPS/GBAS GLS Category I, and MLS. There must be an unambiguous indication the navigation source is provided by GPS/SBAS, GPS/GBAS, or MLS, as appropriate, in the primary field of view.

(a) An unambiguous navigation source annunciation is still necessary if there is no MLS capability on the aircraft and AZ/EL is being used for a combination of only LPV and GLS Category I.

(b) LNAV/VNAV and LNAV approach types must still be annunciated, when applicable, if the applicant uses AZ/EL for MLS, LPV, or GLS Category I.

c. Changes in the approach type annunciations should be very clear and distinctive to quickly catch the flight crew's attention. This is so the flight crew knows and understands that there has been a change in service level and will make adjustments as needed to fly the appropriate approach minimums.

d. Aircraft installations containing both GPS/SBAS-provided vertical guidance and baro-VNAV vertical guidance capability should be carefully evaluated to ensure the annunciations clearly indicate the approach service provided and the sensor driving the vertical display (see paragraph 18-5).

15-7.7 Accessibility.

a. Single equipment installations must be accessible and usable by the pilot. For aircraft requiring two crew members, the equipment should be accessible and usable by either pilot located at a pilot or copilot crew station.

b. Dual (or more) equipment installations must have a convenient and expedient way to update data, information and programs, and a means to ensure consistency between the equipment (e.g., a "cross-load" capability can ensure identical data).

15-7.8 GPS/SBAS Glidepath Low Deviation Alerting Function.

a. To help prevent controlled flight into terrain, manufacturers and operators of aircraft that install a GPS/SBAS LPV and LNAV/VNAV approach capability are highly encouraged to install a glidepath deviation alerting function.

> **Note:** There is no differentiation between LPV approaches using a 35m VAL or 50m VAL in the FAS datablock. The guidance above is intended for all LPV approaches.

b. If implemented, GPS/SBAS vertical performance monitoring and alerting based on deviation guidance outputs (i.e., FTE) can be used to provide a glidepath deviation alerting function. The alert must be prominent and easily recognized by pilots and may be either aural or visual or both. Manufacturers may propose other alternatives.

15-8. GPS/GBAS VDB Receiver.

This paragraph provides guidance related to the installation of a VDB receiver, including those embedded within a multi-mode receiver (MMR). This guidance applies to all installations, but is only expected to be specifically evaluated as part of the initial airworthiness approval (i.e., initial airworthiness approval may provide sufficient substantiation for follow-on installations).

15-8.1 Interference – EMC.

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

b. At least 53 decibels relative to carrier power (dBc) of isolation is required to protect the VDB receiver from desensitization for horizontally polarized VDB antennas operating in the presence of a +40 decibels referenced to one milliwatt (dBm) (effective isotropically radiated power) vertically polarized VHF communications transmission. This isolation may be achieved through a combination of 15 dBc of cross-polarization rejection and -38 dBc of antenna coupling.

c. The full 53 dBc must be achieved through antenna coupling for aircraft using a vertically polarized VDB antenna. It is not feasible to accomplish this isolation simply due to free space path loss. Special considerations will be required.

15-8.2 Compatibility with Other Systems.

The VDB receiver may use the localizer or VOR antenna. If this involves introducing additional splitters in the RF path, the performance of the localizer or VOR receivers must be re-assessed due to the degradation in signal strength resulting from the splitter. The latest revisions of AC 23-8, AC 25-7, AC 27-1, and AC 29-2 provide guidance material on these installations.

15-8.3 VDB Aircraft Implementation Loss.

The aircraft implementation loss should be less than 6 dB (gain) and greater than -15 dB (loss) for a horizontally polarized antenna, or less than 6 dB (gain) and greater than -11 dB (loss) for a vertically polarized antenna. The total implementation loss is the algebraic sum (in dBs) 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 voltage standing wave ratio (VSWR) mismatch losses. The implementation loss should be verified over the frequency range 108.00 to 117.95 MHz.

> **Note:** Integrations that re-use VOR and localizer antennas may be problematic when trying to meet the -15 dB aircraft implementation loss allocation due to aircraft-level issues (e.g., antenna patterns, cabling losses, splitters, connectors, etc.) and/or receiving the signal from any direction (see paragraph 5-4.1.b).

15-9. GPS/GBAS Navigation Computer Receiver.

This paragraph provides guidance related to the installation of GPS/GBAS equipment supporting GLS Category I approaches. This guidance applies to all installations, but is only expected to be specifically evaluated as part of the initial airworthiness approval (i.e., initial airworthiness approval may provide sufficient substantiation for follow-on installations).

15-9.1 GPS/GBAS Equipment Intended for Category I.

Category I approach operation must provide for the following:

a. The GPS/GBAS approach and landing systems should meet the guidance set forth in AC 120-29 (latest revision), *Criteria for Approval of Category I and Category II Weather Minima for Approach*, appendix 2.

> **Note 1:** GPS/GBAS no longer requires proof of concept testing to establish appropriate criteria for operational approval and certification testing for Category I as stated in AC 120-29a, appendix 2.
>
> **Note 2:** AC 120-29a will be replaced soon with a new 90-series AC.

b. For installations where the GPS/GBAS sensor is integrated with other landing systems, such as an MMR, the "ILS look-alike" implies that the MMR signal to the autopilot is scaled in terms of depth of modulation (DDM) units, with sensitivity as described in RTCA/DO-253C, paragraph 2.3.11.5.1.1.1 and paragraph 2.3.11.5.1.2.1.

c. Aircraft integrating GPS/GBAS must have an RNAV capability for the initial, intermediate, and missed approach segments.

d. FMSs that are part of GPS/GBAS integrations should provide the RNAV capability for the initial and intermediate approach segments to place the aircraft in proper position for the GPS/GBAS equipment to conduct the GLS final approach segment. The FMS should also provide RNAV capability for the missed approach segment.

(1) RNAV capability for the initial, intermediate, and missed approach segments can be accomplished by the FMS according to its TSO-C115b (or later revision) or TSO-C146(AR), approval. However, to provide the RNAV function, the FMS will need the ability to recognize a GLS RWY XX approach procedure, store the appropriate segment information in the database, and recall the information as part of the selected approach procedure.

(2) FMS RNAV capability to support GPS/GBAS approaches should be addressed as part of the considerations for installation approval.

e. All installations should meet the constraints on the total differential group delay for the antenna, navigation computer receiver, and all cables/connections referenced in RTCA/DO-253C paragraphs 2.3.6.4 for GPS satellites and 2.3.6.5 for GPS/SBAS satellites.

15-9.2 GPS/GBAS Stand-Alone or MMR Equipment Intended for Category I.

When implementing GPS/GBAS to support GLS Category I operation either as stand-alone equipment or integrated as part of the MMR, the following criteria should be addressed:

a. The airplane's system response to a loss of GPS/GBAS guidance should be no worse than a similar ILS event (minor) and should be free of objectionable transients and sustained oscillations.

b. The GPS/GBAS should be shown to be compatible with a GPS/GBAS service provision consistent with criteria contained in ICAO Annex 10 (as modified by amendment 84) or, accepted by ICAO for incorporation into Annex 10. It is noted that the GPS/GBAS ground facility approval process is outside of the airborne system approval process.

c. It should be possible to initiate a missed approach at any point during the approach down to the minimum altitude sought by the applicant for operational use. Safe go-around should be demonstrated at this minimum altitude.

> **Note:** The presence of large navigation system errors (detectable only by pilot visual reference out-the-window) should not hinder the pilot's decision to land or conduct a missed approach. Annex 10 integrity limits for Category I operations reference vertical errors as large as 35 m and lateral errors as large as 40 m.

15-9.3 Performance and Performance Monitoring.

Sufficient information must be provided in the flight deck to allow the crew to monitor the approach operation progress and safety. This in-flight performance monitoring must include:

a. Unambiguous identification of the intended path for the approach (e.g., approach type, approach identifier, frequency or channel number); and

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

15-9.4 Integrity.

The onboard landing system components, considered separately and in relation to the other associated onboard systems, should be designed to comply with the appropriate 14 CFR part 2X.1309, considering any specific safety-related criteria in the latest revision of AC 120-29, appendix 2 and the operating rules. Presenting misleading information to the flight crew on a GPS/GBAS approach should be considered a Hazardous failure condition (see Table 8).

> **Note:** AC 120-29a will be replaced soon with a new 90-series AC.

15-9.5 Continuity of Navigation.

a. Verify continuity of navigation data during normal aircraft maneuvering on the GPS/GBAS approach.

b. Unlike ILS, where the ILS facility is always located in front of the aircraft on approach, a GPS/GBAS facility could be located anywhere with respect to the approach path. Therefore, the flight test should verify VDB signal reception at all angles relative to the airframe.

15-9.6 Fault Detection and Annunciation.

The automatic means to detect and annunciate misleading guidance signals should have coverage and integrity similar to that of an ILS system when used in the approach flight phase and during go-around.

15-9.7 System Status.

The flight crew must have a means to evaluate the capability of the aircraft elements to accomplish the approach operation prior to and after departure. The flight crew must be advised of failed aircraft systems or components affecting the decision to continue to the destination or divert to an alternate airport.

15-9.8 Annunciation.

a. For installations containing more than one approach navigation source, the navigation source (for example, ILS, GPS/GBAS, etc.) selected for the approach must be positively indicated in the primary field of view. Consideration should be given to the overall aircraft-level annunciation philosophy.

> **Note:** Aircraft requiring two pilots must have this annunciation at each pilot station.

b. The approach type (GLS) must be clearly annunciated to the flight crew prior to and throughout the entire approach in the primary field of view.

(1) It is acceptable for a primary flight display to annunciate localizer/glideslope using an abbreviation such as LOC/GS, when the aircraft integration includes GPS/SBAS LPV, GPS/GBAS GLS Category I, and ILS. There must be an unambiguous indication the navigation source is provided by GPS/SBAS, GPS/GBAS, or ILS as appropriate in the primary field of view.

(a) LNAV/VNAV and LNAV approach types must still be annunciated when applicable if the applicant uses LOC/GS for LPV, GLS Category I, or ILS.

(2) It is acceptable for the primary flight display to annunciate azimuth/elevation using an abbreviation such as AZ/EL when the aircraft integration includes GPS/SBAS LPV, GPS/GBAS GLS Category I, and MLS. There must be an unambiguous indication the

navigation source is provided by GPS/SBAS, GPS/GBAS, or MLS as appropriate in the primary field of view.

(a) An unambiguous navigation source annunciation is still necessary if there is no MLS capability on the aircraft and AZ/EL is being used for a combination of only LPV and GLS Category I.

(b) LNAV/VNAV and LNAV approach types must still be annunciated, when applicable, if the applicant uses AZ/EL for MLS, LPV, or GLS Category I.

15-9.9 Accessibility.

a. Single equipment installations must be accessible and usable by the pilot. For aircraft requiring two crew members, the equipment should be accessible and usable by either pilot located at a pilot or copilot crew station.

b. Dual (or more) equipment installations must have a convenient and expedient way to update data, information and programs, and a means to ensure consistency between the equipment (e.g., a “cross-load” capability can ensure identical data).

15-9.10 Glidepath Capture.

Demonstrate that acceptable glide-path capture, followed by a stable approach, can be accomplished. This demonstration may include simulations and flight test evaluations. Factors that influence an acceptable capture followed by a stable approach may include, but are not limited to, angular offset with the glide-path centerline, altitude at which the airplane acquires that centerline, airplane flying qualities, wind and turbulence conditions, flap settings and center of gravity conditions, and time interval required by the flight control computer algorithm to acquire stable signals.

> **Note:** With some GPS/GBAS ground facilities, guidance may not be available until the aircraft is within 20 NM of the approach runway. This is because the differential corrections are used in the avionics only within a service region defined for the specific ground facility providing the approach. The ground facility VHF data broadcast indicates the limit of this service region. Although service regions smaller than 20 NM may be indicated, they would not meet the normal, minimum coverage required to support precision approach operations.

15-9.11 Equipment Qualification.

The GPS/GBAS positioning and navigation equipment should meet the minimum performance standard in TSO-C161a. The GPS/GBAS VHF data broadcast equipment should meet the minimum performance standard in TSO-C162a.

15-9.12 Interoperability.

Any GPS/GBAS ground installation provided or used by the applicant for the purpose of performance demonstration should be shown to be consistent with ICAO Annex 10, of *Standards and Recommended Practices Applicable for Category I*. The applicant must show that the GPS/GBAS ground installation complies with the requirements of ICAO Annex 10. If this compliance cannot be shown, the applicant should identify and evaluate differences between the GPS/GBAS Annex 10 requirements and the flight test site. The applicant should address the implications of those differences with respect to the validity of the flight test demonstrations and address any possible implications on aircraft interoperability when used with an ICAO Annex 10-compliant ground subsystem.

15-9.13 GPS/GBAS Glidepath Low Deviation Alerting Function.

a. To help prevent controlled flight into terrain, manufacturers and operators of aircraft that install a GPS/GBAS GLS approach capability are highly encouraged to install a glidepath deviation alerting function.

b. If implemented, GPS/GBAS vertical performance monitoring and alerting based on deviation guidance outputs (i.e., FTE) can be used to provide a glidepath deviation alerting function. The alert must be prominent and easily recognized by pilots and may be either aural or visual or both. Manufacturers may propose other alternatives.

15-10. Special Use Mission Equipment - Not for Navigation.

A special approval category for GNSS equipment is “Special Use -- Not for Navigation.” Systems that are installed for special use (agriculture, search and rescue, etc.) that will not be used for aircraft positioning or navigation can be approved on a non-interference basis using less strict airworthiness approval methods. Field approvals are normally acceptable for special use GNSS mission equipment. Inspectors should ensure the flight evaluation includes maneuvers that will normally take place while the GNSS equipment is in use and the equipment does not interfere with any required systems on the aircraft. AC 20-168 (latest revision), *Certification Guidance for Installation of Non-Essential, Non-Required Aircraft Cabin Systems and Equipment* and AC 20-169 (latest revision), *Guidance and Certification of Military and Special Mission Modifications and Equipment for Commercial Derivative Aircraft (CDA)* provides additional guidance on miscellaneous, non-required equipment installations.

Chapter 16. Installation Considerations - RNAV Multi-Sensor Equipment.

16-1. Introduction.

When installing GNSS as part of a multi-sensor system, the installation issues of chapter 15 apply and will take precedence if any conflicts with this chapter arise.

16-2. Interface to Primary Navigation Display.

Navigation data, including a TO/FROM indication and a failure indicator, must be displayed on a lateral deviation display such as a CDI, (E)HSI and/or a navigation map display. If using a navigation map display, it should give equivalent functionality to a lateral deviation display and be readily visible to the pilot with appropriate map scales (scaling may be set manually by the pilot). The navigation data will be used as primary flight instruments for aircraft navigation, for maneuver anticipation, and for failure/status/integrity indication. The display of navigation parameters data should meet the following:

> **Note:** See paragraph 8-3.g(2) for TO/TO navigation computer displays.

a. The navigation system in use must be clearly and unambiguously indicated for installations where multi-sensor outputs can drive a display that is shared in common with other navigation equipment (for example, VOR/DME, DME/DME/IRU, ILS, GNSS, baro-VNAV, etc.).

b. When in terminal and approach modes, the bearing and distance to the active waypoint must be displayed with a minimum resolution of 1 degree and 0.1 NM up to a range of 99.9 NM. Alternate means may be a moving map display where waypoint passage is clearly indicated. Waypoint passage may be indicated with a waypoint alert (per latest revisions of AC 25-15, paragraph 5e(5)(iv) and AC 20-159); or, with VNAV guidance where level change is alerted and initiated upon sequencing the waypoints. If a moving map is provided, the map may obviate the need for a numerical output provided there is adequate resolution.

> **Note:** Moving maps where the finest resolution is 5nm are inadequate to negate displaying a numerical value.

c. Navigation data, including a TO/FROM indication and a failure indicator, must be displayed on a lateral deviation display such as a CDI, (E)HSI and/or a navigation map display. These navigation data will be used as primary flight instruments for aircraft navigation, for maneuver anticipation, and for failure/status/integrity indication. The data should meet the following:

> **Note:** See paragraph 8-3.g(2) for TO/TO navigation computer displays.

16-2.1 Non-numeric Deviation Displays.

a. Non-numeric cross-track deviation must be continuously displayed in all navigation modes.

b. Non-numeric deviation displays (for example, a CDI or (E)HSI) with a TO/FROM indication and a failure annunciation should have the following attributes:

Note: See paragraph 8-3.g(2) for TO/TO navigation computer displays.

(1) The distance to the active waypoint must be displayed either in the pilot's primary field of view or on a readily accessible display page unless there are alternate means to indicate waypoint passage.

(2) Non-numeric vertical deviation must be continuously displayed when in an approach mode containing vertical guidance.

c. The lateral deviation scaling must be consistent with any alerting and annunciation limits, if implemented.

d. The lateral deviation display must also have a full-scale deflection suitable for the current phase of flight and must be based on the required total system accuracy.

e. The display scaling may be set automatically by default logic or set to a value obtained from a navigation database. The full-scale deflection value must be known or must be available for display to the pilot commensurate with enroute or terminal values.

f. The lateral deviation display must be automatically slaved to the RNAV computed path. The course selector to the deviation display should be automatically slewed to the RNAV computed path or the pilot must adjust the omni bearing selector (OBS) or HSI selected course to the computed desired track.

Note: The normal function of stand-alone GNSS equipment meet this criteria.

16-2.2 Map Displays.

Map displays should give equivalent functionality to a non-numeric lateral deviation display described above, and be readily visible to the pilot with appropriate map scales (scaling may be set manually by the pilot.)

16-3. Interface to Remote Annunciator.

a. Multi-sensor equipment may drive remote annunciators in the primary field of view.

b. 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.

c. Waypoint sequencing, start of a turn, turn anticipation, TO/FROM indication, approach mode annunciation, and automatic mode switching should be located within the pilot's primary field of view or on a readily accessible display page.

> **Note:** See paragraph 8-3.g(2) for TO/TO navigation computer displays.

d. The multi-sensor equipment should provide annunciations for loss of integrity monitoring, loss of navigation, TO/FROM indication, and approach mode annunciation within the primary field of view.

> **Note 1:** Loss of integrity monitoring is not applicable for GPS/SBAS Class Delta-4 implementations because this equipment only functions on the final approach segment (or its extension) where loss of integrity monitoring is defined as a loss of navigation. Normal loss of navigation indication is sufficient.

> **Note 2:** See paragraph 8-3.g(2) for TO/TO navigation computer displays.

16-4. Unique Software Considerations.

a. If software was developed using RTCA/DO-178A (as is specified in TSO-C115a), the applicant may need to further evaluate some features of the software. RTCA/DO-178A does not address some applications of digital technology commonly found in multi-sensor equipment (e.g., use of user-modifiable software including data bases, option-selectable software, software development and verification tools, previously developed software in modular architectures, and field loadable software capabilities). In these cases RTCA/DO-178A does not provide adequate procedures and the applicant must include in the software aspects of certification plan the means for showing that these features comply with pertinent airworthiness requirements. One acceptable means for demonstrating such features comply with the airworthiness requirements is to comply with pertinent portions of the requirements contained in RTCA/DO-178B or 'C', which would supplement the basic requirements contained in RTCA/DO-178A.

b. The FAA strongly recommends that the applicant use the procedures described in RTCA/DO-178C, as referenced in AC 20-115C to show that the software aspects of a system comply with pertinent airworthiness requirements. For software developed prior to the availability of RTCA/DO-178C, AC 20-115C provides a method for upgrading a baseline for software development so that changes can be made in accordance with the requirements contained in RTCA/DO-178C.

16-5. Installed Performance Capability.

a. It is essential that procedures or optional functions an aircraft is not capable of performing are either removed from the RNAV multi-sensor equipment database, or otherwise inhibited, even if the avionics do support the function. The AFM(S)/RFM(S) must contain an appropriate entry for any limitations (see paragraph 12-7 and 12-8).

b. Data Quality Requirements (DQRs) for installed databases are normally addressed at the equipment design level. The DQRs applicable to the intended function must be confirmed at the aircraft level during airworthiness approval. A Type 2 LOA may be used to ensure the database requirements, including tool qualification, is appropriate for the intended function of the installed equipment. A Type 2 LOA also provides evidence the data quality characteristics are described and valid for the compatible equipment listed on the LOA (see paragraph 19-8).

Chapter 17. Installation Considerations - RNP.

17-1. Introduction.

This chapter contains installation consideration guidance for RNP. RNP AR installation considerations are in appendix 2 of this AC and Advanced RNP Function installation considerations are in appendix 3.

17-2. Flight Technical Error.

The aircraft manufacturer should verify maintenance of FTE (95% of the flying time) per Table 9 below. Alternate FTE values may be demonstrated using the methods described below.

RNP (nm)	FTE (nm)	FTE Basis
0.3	0.125 0.25	Autopilot Flight Director or Manual Operation
1.0	0.5	Autopilot, Flight Director or Manual Operation
2.0	1.0	Autopilot, Flight Director or Manual Operation
4.0	2.0	Autopilot, Flight Director or Manual Operation

Table 9. RNP FTE Performance

Note: Table 9 is consistent with current information in RTCA/DO-283B for GPS and was derived from data in RTCA/DO-208 appendix E.

a. FTE assessments for approach, missed approach, or other defined operations, may be made by an aircraft manufacturer, avionics manufacturer, or operator to establish alternate values of expected FTE to be used for navigation system or procedure authorization. The alternate FTE values may then be applied toward TSE in lieu of using the standard FTE values shown in Table 9.

b. FTE values may be established by analysis (e.g., of existing data), by simulation (e.g., in a suitable flight training simulator), through flight verification (e.g., data collected from flight demonstration(s) with an appropriately configured aircraft), or any combination of these methods. The FTE assessment should produce repeatable, consistent FTE level(s) and should key to:

- Types of procedures to be flown;
- Operations being normal or not (i.e., normal, non-normal, rare normal, etc.);

- Pilot capability; and
- System variability.

c. The advantage to using lab analysis and engineering simulation for FTE assessments is the possibility to reduce the number of aircraft demonstrations. The number of planned aircraft demonstrations can be reduced when the initial aircraft demonstration data mimics and validates the FTE performance data collected through analysis and engineering simulation.

17-3. Radius to Fix (RF) Legs.

All information on RF legs is consolidated into appendix 3 (see paragraph A3-2).

17-4. Interface to FGS.

a. Verify autopilot compatibility with the installed navigation system RNP capability. Refer to the appropriate installation guidance chapters for the navigation system.

b. Verify acceptable autopilot response to an RNP fault by simulating a representative fault consistent with the equipment architecture (e.g., pulling the circuit breaker) for the RNP equipment. The aircraft manufacturer or installer should complete this test in each of the RNP and autopilot modes, as applicable.

Chapter 18. Installation Considerations - Baro-VNAV.

18-1. Failure Protection.

Any probable failure of the airborne baro-VNAV system should not degrade the normal operation of other required equipment or create a flight hazard. Normal operation of the baro-VNAV equipment installation should not adversely affect the performance of other aircraft equipment.

18-2. Manufacturer's Instructions.

a. Baro-VNAV equipment should be installed in accordance with instructions and limitations provided by the manufacturer of the equipment.

b. A special concern is using baro-VNAV vertical path guidance on published instrument procedures due to potential anomalies. A baro-VNAV airworthiness approval must have language in the installation instructions for an AFM(S)/RFM(S) limitation on baro-VNAV vertical path guidance. The limitation is that flight crews/pilots must not rely solely on the baro-VNAV vertical path guidance for compliance to published altitude restrictions during SIDs, STARs and LNAV or LP approach procedures. The flight crew/pilots must use the primary barometric altimeter to confirm compliance with all published altitude restrictions. This includes use of the primary barometric altimeter to ensure compliance with all step-down fixes in the final approach segment of an instrument approach (see paragraph 12-8). The AFM(S)/RFM(S) (or equivalent documentation) limitation language must be equivalent to the following:

> "When using the <insert name> VNAV system, the barometric altimeter must be used as the primary altitude reference for all operations; including instrument approach procedure step-down fixes."

> **Note:** Baro-VNAV systems certified before 11/20/1989 may have been certified to a lesser standard that is not consistent with a major failure condition. Operators of these aircraft should apply the final approach segment step-down fix to the LNAV/VNAV line of minima and should use the primary barometric altimeter to ensure meeting the step-down fix altitude constraint.

18-3. Annunciations.

a. 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.

b. Audible alarms should be sufficiently loud and of appropriate pitch quality, duration and pattern. Alarms should be easily deactivated (but not easily deactivated inadvertently). Audible alarms must not interfere with other aircraft audio alarms or alerts of higher priority (e.g., stall warnings, gear warning, or chip-detect).

18-4. Software Changes.

a. Changes to software that affect navigation functions should be carefully evaluated to determine if they are major changes to the equipment's design approval (see 14 CFR 21.611 if part of a TSO'd article). Unless software partitioning has been previously established, any change to level C or higher software in baro-VNAV equipment should be verified and validated to the appropriate level, and should be demonstrated to not inadvertently affect the remaining navigation functions.

> **Note:** Baro-VNAV is typically included as a sensor function in FMSs that may have a TSO-C115(AR) authorization. Baro-VNAV is treated under TSO-C115(AR) similarly to inertial navigation systems that also do not have a separate TSO.

b. All software changes must be identified with the associated line replaceable unit using acceptable methods in accordance with the criteria in RTCA/DO-178B or 'C'. Software changes in TSO approved equipment must be reported, as required, to the appropriate ACO. If the equipment displays a software identifier to the flight crew, the AFMS/RFMS (or appropriate placard) should indicate the approved identifier. Software changes incorporated in equipment already installed in an aircraft may require additional evaluation and possible flight manual revision prior to returning the aircraft to service, depending on the scope of the change.

18-5. Integration with GNSS-Provided Vertical Guidance.

a. Many aircraft integrations have implemented baro-VNAV for use in all phases of flight, and for vertical guidance on an LNAV/VNAV approach.

b. The applicant must address the following issues when the aircraft integration includes baro-VNAV and GPS/SBAS and/or GPS/GBAS vertical guidance:

(1) Transitions between GPS/SBAS or GPS/GBAS (GNSS height) and baro-VNAV vertical guidance should be smooth.

(a) Smooth guidance means there should be no transients or jumps between GPS/SBAS or GPS/GBAS guidance and baro-VNAV guidance in the vertical guidance displays that would indicate a sudden change in aircraft flightpath position.

(b) There should be no transients or jumps in vertical guidance commands that disrupt stabilized flight.

> **Note:** For paragraphs 18-5.b(1)(a) and (b), minor transients or jumps may be acceptable depending on the integration. The applicant will need to demonstrate that minor transients or jumps do not adversely affect the aircraft flight path.

(c) Baro-VNAV performance has not been shown to be adequate for vertical guidance on LPV or GLS approaches.

(2) Transitioning from a GPS/SBAS vertically guided approach to LNAV/VNAV minimums using baro-VNAV must only occur prior to the FAF. If the aircraft is established on the final approach segment after passing the FAF using GPS/SBAS-provided VNAV, the transition must be to GPS/SBAS LNAV (vertical guidance flagged) if supported by the GPS/SBAS equipment.

(a) Issues with transitioning from GPS/SBAS to baro-VNAV vertical guidance on the final approach segment include:

(i) Temperature errors, particularly if the GPS/SBAS approach was started outside the allowable baro-VNAV temperature range.

(ii) MSL versus WGS-84 ellipsoid for path definition.

(iii) Curved baro-VNAV path versus straight GPS/SBAS path.

(iv) Linear baro-VNAV guidance versus angular GPS/SBAS guidance.

(b) These issues can cause discontinuities or jumps that could potentially de-stabilize the critical final approach segment and result in unacceptable pilot workload.

(3) Transitioning from a GPS/GBAS GLS approach to another procedure with LNAV/VNAV minimums using baro-VNAV must only occur prior to the FAF. There is no transition from a GPS/GBAS vertically guided approach after passing the FAF. After the FAF, a missed approach is necessary for a GPS/GBAS navigation or integrity disruption.

Note: GPS/GBAS approaches have a different naming convention from other RNAV approaches and will not have LNAV/VNAV or LNAV minimums published with the GLS procedure.

(4) It should be clearly indicated to the pilot whether the approach vertical guidance is based on GPS/SBAS, GPS/GBAS, or baro-VNAV.

(5) Baro-VNAV implementations demonstrating vertical containment about a fixed path in space may not need to differentiate between GPS/SBAS or GPS/GBAS VNAV and baro-VNAV. However, this should only be done when the vertical containment demonstrated with baro-VNAV clearly meets or exceeds the vertical performance requirements of GPS/SBAS or GPS/GBAS.

Note: There is no public standard for definition of “vertical RNP” nor does this guidance material intend to define “vertical RNP.” Future performance-based operations may define “vertical RNP.”

(6) Consideration should be given to operating manual descriptions and different procedural training between GPS/SBAS, GPS/GBAS and baro-VNAV.

(a) Effects of cold temperature deviations from International Standard Atmosphere must be considered for baro-VNAV operations, and whether or not the baro-VNAV equipment includes temperature compensation.

(b) Baro-VNAV may not be authorized at airports with remote altimeter settings.

(7) There should be an annunciation in the primary field of view indicating the active approach type (for example, GLS, LPV, LP, LNAV/VNAV, LNAV). The intent is to ensure the crew has an unambiguous indication of the active approach in the primary field of view that will correlate to a line of minima on the approach chart. Consideration may be given to the aircraft's overall cockpit alerting philosophy to reduce the number of independent indicators.

18-6. Glidepath Low Deviation Alerting Function.

a. To help prevent controlled flight into terrain, manufacturers and operators of aircraft that install baro-VNAV capability are highly encouraged to install a glidepath deviation alerting function.

b. If implemented, baro-VNAV vertical performance monitoring and alerting based on deviation guidance outputs (i.e., FTE) can be used to provide a glidepath deviation alerting function. The alert must be prominent and easily recognized by pilots and may be either aural or visual or both. Manufacturers may propose other alternatives.

Chapter 19. Installed Performance - Data Submittal.

19-1. Introduction.

This chapter identifies documentation typically required by the aircraft certification authorities to support installation airworthiness approval. The information described in this chapter is applicable to obtaining an STC, amended STC, TC, or an amended TC.

19-2. Project Specific 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 positioning and navigation equipment will meet the applicable airworthiness requirements and any special conditions. The FAA and Industry Guide to Product Certification (second edition) provides guidance on developing a project specific certification plan. Additional information can be found in the latest revision of AC 21-40.

19-3. TSO Technical Data.

Due to positioning and navigation equipment complexity, applicants applying for a TSOA/LODA should be prepared to provide data for the ACO to:

a. Evaluate applicant supplied bench test data on the equipment and verify that the tests comply with the relevant procedures and requirements.

b. Evaluate the applicant’s reliability data or analysis establishing that all probable failures affecting the navigation function are detected. Qualitative analysis may be used under the latest revision of AC 23.1309-1, AC 25.1309-1, AC 27-1, or AC 29-2 as appropriate.

c. Evaluate the applicant’s system safety assessment to confirm that all failure conditions have been identified, classified and described in functional and operational terms.

d. Verify compliance of the system design consistent with the failure condition classification for the equipment’s intended function.

(1) This verification includes confirming installation instructions have a summary of the equipment limitations relative to the design assurance levels, particularly if the criteria in AC 23.1309-1D for different classes of 14 CFR part 23 aircraft are applied. For example, TSO-C146d Class 3 equipment (GPS/SBAS stand-alone LPV capable equipment with a hazardous failure condition for HMI) that has software developed to RTCA/DO-178B or ‘C’ Level C would state the following:

> “This TSO-C146d equipment complies with paragraph 13a in AC 23.1309-1D for Class I, II, and III aircraft. This equipment is not eligible for installation in 14 CFR part 25, 27, 29 or part 23 Class IV aircraft unless the LPV approach mode is disabled through the following equipment configuration setting: ….”

19-4. Review the installation manual.

a. The applicant should include all known installation and performance limitations. Special attention should be given to reviewing those limitations in light of the variety of different installation configurations that are supported.

b. The installation manual should include instructions for standard practices used in the installation and should address the unique equipment issues in chapters 12 through 23 of this AC.

c. Installation approvals are aided when the installation manual identifies which equipment is compatible with the newly installed positioning and navigation equipment, and/or provides detailed interface information. A data flow diagram can be a useful aid in depicting all the interfaces. Examples of typical installed equipment interfaces are: barometric altimeter, FMS, FGS, antenna(s), displays, deviation indicators, TAWS/HTAWS, ADS-B, external switches, and lightning detection. The applicant should consider developing information for the installation instructions on conducting ground and/or flight checks so the installer can ensure proper functioning of these interfaces. In addition, the installation manual should include instructions that address the critical areas unique to each installation, for example:

(1) Antenna placement;

(2) Unit placement (for controls/display);

(3) Equipment calibration and installed performance test procedures;

(4) Switching, external annunciations, configuration programming, and cockpit layout;

(5) Wiring diagrams of the installation process;

(6) Electromagnetic compatibility; and

(7) Interface compatibility.

d. Particular attention should be focused on the FGS and autopilot approach interface to ensure compatibility with the gain scheduling employed by some equipment during approaches. For example, some autopilots depend upon a radio altimeter, or, middle marker beacon passage inputs to enable a "glideslope extension" function to reduce "porpoising" or aerodynamic instability when coupled to a glideslope signal during the final approach phase. But WAAS LPV approaches do not have middle marker beacons so autopilot response needs to be evaluated when incorporating LPV capability.

19-5. Structural Analysis.

The positioning and navigation equipment installation, 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, considering the unique installation and the aircraft TC airworthiness basis.

19-6. 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. This includes describing the primary power bus for the equipment and how the equipment is powered in an emergency condition.

19-7. Environment.

Provide qualification data substantiating that the aircraft environment in which the positioning and navigation equipment is to be installed is appropriate to the environmental categories (or criteria) in the appropriate RTCA/DO-160 revision per the TSO to which the equipment has been tested.

> **Note:** Equipment produced to different TSO revisions can reference different RTCA/DO-160 revisions for environmental testing. Manufacturers may use later RTCA/DO-160 revisions than what is stated in the TSO, but their ACO will need to approve a deviation request to document the change.

19-8. Database.

a. AC 20-153 (latest revision) defines an acceptable means of ensuring that the aeronautical data process does not corrupt data, from the publication of data by the originating source to its application in the equipment, for those navigation systems that comply with the latest revisions of ACs 90-100 and 90-105. The TSOA provides sufficient evidence for compliance to AC 20-153(latest revision) for the installation approval, but operational approval for IFR use is based upon a database assurance process through a type 2 LOA. A type 2 LOA provides database objective evidence of integrity consistent with the monitoring and alerting requirement for GNSS and other RNP systems.

b. Verify the navigation database type 2 LOA exists with reference to AC 20-153 (latest revision). If there is no evidence of a Type 2 LOA, it is appropriate to place a limitation in the AFM(S)/RFM(S) stating “Not approved for IFR operations without a Type 2 LOA.”

19-9. Operations manual or AFMS/RFMS.

An AFMS/RFMS must be provided that contains the limitations and operating procedures applicable to the installed equipment configuration. The AFMS/RFMS must address the operation of the equipment and the related components as they are installed (e.g., remote source selector). An AFM/RFM supplement is required if the installation is based on a prior approval that had an AFM/RFM, or if there are any limitations associated with the operation of the equipment. See paragraph 15-4 for additional documentation considerations specific to GNSS.

19-10. Stand-Alone Navigation Equipment.

Navigation systems designed as a combination navigation computer/sensor configuration must develop a pilot's guide and a quick reference guide. These guides are typically developed by the equipment manufacturer.

a. Pilot's Guide.

An operations manual (pilot's guide) describing the equipment, functions and procedures must be provided with the positioning and navigation equipment. It is essential that the pilot's guide be complete, concise, and easy to understand. Have an FAA flight test pilot familiar with the equipment review the pilot's guide and required training programs. 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.

b. Quick Reference Guide.

A quick reference guide must be provided with the positioning and navigation equipment as a training aid for the operation of the positioning and navigation equipment. The guide should be evaluated by a flight test pilot familiar with the equipment.

19-11. 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 chapters 19 through 23), regulatory compliance, and EMI/EMC testing.

Chapter 20. Installed Performance - Test (General).

20-1. Intended Function.

Assess the ability for the equipment and aircraft combination to perform the intended function for the operation. The installed equipment may have the capability to perform an operation that is beyond the aircraft's performance limit or current approval (or visa versa) and may require an AFMS/RFMS limitation. For example, a particular rotorcraft may only be approved for six degree steep angle approaches even though the installed equipment is capable of steeper angles.

20-2. Power Supply.

Assess all switching and transfer functions, including electrical bus switching, pertaining to the positioning and navigation installation.

20-3. Accuracy.

The accuracy of GNSS equipment is not a function of the installation, and should not be evaluated for each GNSS or multi-sensor installation. The accuracy of the GNSS equipment will be demonstrated during the sensor evaluation, typically as part of a TSOA/LODA.

20-4. Human Factors.

a. Visibility of the controls, displays, and annunciators relating to the 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.

b. 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.

c. 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.

d. Additional human factor considerations are in RTCA/DO-283B, appendix F.

> **Note:** RTCA/DO-257 is currently under revision and may provide additional human factors information upon publication.

Chapter 21. Installed Performance - Test (GNSS).

21-1. Ground Test - GPS, GPS/SBAS, and GPS/GBAS.

21-1.1 Interference.

a. The lack of interference from VHF radios 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. Re-evaluation of installed VHF transceiver performance is not necessary if the filter insertion loss is 2 dB or less.

b. Evaluate the following VHF frequencies (25 kHz channels):

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

c. For VHF radios with 8.33 kHz channel spacing, evaluate the following additional VHF frequencies:

121.185 MHz	121.190 MHz
130.285 MHz	131.290 MHz

d. For installations on rotorcraft, ensure that the rotor blades do not interfere with the received signals. This problem has been experienced in some rotorcraft and varies with the rotation rate.

21-1.2 Antenna to Aircraft Navigation Reference Offset.

RTCA/DO-229D, Change 1, paragraph 2.2.4.3.3 (Class Gamma equipment) and RTCA/DO-253C, paragraph 2.3.11.5.1 stipulates the equipment will support installations with the ability to compensate for the navigation center to antenna offset. If applicable, confirm that the antenna to aircraft center of navigation offset is appropriate to the installation for GPS/SBAS or GPS/GBAS equipment supporting LPV or GLS approach capability.

> **Note:** The fact that the GNSS antenna is top-mounted can result in several feet of vertical difference between the antenna and the aircraft center of navigation, significantly larger than for ILS antennas. The center-of-navigation to wheel-crossing height should be evaluated for each installation. For most installations, a fixed vertical offset is adequate.

21-1.3 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 chapters 14 and 15.

21-1.4 Stand-Alone Navigation Equipment Installation.

a. Navigation parameters displayed on cockpit instruments such as HSI, CDI, distance display, electronic flight instrument system, moving maps, FMSs, etc. should be evaluated against the criteria described in chapters 12, 14, and 15 of this AC.

b. Failure modes and associated annunciations, such as loss of electrical power, loss of signal reception, GNSS equipment failure, autopilot/FD response to flags, etc., should be reviewed against the criteria described in chapters 12, 14, and 15 of this AC.

21-2. Flight Test - GPS, GPS/SBAS, and GPS/GBAS.

21-2.1 Equipment Installation.

a. Verify navigation data continuity 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 take-off, departures, approaches, landing and missed approaches as applicable).

b. Verify the overall GNSS equipment operation to include at least the following:

(1) Hold at a designated waypoint;

(2) Intercept and track to or from a waypoint on a selected course;

(3) Turn anticipation;

(4) Waypoint sequencing;

(5) Selection of an approach;

(6) The general presentation of navigational data (depiction of the “TO” waypoint, distance to waypoint, estimated time of arrival, estimated time enroute, ground speed, etc.); and

(7) Evaluate the overall operation on all types of procedures or paths that the equipment supports (e.g., straight legs, DME arcs, and RF legs).

c. Evaluate displayed vertical navigation parameters on interfaced flight deck instruments such as an HSI, CDI, etc. Evaluate how distance to go, course, bearing, etc. are displayed on all flight deck presentations during approach procedures when step-down fixes are included in the navigation database (see paragraphs 12-8 and 18-2.b).

d. Verify that FTE can be maintained at less than 1.0 NM for enroute and approach transition operating modes, and less than 0.25 NM for non-precision approach, both with and without autopilot and/or FD 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.

e. The following issues should be evaluated when the equipment is interfaced with a FGS. The objective of this paragraph is to ensure proper aircraft operation when the GNSS is interfaced with the aircraft's FGS. If these issues cannot be addressed for a particular autopilot (e.g., because the autopilot does not respond to flag indications), the GNSS equipment may still be installed, but either should not be connected to the autopilot, or have an appropriate AFMS/RFMS limitation that mitigates the issue.

(1) Evaluate steering response while the FD 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 enroute through the approach to missed approach modes and then back to enroute. Additionally, evaluate all available display sensitivities.

(2) Execute several fly-by turns with varying wind conditions for the FD 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.

(3) Verify that the lateral maneuver anticipation supplied by the GNSS equipment is appropriate for the aircraft type. Verify that an appropriate annunciation of impending waypoint crossing is provided.

(4) Verify that execution of the Direct-To function with a resultant aircraft heading change does not overshoot and cause "S" turns. Re-initializing the Direct-To function after completion of most of the required track change may be an acceptable means of compliance for equipment which does not inherently account for the change in aircraft heading.

(5) Evaluate the autopilot response to a GNSS fault by simulating a representative fault consistent with the equipment architecture (e.g., pulling the circuit breaker) for the GNSS equipment. This test should be done in all of the GNSS enroute and approach modes.

21-2.2 LP/LPV, LPV and GLS.

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, FD 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 the latest revision of AC 23-17, AC 25.1329-1, AC 27.1329 contained in AC 27-1, or AC 29.1329 contained in AC 29-2 (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.

d. Evaluate full-scale deflection while on approach to ensure the system operates properly.

e. Evaluate the FGS approach functionality to ensure compatibility with the gain scheduling employed by some FGSs during approaches. For example, some FGSs depend upon a radio altimeter, or, middle marker beacon passage inputs to enable a "glideslope extension" function to reduce "porpoising" or aerodynamic instability when coupled to a glideslope signal during the final approach phase. But WAAS LPV approaches do not have middle marker beacons so FGS response needs to be evaluated when incorporating LPV capability.

f. No additional testing is needed to verify LP capability if LPV has been satisfactorily demonstrated. Confirm the cockpit annunciation scheme will provide a clear, unambiguous annunciation of LP service when selected by the pilot. Verify through analysis or previous testing the FGS is able to support horizontal-only approach guidance inputs.

g. 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 and ensure that the switch is accomplished as expected, that it is clearly annunciated, and that the switching itself does not induce any inaccurate guidance. Verify any air data and inertial source select switches are appropriately reflected in the positioning and navigation equipment.

h. 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 visual indication within the pilot’s primary field of view.

i. A crew workload analysis when operating the GNSS equipment in association with other piloting requirements should be conducted during all phases of flight and found to be acceptable, including those non-normal procedures that can be evaluated in flight.

21-2.3 GPS/GBAS VDB Receiver Installation.

a. To verify non-interference (electromagnetic compatibility) between the VDB and VHF communications equipment, a flight test should be accomplished using the highest available VDB broadcast frequency, and transmitting VHF communication at 100 kHz above the VDB channel. Use 118.000 MHz for VHF communications equipment that cannot transmit below 118.000 MHz.

b. VDB receiving capability should be demonstrated in flight. Unlike ILS, where the ILS facility is always located in front of the aircraft on approach, a GPS/GBAS facility could be located anywhere with respect to the approach path. Therefore, the flight test should verify VDB signal reception at all angles relative to the airframe.

Chapter 22. Installed Performance - Test (RNAV Multi-Sensor Equipment).

22-1. Ground Test.

Refer to TSO-C115b/RTCA/DO-187, TSO-C115c/RTCA/DO-283A, or TSO-C115d/RTCA/DO-283B as appropriate, for RNAV multi-sensor equipment ground test information.

22-2. Flight Test.

Flight tests are conducted to verify proper operation and accuracy of the multi-sensor equipment as installed in the aircraft (except for GNSS accuracy, see paragraph 21-2). Flight tests should include at least the following:

> **Note:** Required flight evaluations for the first-time airworthiness approval of multi-sensor equipment are accomplished by the cognizant ACO unless specific tests are delegated by the ACO to a flight test pilot designated engineering representative (DER).

a. Evaluation to determine satisfactory EMC between the multi-sensor equipment installation and other onboard equipment (this test may be partially accomplished as a ground test).

b. Validate multi-sensor equipment navigational accuracy in each operating mode. In addition to overall system navigation performance, particular test requirements for navigational accuracy will vary depending upon the particular sensors integrated in the multi-sensor equipment and whether sensor accuracy performance data has previously been obtained. The performance of each navigation sensor should be evaluated separately and in combination with other sensors as applicable.

c. Initial certification for systems including a VOR/DME or multiple (scanning) DME sensor that has not been previously certified must be based upon a demonstration of system accuracy by recording (at not greater than 15 minute intervals) the VOR/DME and/or DME/DME sensor position and comparing it to the actual position during evaluation flights. The latest revisions of AC 25-7 and AC 23-8 provide guidance on test distances from VOR and DME navigation aids. Recorded data should include sufficient signal parameters and sensor performance data to provide a clear indication of satisfactory sensor performance. The particular flight paths should be selected based upon an analysis of critical signal characteristics, station geometry, signal coverage (including limited station availability with acceptable range), aircraft movement, etc. The system should demonstrate its ability to detect poor signal conditions, inadequate navigation capability, recovery from in-flight power failure, etc. The auto-tune logic should be reviewed and tested to verify that ground stations are identified and tuned correctly.

d. Inertial systems that satisfy the criteria in 14 CFR part 121, appendix G and comply with Table 10 below do not need further evaluation. Based on an evaluation of INS/IRU performance, the growth in position error after reverting to INS/IRU can be expected to be less than 2 NM per 15 minutes. Applicants that desire certification credit for better performance should coordinate with their ACO for the requirements to demonstrate and document the performance.

Time Since Radio Updating (T) (hr)	IRS/IRU 95% Error (NM)
0.0 to 0.5 hr	8*T
0.5 to 1.5 hr	4

Table 10. INS/IRU Accuracy After Loss of Radio Updating

e. Verify navigation data continuity 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).

f. Verify the overall operation of the multi-sensor 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 Fix leg), 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 enroute, ground speed, etc.). Evaluate displayed vertical navigation parameters on interfaced flight deck instruments such as an HSI, CDI, etc. Evaluate how distance to go, course, bearing, etc. are displayed on all flight deck presentations during approach procedures when step-down fixes are included in the navigation database (see paragraphs 12-8 and 18-2.b).

g. Verify that FTE does not exceed 1.0 NM for enroute, 0.5 NM for approach transition and missed approach operating modes, and 0.25 NM for non-precision approach, both with and without autopilot and/or FD 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 while either flying under autopilot control or flying manually using the navigation display provided.

h. If the equipment uses barometric input, verify that the equipment properly interprets the barometer reading. Special consideration should be given to manually entering a barometric correction.

i. Verify/assess all switching and transfer functions, including electrical bus switching, pertaining to the multi-sensor installation. The aircraft system response during any switch over to alternate navigation sources must be evaluated. Particular attention should be given to mode switching and transition requirements associated with the approach mode for equipment incorporating GNSS sensors.

j. Review and verify, where appropriate, various failure modes and associated annunciations, such as loss of electrical power, loss of signal reception, multi-sensor 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.

22-2.1 Interface to FGS.

a. Evaluate steering response while the FD and/or autopilot is coupled to the multi-sensor equipment during a variety of different track and mode changes. This evaluation should include, as applicable, transition from enroute through the approach to missed approach modes and then back to enroute. Additionally, evaluate all available display sensitivities.

b. Several fly-by turns should be accomplished with varying wind conditions for FD and autopilot. Verify the equipment accomplishes the turn as a fly-by waypoint and discourages overshoot. Fly-by turns are defined as turns where the equipment initiates the turning maneuver prior to sequencing the waypoint by an amount equal to the turn anticipation distance.

c. Verify that the lateral maneuver anticipation supplied by the multi-sensor equipment is appropriate for the aircraft type. Verify that if the multi-sensor equipment is coupled to an autopilot or on approach, an appropriate annunciation of impending waypoint crossing is provided.

d. Verify that execution of the Direct-To function with a resultant aircraft heading change does not overshoot and cause “S” turns that exceed the lateral path tracking FTE requirements.

e. Evaluate the autopilot response to a multi-sensor equipment fault by simulating a representative fault consistent with the equipment architecture (e.g., pulling the circuit breaker) for the equipment. This test should be done in each of the sensor modes, if applicable.

22-2.2 GNSS Precision Approach.

a. For equipment that provides GNSS precision approach capability, or for equipment with non-standard navigation displays, conduct several approaches while flying raw data, FD only and coupled to the autopilot, as applicable. The objective of the test is to ensure that the multi-sensor 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 the latest revision of ACs 23-17 or 25.1329-1, or equivalent means.

b. 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.

Chapter 23. Installed Performance - Test (Baro-VNAV).

23-1. Introduction.

Paragraphs 23-2 and 23-3 describe the installed performance test considerations for an initial approval. Subsequent installations are addressed in paragraph 23-4. An initial approval refers to the very first time an applicant presents a particular model of baro-VNAV equipment for FAA certification and airworthiness installation approval for an IFR navigation system. Any new models of baro-VNAV equipment by the same manufacturer should undergo the same approval process as the original equipment unless it can be shown by analysis and test that the new model will function as well or better than the approved equipment.

23-2. Ground Test.

23-2.1 Lab/Bench Tests and Equipment Data Evaluation.

Normally the baro-VNAV equipment manufacturer will accomplish these actions for a certification design approval. This phase consists of the following:

a. Analysis of the manufacturer's procedures for verification and validation of software and review of supporting documentation in accordance with the guidelines of RTCA/DO-178B or 'C'.

b. Verification of compliance with appropriate environmental qualification standards such as RTCA/DO-160F.

> **Note:** Previously certified baro-VNAV systems may have used an earlier RTCA/DO-160 revision. This equipment may still be installed within the provisions of its original certification.

c. Examination of the equipment's display capabilities with emphasis on warning, caution, and advisory annunciations.

d. Analysis of failure modes.

e. Review of reliability data to establish that all probable failures are detected.

f. Evaluate the controls, displays, annunciations, and system behavior from a human performance perspective.

g. Review of installation and maintenance manuals.

h. Evaluation of operator's manual (pilot's guide).

23-2.2 Aircraft Installation Data Evaluation.

Normally the baro-VNAV equipment manufacturer will provide an aircraft as a test bed for a first-time installation approval. The first-time installation approval will serve as a basis for subsequent installation approvals on the same type of aircraft incorporating the same autopilot/FD system and for other aircraft installations not incorporating autopilot/FD interface with the baro-VNAV equipment. The following assessments must be made:

a. Review the installation drawings, wiring diagram, and descriptive wiring routing.

b. Examine the installed equipment cockpit layout with emphasis on equipment controls, applicable circuit breakers (labels and accessibility), switching arrangement and related indicators, displays, annunciators, etc.

c. Analyze the data flow diagram to review which equipment transmits what data to which other equipment.

d. Review the equipment installation structural analysis to ascertain whether all system components are satisfactorily attached to the basic aircraft structure.

e. Examine the electrical load analysis to verify that the system installation's added electrical power requirements will not cause overloading of the aircraft's electrical generating capacity.

f. Evaluate the integration with the associated lateral navigation equipment.

23-3. Flight Test.

23-3.1 Functional Flight Test.

a. Evaluate all baro-VNAV equipment operating modes.

b. Examine the interface (function) of other equipment connected to the baro-VNAV system.

c. Review various failure modes and associated annunciations, such as loss-of electrical power, loss of lateral navigation signals, baro-VNAV equipment failures, etc.

d. Evaluate steering response while the autopilot is coupled to the baro-VNAV equipment during a variety of lateral and vertical track changes including selection of baro-VNAV modes while operating at the maximum and minimum speeds approved for baro-VNAV use.

e. Evaluate displayed baro-VNAV navigation parameters on interfaced flight deck instruments such as an HSI, CDI, etc. Evaluate how distance to go, course, bearing, etc. are displayed on all flight deck presentations during approach procedures when step-down fixes are included in the navigation database (see paragraphs 12-8 and 18-2.b).

f. If equipped, when temperature compensation is enabled ensure that the display of corrected altitude(s) is consistent on all displays in the cockpit.

g. Assess all switching and transfer functions pertaining to the baro-VNAV equipment including high-power electrical loads and electrical bus switching.

h. Evaluate whether magnetic or radio frequency interference exists between the baro-VNAV equipment installation and other onboard equipment, or vice versa.

i. Evaluate the accessibility of all controls pertaining to the baro-VNAV system installation.

j. Evaluate the display(s) and annunciator(s) visibility pertaining to the baro-VNAV system installation during day and night lighting conditions. No distracting cockpit glare or reflections may be introduced.

k. Analyze crew workload and determine acceptability when operating the baro-VNAV equipment.

23-3.2 Navigation Error Flight Test.

a. The initial certification of each baro-VNAV system to be used for IFR approach operations should be based on a system performance demonstration by recording the baro-VNAV equipment vertical guidance and comparing it to the actual aircraft position along a pre-established vertical flight path. This evaluation can be made by using the actual coded path and appropriate path definition.

b. Data should be gathered using a variety of descent rates, angles, and lateral navigation source inputs available to the baro-VNAV system.

> **Note 1:** GPS/SBAS LNAV/VNAV most closely emulates baro-VNAV performance. See paragraph 18-5 for a description of GPS/SBAS versus baro-VNAV differences.
>
> **Note 2:** Some baro-VNAV implementations may provide ascent guidance as well for the missed approach segment or for applications other than approach operations. Data should also be gathered for ascent guidance if the equipment provides that capability.

c. The data should demonstrate that the appropriate accuracy criteria of paragraph 11-2.b are met on a 99.7% probability basis.

d. Flights should verify proper operation of caution indications and lateral navigation interface.

e. Normal flight maneuvers should not cause loss of system sensor inputs and the system dynamic response should be confirmed.

f. Evaluate any unusual flight technical errors or errors from using the autopilot and FD.

23-4. Follow-on Approval.

The applicant or installing agency requesting a follow-on baro-VNAV system installation using FAA Form 337 field approval should:

a. Contact either the manufacturer or organization responsible for obtaining the first-time airworthiness approval to:

(1) Obtain a sample AFMS/RFMS (or supplemental flight manual, as appropriate).

(2) Obtain verification of the equipment approval status, including the software program identification and lateral navigation equipment that may be interfaced with the system.

(3) Discuss any problem areas and seek assistance in their solution.

b. Conduct a similar data evaluation as outlined in the paragraph 23-2.2 for baro-VNAV initial approval.

c. Conduct flight evaluations similar to the flight tests outlined in paragraph 23-3.1 for baro-VNAV initial approval.

d. Verify that the maximum expected groundspeed of the aircraft is less than the maximum operating speed for which the baro-VNAV equipment is qualified.

e. Spot check baro-VNAV approach performance by conducting an evaluation flight incorporating at least three ILS approaches comparing baro-VNAV vertical guidance to that provided by the ILS glideslope and three non-precision approaches that normally don't include vertical guidance (such as LNAV) to a specified minimum descent altitude (not a descent angle).

> **Note:** It is also acceptable to compare baro-VNAV performance to GPS/SBAS LPV, GPS/SBAS LNAV/VNAV or GPS/GBAS GLS vertical guidance in lieu of ILS. GPS/SBAS LNAV/VNAV most closely emulates the baro-VNAV performance.

f. Accuracy should be verified by comparison to the ILS glideslope indication and altimeter reading.

g. The purpose of this evaluation flight is not to validate baro-VNAV navigation error values, but rather to verify that, in the course of this installation, nothing was done to compromise the accuracy of the system as determined by the initial approval.

h. Significant differences between the vertical path data provided by the ILS glideslope and/or altimeter and baro-VNAV equipment must be evaluated to determine possible causes. If a logical explanation is not available, additional flight test data points should be collected. If such error(s) persist, installation approval must be withheld.

Appendix 1. GPS Oceanic/Remote Navigation.

A1-1. GPS Oceanic/Remote Navigation.

a. The following criteria define an acceptable means of compliance for approval of TSO-C129(AR) GPS equipment intended for oceanic and remote operation without reliance on other long-range navigation systems. This approval is granted as a non-TSO function according to existing policy. Equipment that previously demonstrated compliance to Notice 8110.60 or previous revisions of AC 20-138, appendix 1 are still eligible for oceanic and remote operation and do not need re-evaluation.

> **Note 1:** TSO-C129a has been cancelled but equipment with an existing TSO-C129a TSOA may receive approval for oceanic/remote operation without reliance on other long range navigation systems.

> **Note 2:** The FAA has adopted the ICAO term “oceanic/remote” instead of Class II.

b. TSO-C196(AR) and TSO-C145/C146(AR) equipment are inherently capable of supporting this operation without further evaluation if the operator obtains an FDE prediction program (see paragraph 5-2.3). Equipment manufacturers may choose to provide further robustness for oceanic and remote area operations by including barometric aiding in their FDE algorithms. Appendix G of RTCA/DO-316 and RTCA/DO-229D, Change 1 provide an acceptable barometric aiding implementation method for TSO-C196(AR) and TSO-C145/C146(AR) equipment respectively.

> **Note:** Barometric aiding enables the equipment to continue providing integrity when only four satellites are available for use in the position solution. Appendix G of RTCA/DO-229C for TSO-C145a/C146a equipment is identical to appendix G in RTCA/DO-229D, Change 1.

A1-2. Approval Process

a. TSO Authorization.

The criteria in this appendix are in addition to the TSO-C129(AR) requirements and approved as a non-TSO function. The ACO should issue a separate letter of design approval stating that the equipment (including part number) and software prediction program (including revision number) meet the criteria in this appendix. The applicant should be able to substantiate equivalent performance between the FDE prediction program and the airborne receiver algorithm. See paragraph 5-2.3 for information on FDE prediction program performance.

b. Installation Approval.

(1) The applicant obtains the GPS navigation equipment installation approval.

(2) If the equipment manufacturer has previously obtained a letter of design approval as described in paragraph A1-1.a of this appendix, further evaluation as described in paragraphs A1-2 and A1-3 of this appendix is not required.

(3) If the equipment manufacturer has not obtained a letter of design approval, then the applicant must demonstrate compliance with the requirements in paragraphs A1-2.b(4) through A1-3 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 equipment with a mean time between failures of at least 1000 hours each (for dual equipage).

(5) Once the installation has been approved, the AFMS/RFMS should be updated to state: "The XXX GPS equipment as installed has been found to comply with the requirements for GPS oceanic/remote navigation without reliance on other long-range navigation systems when used in conjunction with the XXX prediction program. This does not constitute an operational approval."

Note 1: The term “primary means” is obsolete. This updated AFMS/RFMS language is a clarification of previous guidance.

Note 2: The FAA has adopted the ICAO term “oceanic/remote” instead of Class II.

c. Operational Approval.

The applicant should be aware that an operational approval must be obtained before conducting oceanic/remote navigation. Applicants should contact the appropriate flight standards district office to seek operational approval.

A1-3. Equipment Performance.

a. TSO-C129(AR).

The GPS equipment must have an existing TSO-C129(AR) TSOA.

b. Fault Detection and Exclusion.

(1) The GPS equipment must be able to detect and exclude a GPS satellite failure by means of an FDE algorithm. The exclusion of a satellite failure must be automatic; pilot action is not permitted to accomplish exclusion. Additional augmentations (such as clock aiding or barometric aiding) are not precluded if equipment manufacturers choose to implement these methods to increase FDE robustness. FDE terms are defined in RTCA/DO-316, and RTCA/DO-316 appendix G provides an acceptable barometric aiding implementation method.

(a) Missed alert probability. The probability of missed alert must be less than or equal to 0.001 for every geometry and every navigation mode. This requirement is on the missed alert rate external to the GPS equipment. When related to the internal algorithm, it includes both probabilities of missed detection and false exclusion.

(b) False alert probability. The probability of false alert must be less than or equal to 0.002/hour. This requirement is on the false alert rate external to the GPS equipment. When related to the internal algorithm, it includes both probabilities of false detection and the failure to exclude the false detection.

(c) Failed exclusion probability. The probability of failed exclusion must be less than or equal to 0.001 for every geometry and every navigation mode for which exclusion is implemented. Exclusion must be implemented for the oceanic mode. This requirement is on the alert rate external to the GPS equipment due to failed exclusion.

(d) Time-to-alert. The time-to-alert for oceanic/remote navigation mode is defined to be at least 30 seconds, but must not exceed 5 minutes.

(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.

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

(b) 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 and fault detection is available. The equipment 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).

(3) 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. RTCA/DO-316, paragraph 2.1.1.3.2 provides a description of the parameters that must be checked.

(4) If a GPS satellite failure results in loss of GPS navigation (due to the failure to exclude or due to loss of a critical satellite), an appropriate failure indication must be provided to the flight crew.

(5) It is recommended that the equipment provide, upon request, an indication of the current estimate of position uncertainty in nautical miles.

(a) This estimate must be based on measurement inconsistency and must bound the true error with high confidence (approximately 99.9 percent).

(b) This estimate will not be available if there are only four measurements available (because there is no redundancy).

(c) This position uncertainty estimate is equivalent to the Horizontal Uncertainty Level (HUL) that is an optional output for TSO-C196(AR) and TSO-C145(AR)/C146(AR) equipment, and provides the most time for the exclusion algorithm to exclude the failure without increasing the probability of a missed alert.

(d) This output is intended to provide information about the approximate magnitude of a potential positioning failure, when the horizontal protection level exceeds the alert limit or when a positioning failure has been detected, but not excluded.

Appendix 2. RNP AR Operations.

A2-1. Introduction.

a. This appendix describes the aircraft performance, functional criteria, and installation considerations for aircraft to qualify for RNP AR approaches. The information presented in this appendix has some necessary changes, mostly due to formatting and grammar, but also provides additional clarification information. This AC will take precedence for aircraft qualification if there are any perceived conflicts with the latest revision of AC 90-101. See the latest revision of AC 90-101 for operational approval guidance information.

b. Applicants may establish compliance with this appendix as part of a type certification or supplemental type certification and document this in the aircraft flight manual (supplement). The TC holder of a previously certified aircraft can document compliance with these aircraft qualification criteria without a new airworthiness project (e.g., without AFM/RFM change), and should advise the appropriate ACO of any new performance the original airworthiness approval did not cover. The AFM/RFM or other aircraft qualification evidence should address: the required modes of operation to fly an RNP AR approach; the normal and abnormal flight crew operating procedures; responses to failure alerts and annunciations; and any other operating limitations.

c. FAA headquarters retains oversight of all applications for operations approval to conduct RNP AR operations. To avoid delays in processing these operations applications and confirming aircraft qualification, Aircraft Certification field offices should coordinate all RNP AR aircraft qualification airworthiness applications with the Navigation and Flight Technologies section (AIR-131) at FAA headquarters. Coordinating the application with AIR-131 will ensure the aircraft qualification requirements are met and documented in a manner facilitating an applicant's expeditious RNP AR operations approval.

d. The FAA strongly recommends RNP AR airworthiness applicants (i.e., the TC or STC holder) include a deviation alerting function for excess lateral or vertical deviation during RNP AR approach operations. The intent for this function is to prevent controlled flight into terrain or obstacles during RNP AR operations.

> **Note 1:** This recommendation applies whether the aircraft uses baro-VNAV vertical guidance or GPS/SBAS vertical guidance during RNP AR approach operations.

> **Note 2:** Aircraft with existing, approved deviation alerting functions supporting RNP AR approach operations in service prior to 2016 meet the intent of this guidance.

(1) The deviation alerting function need not be accomplished through the aircraft’s GPWS or TAWS equipment, as this may not be practical from a systems engineering perspective. Applicants may base the alert on flight technical error or total system error.

(2) The FAA recommends applicants provide an alert no later than when a

deviation reaches operational deviation limits for RNP AR approach operations. An alert should occur when a glidepath deviation reaches or exceeds 75 feet; or when a lateral deviation reaches or exceeds a distance equivalent to one times the RNP value in use (i.e., 1×RNP). More conservative alerting schemes are acceptable.

(3) The deviation alert should occur within 10 seconds of reaching a lateral or vertical deviation limit consistent with the RNP AR procedure design assumptions.

(4) The deviation alert may be aural, visual or both. The alert should be easily recognized by the pilot; and, when the implementation uses a visual alert, the visual alert should be in the pilot's primary field of view.

> **Note:** The airworthiness applicant should be cognizant of the existing alerts on the aircraft when implementing the deviation alerting function. The deviation alerting function should not conflict with existing alerts or cause flight crew human factors issues. The deviation alerting should not supersede and prevent initiation of other mandatory alerting functions.

e. The RNP AR airworthiness applicant (i.e., the TC or STC holder) should consider developing: an operations manual detailing flight crew/pilot procedures for executing RNP AR operations; detailed suggestions on training for RNP AR operations; and any necessary maintenance plan(s) for the aircraft to enable ongoing RNP AR operations. The applicant should complete these concurrent with the airworthiness approval to assist operators with their RNP AR operations approval. Use of these standardized products could streamline the operator's RNP AR operational approval. See the latest revision of AC 90-101 for operational approval information.

f. In addition to the specific RNP AR guidance in this appendix, the aircraft's positioning and navigation system(s) must comply with the applicable chapters in this AC.

A2-2. Performance Requirements.

This paragraph defines the general performance requirements for aircraft qualification. Paragraphs A2-3, A2-4, and A2-5 of this appendix provide guidance material on an acceptable means of satisfying these requirements.

a. Path Definition.

The published instrument approach procedure defines the path the aircraft must use to evaluate performance. The aircraft's navigation system will also define the vertical path in the final approach segment by a flight path angle and as a straight line emanating from a fix and altitude.

b. Lateral Accuracy.

The navigation system must provide lateral guidance so aircraft remain within the lateral boundaries of the defined RNP AR procedure at one times the RNP value in use (1×RNP, 95%).

c. Vertical Accuracy.

The vertical system error includes altimetry system error (assuming the temperature and lapse rates of the International Standard Atmosphere), the effect of along-track error, system computation error, data resolution error, and flight technical error. The 99.7% of system error in the vertical direction must be less than the following (in feet):

$$\sqrt{[(6076.115)(1.225)RNP\tan\theta]^2 + (60\tan\theta)^2 + 75^2 + [(-8.8\times10^{-8})(h+\Delta h)^2 + (6.5\times10^{-3})(h+\Delta h) + 50]^2}$$

where θ is the vertical navigation path angle, h is the height of the local altimetry reporting station and Δh is the height of the aircraft above the reporting station.

d. Airspace Containment.

The FAA publishes RNP AR approaches as performance-based approaches. As such, they do not inherently require any specific technology or procedure, but instead require a level of performance.

(1) RNP AR and baro-VNAV.

Establishing compliance to a required level of performance can be difficult. This appendix describes an acceptable means of achieving the required navigation performance. This appendix provides a detailed acceptable means of compliance for aircraft using an RNAV system relying primarily on GNSS and a VNAV system relying on barometric altimetry. Aircraft complying with this appendix provide the requisite airspace containment.

(2) Other Systems or Alternate Means of Compliance.

The probability of the aircraft exiting the lateral and vertical extent of the obstacle clearance volume must not exceed 10^{-7} per approach, including the missed approach. An operator may satisfy this requirement through an operational safety assessment applying:

(a) Appropriate quantitative, numerical methods,

(b) Qualitative operational and procedural considerations and mitigations, or

(c) An appropriate combination of both quantitative and qualitative methods.

Note 1: If the aircraft does not remain within the obstacle clearance volume after annunciating the systems failure, then this requirement applies to the total probability of excursion outside the obstacle clearance volume. This includes events caused by latent conditions (integrity) and by detected conditions (continuity). When ensuring the aircraft does not exit the obstacle clearance volume, an analysis of the aircraft performance should consider the monitor limit of the alert, the latency of the alert, the crew reaction time, and any aircraft response to the alert. The requirement applies to a single approach, considering the exposure time of the operation, the navigation aid geometry, and navigation performance available for each published approach.

Note 2: This containment requirement derives from the operational requirement. This requirement is notably different than the containment requirement specified in RTCA/DO-283B and RTCA/DO-236C, Chg 1. The requirement in RTCA/DO-283B and RTCA/DO-236C, Chg 1 facilitates airspace design and does not directly equate to obstacle clearance.

e. System Monitoring.

The critical components of RNP approach procedure implementation are the RNP requirements of the approach, the ability of the aircraft navigation system to monitor its navigation performance, and to alert the pilot when RNP requirements are not being met.

A2-3. RNP AR General Requirements.

The following information reflects required functions for RNP AR aircraft qualification.

a. TAWS.

(1) The aircraft must be equipped with a Class A TAWS to conduct RNP AR operations. The intent is to ensure the flight crew/pilot has the situation awareness benefits Class A TAWS provides.

(2) To continue eligibility for RNP AR operations, the aircraft's TAWS must contain the most current operating software and the most current terrain and obstacle database offered by the TAWS manufacturer. During a formal RNP AR aircraft qualification airworthiness project, the aircraft manufacturer should establish continuing airworthiness procedures requiring the aircraft operator to keep both the TAWS operating software and the TAWS onboard terrain and obstacle database current. When these procedures are not part of the aircraft manufacturer’s documented RNP AR qualification, the operator must establish procedures to keep the TAWS operating software and terrain and obstacle database current. The operator should include these procedures in their operational application to conduct RNP AR operations.

Note: The intent behind this paragraph is to install updates that correct software deficiencies affecting the TAWS intended function and airworthiness. There is no intent to force installation of new functions or features.

(3) The position solution for the TAWS must be sourced directly from a GNSS sensor or a tightly-coupled GNSS/inertial system without any reference to or interchange with the RNP equipment's (e.g., FMS) position solution output.

Note: There is no intent to exclude a Kalman-filtered position solution taken directly from a tightly-coupled GNSS/inertial sensor.

(4) The TAWS should use altitude that is compensated for local pressure and temperature effects (e.g., corrected barometric or Global Navigation Satellite System (GNSS) altitude). The altitude compensation should not require flight crew/pilot action or input and must not impact the primary barometric altimeter system's function.

b. Position Estimation.

The navigation system must estimate the aircraft's position. This appendix identifies unique issues for the navigation sensors within the context of RNP AR instrument approaches.

(1) GNSS.

(a) The GNSS sensor must comply with the guidelines in chapter 5 of this AC. The total system accuracy analysis may use the following sensor accuracies without additional substantiation: GPS sensor accuracy better than 36 meters (95%), and augmented GPS/SBAS sensor accuracy is better than 2 meters (95%).

Note: Sensors processing other GNSS' may also be able to provide similar or better accuracies without further substantiation. This guidance can be updated once countries with other GNSS' provide an assured statement of operational system accuracy.

(b) In the event of a latent GNSS satellite failure and marginal GNSS satellite geometry (e.g., horizontal protection level (HPL) equal to the horizontal alert limit (HAL) or vertical protection level (VPL) equal to the vertical alert limit (VAL)), the probability the total system error remains within the procedure design obstacle clearance volume must be greater than 95% (both laterally and vertically).

Note: GPS-based sensors output an HPL (see RTCA/DO-229D, Change 1 for definition) that is sometimes referred to as horizontal integrity limit (HIL). The HPL is a measure of the position estimation error assuming a latent failure is present. In lieu of a detailed analysis of the effects of latent failures on the total system error, an acceptable means of compliance for GPS-based systems is to ensure the HPL remains less than twice the RNP value, minus the FTE 95%, (i.e. HPL < ((2*RNP) - FTE 95%)) during the RNP AR approach operation.

(c) A TSO-C145(AR) Class 3 sensor may be used for linear (or angular) vertical guidance. The GPS/SBAS sensor must be within the GPS/SBAS service volume and in an integrity mode that outputs a GPS/SBAS-generated VPL.

Note 1: The navigation computer will adjust the HPL according to its mode. One acceptable integration is using the K_H constant (described in RTCA/DO-229D, Change 1, appendix J) on the interface bus for adjusting the HPL if the sensor provides a K_H output.

Note 2: GPS/SBAS vertical guidance with a 50m VAL has been shown to be consistent with the required total system performance for operations down to RNP 0.23. A 35m VAL is consistent with required performance for operations down to RNP 0.1. These values were validated through FAA technical analysis and flight test. The use of these values requires no further navigation system substantiation.

Note 3: Using GPS/SBAS vertical guidance precludes the need for independent monitoring as prescribed by AC 90-101 (latest revision), appendix 4, paragraph 3.h.

(2) IRS.

An IRS must satisfy the criteria of 14 CFR part 121, appendix G. While appendix G defines the requirement for a 2 NM per hour drift rate (95%) for flights up to 10 hours, this rate does not apply to an RNAV system after loss of position updating. Applicants may assume an IRS demonstrating compliance with 14 CFR part 121, appendix G experiences an initial drift rate of 4 NM for the first 30 minutes (95%) without further substantiation. However, aircraft manufacturers and applicants can choose to demonstrate better inertial performance.

Note: Integrated GNSS/IRU position solutions reduce the rate of degradation after loss of position updating. For “tightly coupled” GNSS/IRU’s, RTCA/DO-229D, appendix R, provides additional guidance.

(3) DME.

GNSS-updating is the basis for initiating all RNP AR approach procedures. The aircraft may use DME/DME-updating as a reversionary navigation mode during an RNP AR approach or missed approach when the navigation system continues to comply with the required RNP value. The applicant should also identify any requirements for the DME infrastructure and/or any necessary operational procedures and limitations to conduct an RNP AR approach procedure through aircraft position updating using DME/DME.

(4) VOR.

The aircraft's RNAV system may not use VOR-updating when conducting public RNP AR instrument approach procedures. The applicant should identify any constraints on the VOR infrastructure or the procedure for a given aircraft to comply with this requirement.

> **Note:** This paragraph does not imply an equipment capability must exist providing a direct means of inhibiting VOR updating. An operational procedure requiring the flight crew to inhibit VOR-updating or a procedure requiring the flight crew to execute a missed approach upon annunciation of reversion to VOR-updating may meet this requirement.

(5) Multi-Sensor Systems.

For multi-sensor systems, there must be automatic reversion to an alternate RNAV sensor if the primary RNAV sensor fails. There need not be automatic reversion from one multi-sensor system to another multi-sensor system.

(6) Altimetry System Error.

The 99.7% aircraft altimetry system error for each aircraft (assuming the temperature and lapse rates of the International Standard Atmosphere) must be less than or equal to the following with the aircraft in the approach configuration:

$$ASE = -8.8 * 10^{-8} * H^2 + 6.5 * 10^{-3} * H + 50 \text{ (ft)}$$

where H is the true altitude of the aircraft.

(7) Temperature Compensation Systems.

Temperature compensation systems with an airworthiness approval providing automatic corrections to the baro-VNAV guidance must comply with RTCA/DO-283B, appendix H. The applicant should document compliance to this standard to allow the operator to conduct RNP approaches when the actual temperature is below or above the published procedure temperature design limits.

c. Path Definition and Flight Planning.

(1) Maintaining Track and Leg Transitions.

The aircraft must have the capability to execute leg transitions and maintain tracks consistent with the following paths:

(a) A geodesic line between two fixes (TF);

(b) A direct path to a fix (DF);

(c) A specified track to a fix, defined by a course (CF), and

(d) A specified track to an altitude (FA).

Note 1: Industry standards for these paths can be found in RTCA/DO-283B, and ARINC Specification 424, which refer to them as TF, DF, CF, and FA path terminators. Also, certain procedures require RF legs as described in paragraph A2-4 and appendix 3. ED-75, RTCA/DO-236C Chg 1, RTCA/DO-283B, and ED-77/RTCA DO-201A describe the application of these paths in more detail.

Note 2: The navigation system may accommodate other ARINC 424 path terminators (e.g., heading to manual terminator (VM)); and the missed approach procedure may use these types of paths when there is no requirement for RNP containment.

(2) Fly-By and Fly-Over Fixes.

The aircraft must have the capability to execute fly-by and fly-over fixes. For fly-by turns, the navigation system must limit the path definition within the theoretical transition area defined in RTCA/DO-236C, Chg 1 and RTCA/DO-283B under the wind conditions identified in Table 11. Since the fly-over turn is not compatible with RNP flight tracks, an RNP AR procedure design will use a fly-over turn at a fix only when there is no requirement for RNP containment.

Note: The RTCA documents do not address fly-over fix theoretical transition area since there is no requirement for RNP containment. Fly-over fixes are addressed in TSO-C115d, appendix 1.

Turn Height Above Airport (Feet)	Standard Tailwind Component (Knots)*	
500	25	
	Standard	AFS-400 Approval
1,000	37.5	30
1,500	50	35
2,000	50	40
2,500	50	45
3,000	50	
3,500	55	
4,000	60	
4,500	65	
5,000	70	
5,500	75	
6,000	80	
6,500	85	
7,000	90	
7,500	95	
8,000	100	
8,500	105	
9,000	110	
9,500	115	
10,000	120	
10,500	125	
≥11,000	130	

Table 11. Tailwind Component (V_{KTW}) for Turn Calculations

*Other tailwind gradients may be used after a site-specific determination of wind based on that location's meteorological history (using available information from other sources). Document the source and value used on the procedure form (the FAA uses Form 8260-9).

Note: A new tailwind component may be interpolated for turns initiated at an altitude located between the values in Table 11. The 0 ft value for wind is 15 knots if an interpolated value is ever used below 500 ft.

(3) Waypoint Resolution Error.

The navigation database must provide sufficient data resolution to ensure the navigation system achieves the required accuracy. Waypoint resolution error must be less than or equal to 60 feet, including both the data storage resolution and the RNAV system computational resolution used internally for flight plan waypoint construction. The navigation database must contain vertical angles (flight path angles) stored to a resolution of hundredths of a degree, with computational resolution such that the system-defined path is within 5 feet of the published path.

(4) Capability for a "Direct-To" Function.

The navigation system must have a "Direct-To" function the flight crew can activate at any time. This function must be available to any fix. The navigation system must also be capable of generating a geodesic path to the designated "To" fix, without "S-turning" and without undue delay.

Note: The applicant should identify any limitations associated with the operational use of the aircraft navigation system's "Direct-To" functions. For example, if there are limitations associated with intercepting an RF leg segment, then the flight manual or aircraft qualification guidance should identify those limitations.

(5) Capability to Define a Vertical Path.

The navigation system must be capable of defining a vertical path by a flight path angle to a fix. The system must also be capable of specifying a vertical path between altitude constraints at two fixes in the flight plan. The navigation system must also define fix altitude constraints as one of the following:

(a) An "AT or ABOVE" altitude constraint (for example, 2400A, may be appropriate for situations where bounding the vertical path is not required);

(b) An "AT or BELOW" altitude constraint (for example, 4800B, may be appropriate for situations where bounding the vertical path is not required);

(c) An "AT" altitude constraint (for example, 5200); or

(d) A "WINDOW" constraint (for example, 2400A3400B).

(6) Altitudes and/or Speeds.

The navigation system must extract the altitudes and/or speeds defined in published terminal procedures from the onboard navigation database.

(7) Path Construction.

The navigation system must be able to construct a path to provide guidance from the current position to a vertically constrained fix.

(8) Capability to Load Procedures from the Navigation Database.

The navigation system must have the capability to load the entire procedure(s) to be flown into the RNAV system from the onboard navigation database. This includes the approach (including vertical angle), the missed approach, and the approach transitions for the selected airport and runway.

(9) Means to Retrieve and Display Navigation Data.

The navigation system must provide the ability for the flight crew to verify the procedure to be flown through review of the data stored in the onboard navigation database. This includes the ability to review the data for individual waypoints and for navigation aids.

(10) Magnetic Variation.

For paths defined by a course (CF and FA path terminators), the navigation system must use the magnetic variation value for the procedure in the navigation database. The navigation database must accurately represent the procedure as promulgated by the procedure designer, including the magnetic variation used in the procedure design.

Note: The above guidance is for using magnetic variation in the navigation computer for path generation.

(11) Changes in RNP Value.

RNP changes to lower RNP values must be complete by the first fix defining the leg with the lower RNP value. Any operational procedures necessary to meet this requirement must be identified.

Note: One acceptable means to meet this requirement may be to require the flight crew to manually set the lowest RNP value the RNP AR procedure uses before commencing the procedure (i.e., prior to the initial approach fix).

(12) Automatic Leg Sequencing.

The navigation system must provide the capability to automatically sequence to the next leg and display the sequencing to the flight crew in a readily visible manner.

(13) Altitude Restriction Display.

A display of the altitude restrictions associated with flight plan fixes must be available to the pilot. If there is an RNP AR procedure with a flight path angle associated with any flight plan leg, the equipment must display the flight path angle for that leg.

d. Flight Technical Error.

The applicant must confirm ability to maintain FTE (95 percent of the flying time) during straight and curved path segments (see paragraph 17-2).

e. Displays.

(1) Continuous Display of Deviation.

(a) The navigation system must provide the capability to continuously display to the pilot flying, on the primary flight instruments for navigation of the aircraft, the aircraft position relative to the RNAV defined path (both lateral and vertical deviation). The display must allow the pilot to readily distinguish if the cross-track deviation exceeds the RNP value (or a smaller value) or if the vertical deviation exceeds 75 feet (or a smaller value).

(b) The aircraft should have an appropriately-scaled, non-numeric deviation display (i.e., lateral deviation indicator and vertical deviation indicator) in the pilot's primary optimum field of view. A fixed-scale CDI is acceptable as long as the CDI demonstrates appropriate scaling and sensitivity for the intended RNP value and operation. With a scalable CDI, the scale should derive from the selection of RNP, and should not require the separate selection of a CDI scale. Alerting and annunciation limits must also match the scaling values. If the equipment uses default RNP values to describe the operational mode (e.g., enroute, terminal area and approach), then displaying the operational mode is an acceptable means from which the flight crew may derive the CDI scale sensitivity.

(c) In lieu of appropriately scaled lateral and vertical deviation indicators in the pilot's primary optimum field of view, a numeric display of deviation may be acceptable depending on the flight crew workload and the numeric display characteristics.

(2) Identification of the Active (TO) Waypoint.

The navigation system must provide a display identifying the active waypoint either in the pilot's primary optimum field of view, or on a readily accessible and visible display to the flight crew.

(3) Display of Distance and Bearing.

The navigation system must provide a display of distance and bearing to the active (TO) waypoint in the pilot's primary optimum field of view. Where not viable, a readily accessible page on a control display unit, readily visible to the flight crew, may display the data.

(4) Display of Groundspeed and Time.

The navigation system must provide the display of groundspeed and time to the active (TO) waypoint in the pilot's primary optimum field of view. Where not viable, a readily accessible page on a control display unit, readily visible to the flight crew, may display the data.

(5) Display of TO/FROM the active waypoint.

The navigation system must provide a TO/FROM display in the pilot's primary optimum field of view.

Note: See paragraph 8-3.g(2) for TO/TO navigation computer displays.

(6) Desired Track Display.

The navigation system must have the capability to continuously display to the pilot flying the aircraft the RNAV desired track. This display must be on the primary flight instruments for aircraft navigation.

(7) Display of Aircraft Track.

The navigation system must provide a display of the actual aircraft track (or track angle error) either in the pilot's primary optimum field of view or on a readily accessible and visible display to the flight crew.

(8) Failure Annunciation.

The aircraft must provide a means to annunciate failures of any aircraft component of the RNAV system, including the navigation sensors. The annunciation must be visible to the pilot and located in the primary optimum field of view.

(9) Slaved Course Selector.

The navigation system must provide a course selector automatically slaved to the RNAV computed path.

(10) RNAV Path Display.

Where the minimum flight crew is two pilots, the navigation system must provide a readily visible means for the pilot monitoring to verify the aircraft's RNAV defined path and the aircraft's position relative to the desired path.

(11) Display of Distance to Go.

The navigation system must provide the ability to display distance to go to any waypoint selected by the flight crew.

(12) Display of Distance Between Flight Plan Waypoints.

The navigation system must provide the ability to display the distance between flight plan waypoints.

(13) Display of Deviation.

The navigation system must provide a numeric display of the vertical deviation with a resolution of 10 feet or less, and the lateral deviation with a resolution of 0.01 NM or less.

(14) Display of Barometric Altitude.

The aircraft must display barometric altitude from two independent altimetry sources, one in each pilots' primary optimum field of view to support an operational cross check of altitude sources.

Note 1: If the aircraft includes the ability to automatically compare the output of the independent altitude sources, including independent aircraft static air pressure systems, and the aircraft can provide an alert in the pilot's primary optimum field of view when deviations between the sources exceed ±100 feet, then the applicant should document this comparator monitoring function in the AFM/RFM or aircraft qualification guidance.

Note 2: As stated in paragraph A2-3.b(1)(c) note 3 of this appendix, using GPS/SBAS vertical guidance precludes the need for independent monitoring as prescribed by AC 90-101 (latest revision), appendix 4, paragraph 3.h.

(15) Display of Active Sensors.

(a) The aircraft must display the current navigation sensor(s) in use. The aircraft should provide this display in the primary optimum field of view.

Note: Flight crew procedures may mitigate the need for this display if the applicant and/or operator can demonstrate the flight crew workload is acceptable.

(b) In-service aircraft that do not display the current navigation sensor in use may still be eligible for RNP AR approach operations. To be eligible, the aircraft manufacturer must demonstrate continued RNP AR approach performance when GNSS is lost (for example, through inertial navigation) and continue to monitor/annunciate loss of RNP capability (i.e., annunciating "Unable RNP"). Since the loss of GNSS is unlikely:

(i) The aircraft performance must show the conditional probability the aircraft exits the final approach obstacle clearance volume is less than 0.001 (one in a thousand). This ensures that 999 times out of 1000 the aircraft can complete an RNP AR approach when a loss of GNSS occurs.

(ii) To support execution of the missed approach procedure, the aircraft performance must show the conditional probability the aircraft exits the missed approach obstacle clearance volume is less than 0.01 (one in a hundred). This will ensure that 99 times out of 100 the aircraft can complete a missed approach procedure from the lowest minimums following loss of GNSS.

Note 1: Executing a missed approach is unlikely given the weather condition requirements to begin an RNP AR approach procedure. Therefore, the conditional probability requirement for the procedure's missed approach is less stringent than the performance requirement for the procedure's final approach segment.

Note 2: The aircraft manufacturer may conduct the aircraft performance demonstration through laboratory and simulation analysis. Flight test data collection and demonstration in the actual aircraft is not required.

f. Hazard Affects.

(1) The system must be consistent with at least a major failure condition for the display of misleading lateral or vertical guidance on an RNP AR approach.

(2) The system must be consistent with at least a major failure condition for the loss of lateral guidance and a minor failure condition for loss of vertical guidance on an RNP AR

approach.

> **Note 1:** Loss of vertical guidance is considered a minor failure condition because the pilot can take action to stop descending or climb when guidance is lost.

> **Note 2:** The guidance in paragraph A2-3.f of this appendix is consistent with the intent of AC 90-101A. However, AC 90-101A contains an editorial error that could cause confusion among RNP AR 0.3 and less than 0.3 for misleading guidance versus loss of guidance.

g. Navigation Database.

The aircraft navigation system must use an on-board navigation database that can:

- Receive updates in accordance with the AIRAC cycle; and
- Allow retrieval and loading of RNP AR procedures into the RNAV system.

h. Database Protection.

(1) The aircraft's navigation system must not permit the flight crew to modify the stored data in the onboard navigation database.

> **Note:** When the flight crew selects and loads a procedure from the onboard navigation database, the RNAV system must execute the procedure as published. This does not preclude the flight crew from having the means to modify a procedure or route already loaded into the RNAV system. However, no modification of the procedures stored in the onboard navigation database may occur, and the procedures must remain intact within the onboard navigation database for future use and reference.

(2) The aircraft must provide a means to display the validity period for the onboard navigation database to the flight crew.

A2-4. Requirements for RNP AR Approaches with RF Legs.

RNP AR procedures may have RF legs intercept the final approach segment of approaches inside the final approach fix and the RNP value of the RF legs can be less than 1.0. RNP AR applicants including RF leg capability must ensure the aircraft systems will support these features. See appendix 3 for detailed RF leg guidance. The AFM(S)/RFM(S) or aircraft qualification guidance should identify whether or not RF leg capability is provided.

A2-5. Requirements for RNP AR Approach values less than 0.3.

The AFM/RFM or aircraft qualification documentation should identify if the aircraft is capable of using lines of minima associated with RNP less than 0.3, and which equipment configuration is required to achieve this capability (e.g., dual autopilots may achieve a smaller RNP capability than dual FDs).

a. No single-point-of-failure can cause the loss of guidance compliant with the RNP value associated with the approach. Typically, the aircraft must have at least the following equipment: dual GNSS sensors, dual FMSs, dual air data systems, dual autopilots, and a single inertial reference unit (IRU).

b. The system must be consistent with at least a hazardous (severe-major) failure condition for the display of misleading lateral or vertical guidance on an RNP AR approach where the procedure requires RNP less than 0.3 while executing an approach.

> **Note:** AC 20-174, *Development of Civil Aircraft and Systems*, provides an acceptable method for establishing design assurance levels and may be used to show compliance with this requirement. This guidance provides an acceptable method for establishing a design assurance process by taking into account the overall aircraft operating environment and the independent functions of the aircraft's systems.

c. The system must be consistent with at least a hazardous (severe-major) failure condition for the loss of lateral guidance and a minor failure condition for the loss of vertical guidance on an RNP AR approach where the procedure requires RNP less than 0.3 while executing an approach.

> **Note 1:** Directly meeting this requirement can substitute for the general requirement for dual equipment (described above).

> **Note 2:** Loss of vertical guidance is considered a minor failure condition because the pilot can take action to stop descending or climb when guidance is lost.

> **Note 3:** The guidance in paragraphs A2-5.b and A2-5.c of this appendix is consistent with the intent of AC 90-101A. However, AC 90-101A contains an editorial error that could cause confusion among RNP AR 0.3 and less than 0.3 for misleading guidance versus loss of guidance.

d. Upon initiating a go-around or missed approach (through activation of TOGA or other means), the flight guidance mode should remain in LNAV. If the aircraft does not provide the ability to remain in LNAV, then the following requirements apply:

(1) If the aircraft supports RF legs, the lateral path guidance after initiating a go-around (given a minimum 50-second straight segment between the RF end point and the DA) must be within 1 degree (1°) of the track defined by the straight segment through the DA point (see Figure 1). The prior turn can be of arbitrary angular extent and radius as small as 1 NM, with speeds commensurate with the approach environment and the radius of the turn.

(2) The flight crew must be able to couple the autopilot or FD to the RNAV system (engage LNAV) by 400 feet AGL.

e. After initiating a go-around or missed approach following loss of GNSS, the aircraft must automatically revert to another means of navigation that complies with the RNP value.

A2-6. Requirements for Approaches with a Missed Approach Segment Less Than RNP 1.0.

a. The AFM/RFM or aircraft qualification guidance should identify whether or not the aircraft can achieve less than RNP 1.0 when executing a missed approach procedure segment. The AFM/RFM or aircraft qualification guidance should also specify the aircraft configurations or modes of operation necessary to achieve RNP values less than 1.0 (e.g., dual autopilots may achieve a smaller RNP capability than dual FD).

b. No single-point-of-failure can cause the loss of guidance or loss of lateral guidance display with the RNP value associated with a missed approach procedure. Typically, the aircraft must have at least the following equipment: dual GNSS sensors, dual FMSs, dual air data systems, dual autopilots, and a single IRU.

(1) The system must be consistent with at least a major failure condition for the loss of lateral guidance compliant with the RNP value on an RNP AR missed approach segment that requires RNP less than 1.0.

> **Note:** What this means is, lateral guidance may still be available even though the RNP value cannot be maintained. As an example, an UNABLE RNP annunciation represents a loss of lateral guidance compliant with the RNP value. However, aircraft navigation remains available because lateral guidance is not lost; there is simply a loss of confidence and integrity in the lateral guidance.

(2) For RNP AR missed approach segment operations requiring less than 1.0, the total loss of display of lateral guidance to the flightcrew is a hazardous (severe-major) failure condition.

(3) The system must be consistent with at least a hazardous (severe-major) failure condition for the display of misleading lateral guidance where the RNP AR missed approach segment requires RNP less than 1.0.

Note: It may be possible to obtain approval for navigation functions that have hazardous level effects with FMS software developed to DO-178B or 'C' level C criteria. AC 20-174 provides an acceptable method for establishing design assurance levels. This guidance may be helpful for navigation architectures containing independent functions.

c. Upon initiating a go-around or missed approach (through activation of TOGA or other means), the flight guidance mode should remain in LNAV to enable continuous track guidance, particularly during an RF leg. If the aircraft does not provide this capability, the following requirements apply:

(1) If the aircraft supports RF legs, the lateral path after initiating a go-around (TOGA) (given a minimum 50 second straight segment between the RF end point and the DA) must be within 1 degree of the track defined by the straight segment through the DA point (see Figure 1). The prior turn can be of arbitrary angular extent and radius as small as 1 NM, with speeds commensurate with the approach environment and the radius of the turn.

(2) The flight crew must be able to couple the autopilot or FD to the RNAV system (engage LNAV) by 400 feet AGL.

d. After initiating a go-around or missed approach following loss of GNSS, the aircraft must automatically revert to another means of navigation that complies with the RNP value.

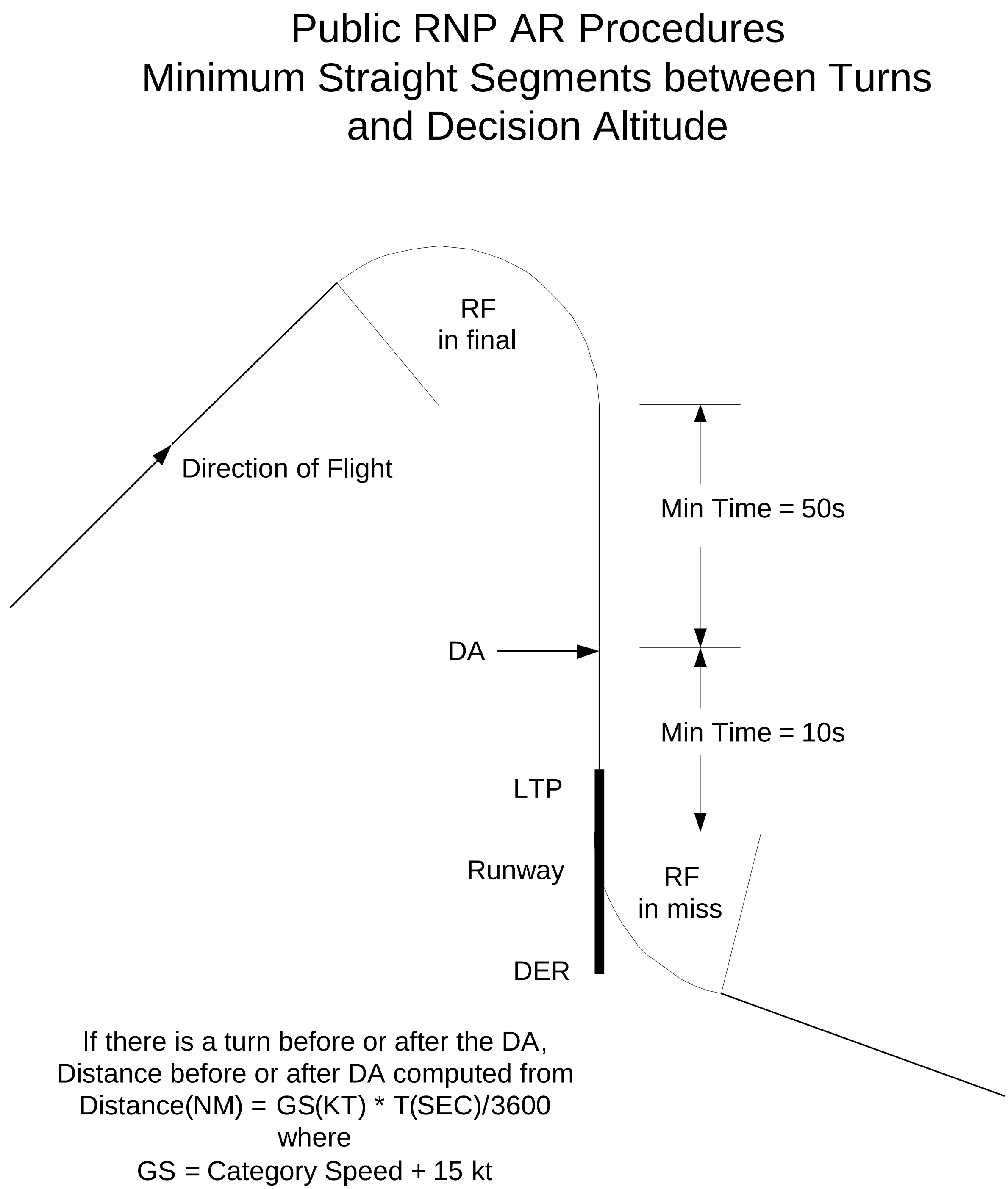

Figure 3. Minimum Straight Path Before DA

A2-7. Navigation Data Validation Program.

The aircraft's onboard navigation database defines the RNP AR procedure path and associated constraints, allowing for lateral and vertical guidance. In view of the reduced obstacle clearance associated with RNP AR procedures, the associated navigation database information warrants special attention and consideration. This paragraph provides guidance for validating RNP AR instrument approach data contained in aircraft navigation databases. The guidance in this paragraph applies in full to aircraft operators performing RNP AR instrument approach procedures, as well as to any other entity with which an operator may contract to provide navigation database validation services.

> **Note 1:** Although an aircraft operator may contract with an outside entity to perform navigation database validation services, the operator is responsible for ensuring the aircraft navigation database contains RNP AR instrument approach procedures validated in accordance with this appendix.

> **Note 2:** An aircraft operator's application to conduct RNP AR procedures should specifically describe the extent and nature of the services provided by an outside entity contracted to perform navigation database validation services.

a. Database Management Process.

The operator must identify in writing the individual responsible for managing the overall onboard navigation database process. The process and procedures for accepting, verifying and loading navigation data into the aircraft must be established in writing and maintained under configuration control (e.g., formal control of revisions and updates to the process). The operator may not contract out this responsibility to a third party.

b. RNP AR Procedure Data Validation.

The operator must ensure an RNP AR instrument approach procedure contained in its database has been validated before flying that approach procedure in IMC. The validation process ensures the RNP AR procedure contained in the navigation database accurately reflects the intended procedure design parameters. Proper data validation includes the following:

(1) Accuracy Check.

Compare the RNP AR procedure in the navigation database with the government source data. The FAA Form 8260-series, specifically form 8260-3 and 8260-10, and other government source data defining the procedure, are available at the FAA Aviation System Standards website. Data for international procedures is available via the respective country's aeronautical information publication (AIP). Any differences between the database and source data must be investigated. A list of the specific procedure data parameters that must be examined during this accuracy check, as well as the allowable differences between source data and that contained in the navigation database for each parameter can be found at the FAA's Performance Based Flight Systems Branch (AFS-470) website located at:

http://www.faa.gov/about/office_org/headquarters_offices/avs/offices/afs/afs400/afs470/rnp/

(2) Flyability Check.

An initial flyability check is required for all non-part 97 U.S. RNP AR procedures, as well as all foreign RNP AR procedures the operator is authorized to fly. Validate the RNP AR instrument approach procedures in the navigation database to ensure they match the published instrument approach procedures using: the actual aircraft in visual meteorological conditions; a flight simulation training device (FSTD) approved for RNP AR; or an appropriately configured desktop/laptop computer. An FSTD or desktop/laptop computer must use software identical to that used by the aircraft (i.e., FMS software) and use an aerodynamic model of the aircraft's flight characteristics. A map display must be used in the aircraft, FSTD or computer to compare the database procedure with that published. This validation process requires flying the entire procedure and should confirm the path is flyable, does not contain any lateral or vertical discontinuities, and is consistent with the published procedure.

c. Data Updates.

(1) Before using an updated navigation database (e.g., 28 day update), the operator must ensure the RNP AR approach data contained in that update remains within the tolerances prescribed in paragraph A2-7.b(1) of this appendix, when compared to the government source data. If a data parameter is found to exceed prescribed tolerances, the operator should consult with the appropriate navigation data supplier to resolve the discrepancy prior to using the approach procedure. Discrepancies may be resolved by correcting the error within the current cycle, removal of the procedure from the database, or potentially through operational mitigations approved by the FAA until the procedure data can be corrected.

(2) The method by which an operator conducts this recurring data comparison is optional, subject to the approval of the principle operations inspector or flight standards district office. One acceptable method is to establish a reference database, sometimes referred to as a “golden database,” containing known validated approach data, and comparing data from subsequent navigation updates against this reference data. Some FMS suppliers provide automated tools that enable a quick comparison of data parameters between databases and alert to any changes or differences. Operators may also choose to compare the navigation data contained in the updated database directly against the government source data. Regardless of the method used, operators must assure the integrity of the validated navigation data at each update cycle.

> **Note:** An operator should be particularly attentive to potential discrepancies when database updates coincide with a change to the data supplier’s packing software. This packing software is used to format the navigation data into code readable by aircraft avionics.

d. Data Suppliers.

As a minimum, data suppliers must have an LOA for processing navigation data in accordance with AC 20-153(latest revision). An LOA recognizes the data supplier as one whose data quality, integrity, and quality management practices are consistent with an acceptable process. The aircraft operator's supplier (e.g., FMS manufacturer) must have a Type 2 LOA. Those entities providing data to the aircraft operator's supplier likewise must possess either a Type 1 or Type 2 LOA.

e. Aircraft Modifications.

If a manufacturer modifies an aircraft system required for RNP AR operations (e.g., software or hardware change), the operator must, before flying any RNP AR procedures in IMC, confirm the aircraft's ability to fly RNP AR procedures as published, with the modified aircraft system(s). The operator should examine a number of RNP AR procedures in its navigation database for this flyability check. The criteria described in paragraph A2-7.b(2) of this appendix should be used to perform this check.

Note: The operator does not need to perform this additional confirmation if the manufacturer documents the modification has no effect on the navigation database, or path computation.

f. Recurrent Audits.

The processes identified in this paragraph for validating and updating RNP AR instrument approaches in navigation databases are subject to recurrent FAA audits. The operator's processes, as well as those performed by any outside entity contracted to provide navigation database services, are subject to audit by the FAA. Additionally, operators are expected to conduct their own recurrent audits of entities with whom they contract to provide navigation database services described in this appendix.

A2-8. Installation Considerations for RNP AR.

a. Detailed Rationale.

The applicant should provide:

(1) RNP Certification Plan.

Provide detailed rationale in the RNP certification plan (or project specific certification plan) for the use of RNP. This rationale should include a detailed explanation as to how the assigned levels support the system safety assessment, as well as a detailed explanation of the system architecture, including any means used to mitigate hazards and failure conditions resulting from the use of RNP. Additionally, include a detailed explanation of the interfaces between the FD, the autopilot and other sensors, and avionics hardware/software required, as it relates to the computed commands used for RNP.

(2) Software Problem Reports.

Present clarification on how existing open software problem reports are resolved within the aircraft or other equipment that could directly or indirectly affect the RNP approval. Open software problems or changes that could affect RNP operations should be addressed.

b. Failure Modes/Annunciation.

Identify any failure modes potentially affecting RNP capability. Verify annunciation of RNP failure modes exists. This verification should be compatible during manual flight and with the aircraft's FGS to ensure unambiguous flight crew action(s). Verify that following failure modes, any pilot selected entries are retained or their cancellations annunciated (e.g., manual entry of RNP type, blackballed navaid, etc.). Typical failure modes include loss of electrical power, loss of signal reception, and RNP equipment failure (including degradation of navigation performance resulting in a loss of RNP containment integrity). The aircraft manufacturer should also verify that a visual alert within the flight crew's primary field of view occurs with a loss of navigation capability and/or loss of RNP containment integrity. An aural alert should accompany the visual alert.

c. Aircraft Manufacturer Installation Guidelines.

The aircraft manufacturer should comply with the following installation guidelines. Avionics manufacturers should note the following guidance to ensure their positioning and navigation equipment can support RNP operations.

(1) Each installation of RNP equipment requires an airplane flight manual containing the limitations and operating procedures applicable to the installed equipment. In addition, an RNP capabilities document for the system should be developed and submitted for FAA approval. The RNP capabilities document should be referenced in the airplane flight manual and made available to the operator upon request. The document will provide a description of the system, including assumed operating environment, the interface of the navigation function to the flight crew, the specific navigation capabilities of the system and potential application. The intended use of the document will be to facilitate operational approval of the navigation capability for RNP operations. The flight manual or referenced capabilities document should contain at least the following information:

(a) A statement indicating the aircraft meets the requirements for RNP and demonstrated the established minimum RNP capabilities. This documentation should include: the phase of flight (e.g., oceanic, enroute, terminal area, approach), mode of flight (e.g., manual, FD on or off, and/or autopilot on or off, and applicable lateral and vertical modes), minimum demonstrated RNP value, and sensor limitations, if any (e.g., GPS required). The phase of flight description should indicate what procedure design criteria the navigation performance is designed to support, as applicable.

(b) Any conditions or constraints on path steering performance (e.g., autopilot engaged, FD or manual control with CDI or map display, including lateral and vertical modes and/or CDI/map scaling requirements).

(c) The criteria used for the demonstration of the system, acceptable normal and non-normal procedures, the demonstrated configurations, type of facilities used, and any constraints or limitations necessary for safe operation.

(d) Define all the assumptions on systems external to the aircraft (e.g., signal in space performance, coverage, and survey accuracy). This includes GNSS-based limitations in the AFM(S)/RFM(S) for RNP AR APCH availability predictions at the destination, or checking NOTAMs. These predictions are consistent with the equipment performance described in chapter 5.

(i) A pre-departure RAIM prediction (FD or FDE as appropriate) is acceptable for GPS-based RNP AR operations that are limited to RNP AR 0.3 accuracy.

(ii) GPS/SBAS provides improved availability and enhanced accuracy during RNP AR operations. An RNP AR operation that is limited to RNP AR 0.3 accuracy based on GPS/SBAS only needs to confirm via NOTAM that there is no GPS/SBAS outage.

(iii) A pre-departure FDE RAIM prediction is acceptable for RNP AR operations limited to RNP AR 0.3 accuracy when outside of the GPS/SBAS coverage area or during a GPS/SBAS outage.

(iv) A pre-departure RNP prediction must be conducted prior to dispatch for accuracy values below RNP AR 0.3 (i.e., RNP AR < 0.3). If no RNP prediction capability is available (either external to the aircraft or within the navigation system), then the operator must not plan to use RNP AR < 0.3. Instead, the operator must plan to use RNP AR 0.3 if that line of minima exists for the procedure.

> **Note:** The guidance on RNP prediction only applies to RNP AR operations conducted in the U.S. national airspace system. This does not apply to RNP AR operations in other ICAO States. When operating in another State's airspace, operators must follow the RNP AR operational requirements for that State.

(2) If compliance to the continuity requirements has been shown through a combination of navigation sensors, the AFMS/RFMS should contain a statement that "Continuity of RNP navigation has been demonstrated only where the operational environment supports all of the following types of sensors: <insert type of sensors for which credit is being sought>.

d. Flight Technical Error (FTE).

The aircraft manufacturer should verify maintenance of FTE (95% of the flying time) during straight and curved path segments per Table 9. The FTE should be demonstrated in each phase of flight and each autopilot mode.

e. Interface to FGS.

Verify acceptable autopilot response to an RNP fault by simulating a representative fault consistent with the equipment architecture (e.g., pulling the circuit breaker) for the RNP equipment. The aircraft manufacturer should complete this test in each of the RNP and autopilot modes, as applicable.

Appendix 3. Advanced RNP Functions.

A3-1. Introduction.

a. ICAO document 9613 Performance Based Navigation (PBN) Manual, fourth edition, 2013 lists six advanced RNP functions. The six functions are:

- RF legs
- Parallel offsets
- Scalable RNP
- RNAV holding
- Fixed radius transitions (FRT)
- Time of arrival control (TOAC)

> **Note:** The PBN Manual includes Higher Continuity as an advanced RNP function. Higher continuity is not really a function, but a result of the hazard level associated with advance RNP functions affecting aircraft equipage (see paragraph A3-1.e).

b. The equipment must include RF legs, Parallel offsets, Scalable RNP, RNAV holding, and FRTs for advanced RNP recognition. The rationale for including all of these functions is for international harmonization. To include advanced RNP recognition, the equipment, at a minimum, must meet the performance and functional criteria for RNP 2.0, RNP 1.0 and RNP APCH to LNAV minima.

(1) TSO-C115d implements RTCA/DO-283B which provides acceptable methods of implementing advanced RNP functions in RNP equipment consistent with the aircraft performance requirements found in RTCA/DO-236C, Chg 1.

(2) At present, the U.S. intends to implement only RF legs, Parallel offsets, and Scalable RNP which constitutes the U.S. definition of advanced RNP. RNAV holding, FRT, and TOAC are presently considered <u>optional</u> advanced RNP functions in the U.S.

(3) Other States may choose to implement a different subset of functions, or all six functions for their advanced RNP definition.

(4) At present, TOAC is a function for longer-term implementation and remains optional for all equipment due to uncertain equipment requirements and airspace implementation.

c. Equipment manufacturers may decide to only implement a select set of advanced RNP functions rather than implementing all functions for “advanced RNP” recognition. Implementing selected functions means the equipment will have limitations for the functions not implemented. That is, aircraft using equipment with a reduced set of functions will not receive “advanced RNP” recognition. These aircraft will be restricted from airspace that requires functions not implemented in the equipment, or that requires “advanced RNP” recognition.

d. This appendix provides the additional equipment guidance unique to implementing advanced RNP functions. Equipment manufacturers that choose to include selected advanced RNP functions or "advanced RNP" recognition should provide an advanced RNP statement of capabilities document in the installation instructions/manual. Airworthiness approval holders must provide an AFM(S)/RFM(S) capabilities statement describing both the advanced RNP functions provided, and the advanced RNP functions not provided (if any).

> **Note:** Advanced RNP functions may have aircraft-level integration dependencies necessary to implement the capability on the aircraft even though the avionics equipment itself includes the functions (see paragraph 12-7).

e. The continuity requirement for advanced RNP implementation is classified as a major failure condition that can be satisfied with dual independent equipage.

f. Manufacturers should refer to RTCA/DO-236C, Chg 1 and RTCA/DO-283B for requirements when implementing RF legs, parallel offsets, scalable RNP, RNAV holding, FRT, and TOAC. Equipment with advanced RNP functions previously approved to RTCA/DO-236B/-283A remains valid for those advanced RNP functions.

A3-2. Radius to Fix Leg Capability.

RF legs are an optional capability rather than a minimum requirement for RNP operations. This capability can be used in the initial, intermediate, and missed approach segments of instrument approaches, RNP DPs and RNP STARS. Additional information on RF legs may be found in the Aeronautical Information Manual. For RNP systems incorporating RF leg capability, the systems must comply with the criteria in chapter 8 for RNP Approach, and chapter 9 for RNP 1.0 (terminal). Appendix 7 provides information on demonstrating RF leg capability. For RNP AR systems incorporating RF leg capability the RNP value can be less than 1.0., and RNP AR procedures may have RF legs intercept the final approach segment inside the final approach fix. RNP AR systems must comply with the criteria in appendix 2.

> **Note:** In the U.S., RF legs will not intercept the final approach segment of an RNP approach inside the final approach fix. However, RF legs may do so for an RNP AR approach.

a. System Criteria.

(1) Path Definition.

Aircraft RNP lateral accuracy performance is evaluated around the path defined by the published procedure. RNP equipment should provide lateral guidance so aircraft remain within the lateral boundaries of the RF leg.

(2) Demonstration of Path Steering Performance.

The navigation system must have the capability to execute leg transitions and maintain tracks consistent with an RF leg between two fixes. There is no requirement for the aircraft to include a redundant navigation capability to perform RF legs should a loss of navigation occur during the RF leg. However, TC or STC applicants for RNP approval that include RF legs are encouraged to provide a redundant navigation capability on the aircraft that can maintain the RF leg track.

> **Note:** The AFM/RFM or aircraft qualification guidance should document limitations if: 1) the aircraft cannot proceed "Direct-To" the initial fix defining an RF leg segment, 2) the aircraft cannot accept a radar vector (a heading assigned by ATC) to the middle of an RF leg segment for intercepting and completing the RF leg segment from that point while sustaining the desired level of performance.

(3) Flight Technical Error (FTE).

System documentation should support maintenance of FTE (95 percent of the flying time) during straight and curved path segments, for each phase of flight and each autopilot and/or FD mode requested. If using FTE values other than those listed in Table 9, the applicant must complete the demonstration in accordance with paragraph 17-2.

(4) Interface to FGS.

An acceptable autopilot and/or FD response to an RNP system failure or loss must be verified in each autopilot and FD mode, as applicable.

> **Note:** If autopilot malfunction testing was performed for worst case failures, no further validation is required. In this case, the aircraft or equipment manufacturer must provide a statement of confirmation.

(5) Failure Modes/Annunciation.

System documentation should identify any failure modes potentially affecting RNP system RF Leg capability. Failure modes may include loss of electrical power, loss of signal reception, and RNP equipment failure, including navigation performance degradation, resulting in a loss of RNP containment integrity. The applicant should verify that a visible alert occurs within the flight crew's primary field of view when loss of navigation capability and/or loss of integrity are experienced.

b. Functional Criteria.

(1) Autopilot and Flight Director.

Flight Standards requires using an autopilot or FD with at least “roll-steering” capability that is driven by the RNP system during RNP procedures with RF legs (see guidance in AC 90-105A). The autopilot/FD must operate with suitable accuracy to track the lateral and, as appropriate, vertical paths required by a specific RNP procedure.

(2) Bank Angle.

The flight management computer, the FD system, and the autopilot must be capable of commanding a bank angle up to 30 degrees above 400 feet AGL. Aircraft with lower speeds will typically not achieve these bank angles in normal operations. For these aircraft it may be acceptable for the flight management computer, the FD system, and the autopilot to command bank angles less than 30 degrees consistent with their maximum airspeed provided the airworthiness applicant can demonstrate RF leg performance (see appendix 7). For RNP AR applications, the flight management computer, FD system and autopilot must be capable of commanding a bank angle up to 8 degrees below 400 feet AGL.

> **Note:** The specified bank angles comply with RTCA/DO-283B and RTCA/DO-236C, Chg 1. These are consistent with a common procedure design criteria that accommodates all aircraft categories; including those with the highest approach speeds.

(3) Electronic Map Display.

The aircraft should have an electronic map display depicting the RNP computed path of the selected procedure including RF legs. The map display should be capable of depicting the curved, RF leg segments without discontinuities on both active and inactive leg segments if a moving map display is included with or interfaced to the positioning and navigation equipment. Positioning and navigation equipment manufacturers should include a list of compatible moving map displays in the installation manual/instructions by part number, model, and/or software version as applicable to support RF leg capability.

(4) Maintaining LNAV in Missed Approach.

If abandoning a procedure while on an RF leg or initiating a go-around or missed approach (through activation of TOGA or other means), the flight guidance mode should remain in LNAV to enable deviation and positive course guidance display during an RF leg. If the aircraft does not provide this capability, crew procedures must be used that assure the aircraft will adhere to the specified flight path during the RF Leg segment.

> **Note 1:** For missed approaches with an RF Leg, the flight crew must be able to couple the autopilot or FD to the RNP system (engage LNAV) by 500 feet AGL.

Note 2: For RNP AR, if the flight guidance does not remain in LNAV upon initiation of a go-around or missed approach, then the applicant and/or operator should define flight crew contingency procedures for maintaining compliance with the desired track and re-engaging LNAV as soon as possible. These contingency procedures should clearly address flight crew actions should a go-around or missed approach begin with the aircraft established on or having just completed an RF leg segment.

(5) Crew Workload Analysis.

The installation applicant should analyze the crew workload and determine acceptability when flying and monitoring track adherence in association with RF legs during all phases of flight, including those non-normal procedures that can be evaluated in flight.

c. System Approval - Eligibility Airworthiness Documents.

The flight manual or referenced document should contain the following information:

(1) A statement indicating the aircraft meets the criteria for RNP operations with RF legs and has demonstrated the established minimum capabilities for these operations. This documentation should include the phase of flight, mode of flight (e.g., FD on or off and/or autopilot on or off; and applicable lateral and vertical modes), minimum demonstrated RNP value, and sensor limitations, if any.

(2) Any conditions or constraints on path steering performance should be identified (e.g., autopilot engaged, FD with map display, including lateral and vertical modes, and/or CDI/map scaling criteria). Use of manual control with CDI only is not allowed on RF legs.

(3) The applicant should identify the criteria used for the system demonstration, acceptable normal and non-normal procedures, the demonstrated configurations, type of facilities used, and any constraints or limitations necessary for safe operation.

A3-3. Parallel Offsets.

a. Parallel offsets can be used on route segments in enroute and terminal areas, and are intended to replicate all of the centerline route characteristics at the desired offset to the left or right of the centerline route. Parallel offsets are not intended for approach segments, arrivals, or departures. RTCA/DO-283B paragraph 2.2.1.2.7 provides detailed requirements for implementing parallel offsets in RNP equipment consistent with the aircraft performance requirements in RTCA/DO-236C Chg 1, paragraph 3.2.4.3.

Note: RTCA/DO-236C and RTCA/DO-283B requirements specify increments of 0.1 nm to support using parallel offsets for both terminal and enroute/oceanic operations. Previous revisions specified 1.0 nm increments consistent with the PBN Manual to support parallel offsets for enroute/oceanic operations only.

b. TSO-C115d Class A equipment requires FRT and parallel offset capability along with the ability to continue a parallel offset through an FRT. FRTs are optional in Class B and earlier TSO-C115 revisions. Equipment including both parallel offset and FRT advanced RNP functions must have the ability to continue parallel offsets through an FRT. Equipment without an FRT function does not need to address FRTs in conjunction with the parallel offset function.

A3-4. RNAV Holding.

a. RNAV holding is intended to give aircraft the ability to fly either ATC-defined ad hoc or published holding patterns with the performance, monitoring and alerting abilities associated with RNP. RTCA/DO-283B paragraph 2.2.1.2.6 defines RNP equipment requirements for RNP holding consistent with the aircraft performance requirement found in RTCA/DO-236C, Chg 1, paragraph 3.2.4.1. RNP holding implemented per these RTCA documents is acceptable for meeting RNAV holding.

b. Aircraft implementing RNAV holding capability should have an electronic map display capable of depicting all segments of an RNAV holding procedure. A map display depicting the RNAV holding segments enhances situation awareness.

A3-5. Scalable RNP.

a. Scalable RNP is intended for legs on RNP routes or procedures where ATC, terrain, and/or obstacle considerations provide a benefit on selected legs to using RNP values other than RNP 2.0 or RNP 1.0. RTCA/DO-283B paragraph 2.2.1.2.12.1 and 2.2.1.2.12.2 provides RNP equipment requirements for scalable RNP consistent with the aircraft performance requirements found in RTCA/DO-236C, Chg 1, paragraph 3.2.6.

b. The RNP scaling, monitoring and alerting value for scalable legs must be entered into the RNP navigation system automatically from the database. RTCA/DO-283B and RTCA/DO-236C, Chg 1 provides an order of precedence for entering leg RNP values.

Note: State operational implementation may permit manually entering an accuracy values for legs provided the equipment also changes the scaling, monitoring, and alerting consistent with the accuracy value.

(1) The RNP navigation system must provide the ability to enter RNP values in tenths of a nautical mile between 0.3 and 2.0.

(2) It is acceptable to have a smaller RNP value entered in the RNP navigation system than the leg requires. As an example only to illustrate the point, it is acceptable to have the RNP system set to RNP 1.0 for a leg that requires RNP 1.4.

(3) The applicant must identify any conditions or constraints on path steering performance (for example, autopilot engaged, FD with map display, and/or CDI/map scaling criteria). This is particularly true for RNP values less than RNP 1.0.

(4) The RNP navigation system must provide an alert prior to the upcoming waypoint when the system cannot support the upcoming RNP value.

(5) The deviation guidance cues must be scaled to the RNP value.

c. The RNP navigation system must provide an alert for any failure mode that potentially affects the navigation performance relative to the selected RNP value. Failure modes may include loss of electrical power, loss of signal reception, and RNP equipment failure, including navigation performance degradation, resulting in a loss of RNP containment integrity. The applicant should verify that a visible alert occurs within the flight crew's primary field of view when loss of navigation capability and/or loss of integrity are experienced.

A3-6. Fixed Radius Transitions.

FRTs are a waypoint transition between enroute legs using a defined radius. The intent is to define waypoint transitions along airways where separation between parallel routes is required and fly-by transitions are not compatible with the separation criteria. RTCA/DO-283B paragraph 2.2.1.2.9.2 defines equipment requirements for FRTs consistent with the aircraft performance requirements found in RTCA/DO-236C, Chg 1, paragraph 3.2.5.4.2.

A3-7. Time of Arrival Control.

TOAC is an advance RNP function that is not well defined for either equipment requirements or airspace implementation. RTCA/DO-283B paragraph 2.2.4 provides an initial implementation method for RNP equipment that is consistent with RTCA/DO-236C, Chg 1 paragraph 2.2. This section will be updated in the future consistent with TOAC airspace implementation plans.

Appendix 4. GNSS Tests to Support ADS-B.

A4-1. Introduction.

a. The information in this appendix describes bench test procedures that GNSS equipment manufacturers can use as an acceptable means to establish the GNSS equipment meets the required outputs described in AC 20-165 (latest revision). This appendix only addresses those ADS-B parameters that require specific tests because the GNSS TSOs do not adequately address the parameter. Other ADS-B parameters simply require coordination among the ADS-B and GNSS equipment manufacturers to properly integrate the equipment. A complete requirements compliance description will be contained in AC 20-165A (or later revision), appendix 2.

b. The tests are only required if the equipment manufacturer chooses to have their equipment provide inputs to ADS-B equipment. Which tests are necessary to qualify as an ADS-B position source is dependent upon which TSO the GNSS equipment has. The tests described below are intended for generating data to prove compliance with the following ADS-B parameters if the GNSS TSO requirements are not adequate: velocity accuracy, height above ellipsoid (HAE), horizontal/vertical position accuracy metric, and true track angle/true track angle validity.

A4-2. Velocity Accuracy and Velocity Figure of Merit Tests.

a. All GNSS TSO equipment should use the tests in paragraphs A4-3 through A4-8 to demonstrate both velocity accuracy and velocity figure of merit qualifying as navigation accuracy category - velocity (NAC_V) = 1. Manufacturers that want their equipment qualified NAC_V = 2 must also complete the test in paragraph A4-9.

b. AC 20-165 (latest revision), appendix 2 (paragraphs 3h and 4n in revision 'A'), state that installations with a position source capable of providing velocity accuracy should have the NAC_V derived from the position source, and the velocity accuracy should be validated during the position source manufacturer's certification testing. The following procedures, developed by RTCA SC-159, are one means of accomplishing this testing.

c. The purpose of the GNSS velocity accuracy test is to characterize the 95% horizontal and 95% vertical velocity accuracies during normal maneuvers as specified in RTCA/DO-229D, RTCA/DO-253C, and RTCA/DO-316 receiver MOPS for equipment intended to support either NAC_V =1 or NAC_V = 2. Test procedures for higher levels are expected to be developed as more demanding ADS-B applications mature.

d. The tests to verify velocity accuracy performance shall be run for each of the scenarios described below for all operating modes of the receiver where a valid position and/or velocity could be output by the receiver.

(1) It is possible that a given receiver may use a different velocity algorithm when computing an un-augmented GPS position solution versus computing a solution augmented with differential corrections. In that case, this test must be repeated for both the augmented and

un-augmented modes of operation. Even in the case where the velocity algorithm is the same whether in un-augmented or augmented mode, there are still enough variables like the software path, inputs, outputs etc., that it is required to repeat the test.

(2) It is not required to repeat the test for different sub-modes of an un-augmented or augmented mode where the inputs, velocity algorithm and outputs are the same.

(3) For GNSS equipment that was not required to meet the current environmental noise standard prescribed by DO-235B, the velocity tests in paragraphs A4-3 through A4-8 use environmental noise test conditions that may cause the equipment to stop functioning. That is, the equipment may lose satellite acquisition and tracking capability causing the equipment to stop outputting velocity. This contributes to an ADS-B availability issue for operators, but loss of function will not prevent the equipment from being used as an ADS-B velocity input provided:

- The equipment does not output misleading velocity information at or after the onset of the triggering interference levels.

  Note: A method to accomplish this is first running the test at the higher noise level to ensure there is no misleading velocity information at loss of function before running the complete test at the lower noise level.

- The GNSS equipment manufacturer documents the interference levels that cause the equipment to lose function.

- The GNSS equipment manufacturer factors the lower interference levels into an overall ADS-B availability calculation to be included within the installation instructions.

(4) If the conditions in paragraph A4-2.d(3) are met, the velocity tests in AC 20-138D, Appendix 4 can be run using an environmental noise level that does not cause the equipment to lose acquisition and tracking.

A4-3. Horizontal Velocity Accuracy Test Conditions Commensurate with NAC_V = 1.

a. Ensure the simulator scenario has enough GPS satellites to provide a horizontal dilution of precision (HDOP) of 1.5 or less.

b. One satellite shall be set at maximum power (including maximum combined satellite and aircraft antenna gain), and the other satellites shall be set at minimum power (including minimum antenna gain).

c. Broadband GNSS test noise ($I_{GNSS,Test}$) of spectral density as defined in RTCA/DO-229D, paragraph 2.5.8, broadband external interference ($I_{ext,test}$) and thermal noise contribution from the sky and the antenna ($N_{sky,antenna}$) shall be simulated.

Note: In RTCA/DO-229D, paragraph 2.5.8.2 step 2, replace -173.0 dBm/Hz with -172.8 dBm/Hz for total GNSS noise (I_{GNSS}) when running separate GPS/SBAS testing for accuracy verification and/or GPS/SBAS message loss rate data.

d. The airborne equipment shall be initialized with the appropriate position and time. It is assumed that the receiver has obtained a valid almanac for the simulator scenario to be tested prior to conducting the test.

e. Platform dynamics for the horizontal velocity accuracy test shall be as defined in Table 12 below.

Time (s)		Dynamics	Start Jerk (g/s)				End Jerk (g/s)			
From	To		North	East	Down	Total	North	East	Down	Total
0	T	Static	0	0	0	0	0	0	0	0
T+1	T+71	0.58g longitudinal acceleration to 411 m/s	0.xx *Note 1*	0.xx *Note 1*	0	0.25	0.xx *Note 1*	0.xx *Note 1*	0	0.25
T+72	T+129	Straight un-accelerated flight	0	0	0	0	0	0	0	0
T+130	T+194	-0.45g longitudinal acceleration to 125 m/s	0.xx *Note 1*	0.xx *Note 1*	0	0.2	0.xx *Note 1*	0.xx *Note 1*	0	0.2
T+195	T+254	Straight un-accelerated flight	0	0	0	0	0	0	0	0
T+255	T+325	turn 180° with 0.58g lateral acceleration	0.xx *Note 1*	0.xx *Note 1*	0	0.25	0.xx *Note 1*	0.xx *Note 1*	0	0.25
T+326	T+420	Straight un-accelerated flight	0	0	0	0	0	0	0	0

Table 12. Platform Dynamics for Horizontal Velocity Accuracy Test

Note 1: The components of the jerk in the north and east direction depends on the heading chosen in the scenario. The total jerk is not to exceed the vector combination of north, east, and down jerk components. The maximum total jerk to quickly achieve the desired dynamics should be used, but the jerk should not exceed the normal maneuver total jerk requirement of 0.25 g/s.

Note 2: The actual times may vary based on the simulator scenario control settings.

f. Signal and radio frequency interference (RFI) conditions can be modified during static period to aid acquisition. Ensure the receiver enters the desired operation mode before dynamics and appropriate signal and interference conditions are applied.

g. Use the simulator velocity truth data ($V_i^{east\_truth}, V_i^{north\_truth}$) and the GNSS receiver velocity data (V_i^{east}, V_i^{north}) to determine the horizontal velocity error h_i after the GNSS receiver has entered the desired navigation mode with the specified signal and RFI conditions:

$$h_i = \sqrt{\left(V_i^{east\_truth} - V_i^{east}\right)^2 + \left(V_i^{north\_truth} - V_i^{north}\right)^2}$$

A4-4. Horizontal Accuracy Pass/Fail Determination.

a. The 95% horizontal velocity accuracy statistic shall be computed using the formula given below. The equipment shall pass if the statistic is less than or equal to 10-LSB m/s.

> **Note:** The notation "10-LSB m/s" specifies that the pass threshold is 10 m/s minus the magnitude of the least significant bit of the output data fields representing the horizontal velocity components. The intent is to ensure that quantization error in the velocity output does not degrade the accuracy below the threshold.

$$2 * \sqrt{\frac{\sum_{i=1}^{N} \left(\frac{1.5(h_i)}{HDOP_i}\right)^2}{N}}$$

Where:

h_i = horizontal velocity error (m/sec).
$HDOP_i$ = horizontal dilution of precision at epoch i.
N = number of sample points used.

b. For this test, the number of samples shall include all samples where the receiver is in the desired navigation mode and when in motion.

> **Note:** The minimum number of samples is 420 for a 1 Hz solution and 2100 for a 5 Hz solution (i.e., 5* 420).

A4-5. Horizontal Velocity Figure of Merit Pass/Fail Determination.

The receiver velocity data and the horizontal figure of merit - velocity ($HFOM_V$) data shall be used to determine the percentage of samples bounded by the $HFOM_V$ as shown below. The test passes if $TS_{h,b}$ is greater than or equal to 0.95.

$$TS_{h,b} = \frac{1}{N}\sum_{i=1}^{N} b_{h,i}$$

N = number of samples

$$b_{h,i} = \begin{cases} 1 & h_i \leq HFOM_V \\ 0 & h_i > HFOM_V \end{cases}$$

A4-6. Vertical Velocity Accuracy Test Conditions Commensurate with NAC_V = 1.

a. Ensure the simulator scenario has enough GPS satellites to provide a vertical dilution of precision (VDOP) of 3.0 or less.

b. One satellite shall be set at maximum power (including maximum combined satellite and aircraft antenna gain), and the other satellites shall be set at minimum power (including minimum antenna gain).

c. Broadband GNSS test noise ($I_{GNSS,Test}$) of spectral density as defined in RTCA/DO-229D, paragraph 2.5.8, broadband external interference ($I_{ext,test}$) and thermal noise contribution from the sky and the antenna ($N_{sky,antenna}$) shall be simulated.

> **Note:** In RTCA/DO-229D, paragraph 2.5.8.2 step 2, replace -173.0 dBm/Hz with -172.8 dBm/Hz for total GNSS noise (I_{GNSS}) when running separate GPS/SBAS testing for accuracy verification and/or GPS/SBAS message loss rate data.

d. The airborne equipment shall be initialized with the appropriate position and time. It is assumed that the receiver has obtained a valid almanac for the simulator scenario to be tested prior to conducting the test.

e. Platform dynamics for the vertical velocity accuracy test shall be as defined in Table 13 below.

Time (s)		Dynamics	Start Jerk (g/s)				End Jerk (g/s)			
From	To		North	East	Down	Total	North	East	Down	Total
0	T	Static	0	0	0	0	0	0	0	0
T+1	T+71	0.58g longitudinal acceleration to 411 m/s	0.xx *Note 1*	0.xx *Note 1*	0	0.25	0.xx *Note 1*	0.xx *Note 1*	0	0.25
T+72	T+130	Straight and level un-accelerated flight	0	0	0	0	0	0	0	0
T+131	T+131+X	Climb, increasing the vertical climb rate from 0 to 21 m/s, then decrease the rate back to 0 m/s and repeat this increasing and decreasing pattern until the time out.	0	0	0.xx *Note 1*	0.25	0	0	0.xx *Note 1*	0.25
T+132+X	T+192+X	Straight and level un-accelerated flight	0	0	0	0	0	0	0	0
T+193+X	T+193+2X	Descend, increasing the vertical descent rate from 0 to 21 m/s, then decrease the rate back to 0 m/s and repeat this increasing and decreasing pattern until the time out.	0	0	0.xx *Note 1*	0.25	0	0	0.xx *Note 1*	0.25
T+194+2X	T+274+2X	Straight and level un-accelerated flight	0	0	0	0	0	0	0	0

Table 13. Platform Dynamics for Vertical Velocity Accuracy Test

Note 1: The components of the jerk in the north and east direction depends on the heading chosen in the scenario. The total jerk is not to exceed the vector combination of north, east, and down jerk components. The maximum total jerk to quickly achieve the desired dynamics should be used, but the jerk should not exceed the normal maneuver total jerk requirement of 0.25 g/s.

Note 2: The actual times may vary based on the simulator scenario control settings.

Note 3: The value of X must be at least 63 seconds to have enough samples during vertical acceleration.

f. Signal and RFI conditions can be modified during the static period to aid acquisition. Ensure the receiver enters the desired operation mode before dynamics and appropriate signal and interference conditions are applied.

g. Use the simulator velocity truth data ($V_i^{vertical\_truth}$) and the GNSS receiver velocity data ($V_i^{vertical}$) to determine the vertical velocity error (V_i) after the GNSS receiver has entered the desired navigation mode with the specified signal and RFI conditions:

$$V_i = \left|V_i^{vertical\_truth} - V_i^{vertical}\right|$$

A4-7. Vertical Velocity Accuracy Pass/Fail Determination.

a. The 95% vertical velocity accuracy statistic shall be computed using the formula given below. The equipment shall be considered pass only if the statistic is less than or equal to 50-LSB ft/s.

$$2 * \sqrt{\frac{\sum_{i=1}^{N}\left(\frac{3(V_i)}{VDOP_i}\right)^2}{N}}$$

Where:

v_i = vertical velocity error (ft/sec).
$VDOP_i$ = vertical dilution of precision at epoch i.
N = number of sample points used.

b. For this test, the number of samples shall include all samples where the receiver is in the desired navigation mode.

Note: The minimum number of samples is 420 for a 1 Hz solution and 2100 for a 5 Hz solution.

A4-8. Vertical Velocity Figure of Merit Pass/Fail Determination.

The receiver velocity data and the vertical figure of merit - velocity ($VFOM_V$) data shall be used to determine the percentage of samples bounded by the $VFOM_V$ as shown below. The test passes if $TS_{v,b}$ is greater than or equal to 0.95.

$$TS_{v,b} = \frac{1}{N}\sum_{i=1}^{N} b_{v,i}$$

N = number of samples

$$b_{v,i} = \begin{cases} 1 & v_i \le VFOM_v \\ 0 & V_i > VFOM_v \end{cases}$$

A4-9. Additional Tests to Demonstrate Accuracy Commensurate with NAC_V = 2.

The following procedure is one acceptable means for equipment capable of better accuracy performance to demonstrate compliance with the horizontal velocity error requirement of less than 3 m/s.

a. Run the scenario in Table 13 with all satellites set at high power and no RFI.

b. This accuracy evaluation shall only include those data samples collected during the acceleration period.

c. Find the particular h_i (noted as T_{acc}) so that 95% of h_i samples are less than or equal to T_{acc}.

d. Re-run the scenario in Table 13 with the same satellite and RFI conditions as the 10 m/s (NAC_V=1) test.

e. This time only the data samples during the non-acceleration period with the specified signal and RFI conditions are used.

f. Compute:

$$T_{non\_acc} = 2 * \sqrt{\frac{\sum_{i=1}^{N_{non\_acc}} \left(\frac{1.5\left(h_{i_{non\_acc}}\right)}{HDOP_{i\_non\_acc}}\right)^2}{N_{non\_acc}}}$$

Where:

$HDOP_{non\_acc}$ and N_{non_acc} are the HDOP values for each sample *i* and the total number of samples (non-acceleration period), respectively.

g. The test passes only if T_{acc} + T_{non_acc} is less than or equal to 3-LSB m/s.

h. The velocity figure of merit is evaluated in the same way as for the 10 m/s test, i.e., the samples during acceleration and non-acceleration periods of the above 2 runs are evaluated together against the 0.95 threshold.

i. The vertical velocity requirement of 15 ft/s should be tested using the exact same philosophy as the test of 3 m/s above but with the scenario in Table 13.

A4-10. Test to Demonstrate HAE Output and Vertical Position Accuracy Metric.

a. The following procedure is one acceptable means for equipment to demonstrate compliance with the HAE and 95% vertical position accuracy output requirements needed to support ADS-B. This parameter is commonly called the vertical figure of merit (VFOM) and should not be confused with the vertical velocity figure of merit ($VFOM_V$) from the velocity accuracy tests. All GNSS TSO equipment should use this test to demonstrate both HAE and 95% vertical position accuracy outputs.

b. The HAE output must be calculated using the general least squares position solution of DO-229D appendix J.1 (or any mathematically equivalent linear combination of range measurements). There is no restriction on the choice of the weight matrix W (including non-weighted solutions), and using the LNAV/VNAV, LP, LPV approach weight ($w_i = 1/\sigma_i^2$) is optional.

c. The HAE accuracy must be tested using the procedure of DO-229D section 2.5.8.3. The σ_i^2 used to compute the variance d_U^2 must be greater than or equal to those listed in appendix J when the equipment uses SBAS-provided integrity and greater than or equal to those listed as an acceptable means for FDE-provided integrity in section 2.1.2.2.2.2 when the equipment does not use SBAS-provided integrity. A fixed sigma of 33.3 m is considered a sufficient over-bound when using FDE-provided integrity. For equipment that uses SBAS-provided integrity, testing only in the highest mode attainable for its declared operational class as specified in the test itself is acceptable.

d. Performing the test described in paragraphs A4-10.a through A4-10.c confirms that the σ_i and d_U used to compute the VFOM accuracy metric provides a sufficient error over-bound. The vertical position accuracy metric must be greater than or equal to 1.96 d_U where d_U is computed using the same σ_i employed during the HAE accuracy test procedure. This VFOM calculation does not require any specific additional testing.

> **Note 1:** The scaling factors for the vertical position accuracy metric can be rounded to 2 decimal places but there is no intention to prohibit the use of a more accurate number.
>
> **Note 2:** The vertical position accuracy metric listed above is the standard metric used to provide a minimum of 95% containment under the assumption that a Gaussian distribution with a sigma of σ_i over-bounds the error of the range measurements. The use of a general least squares position solution (or mathematical equivalent) results in a jointly Gaussian distribution for the components (North, East, Up) of the position error. Any accuracy metric that can be mathematically demonstrated to provide a minimum 95% containment in the position domain under this Gaussian assumption is also acceptable.

A4-11. Test to Demonstrate Horizontal Position Accuracy Metric.

a. The following procedure is one acceptable means for equipment to demonstrate compliance with the 95% horizontal position accuracy output requirements needed to support ADS-B. This parameter is commonly called the horizontal figure of merit (HFOM) and should not be confused with the horizontal velocity figure of merit ($HFOM_V$) from the velocity accuracy tests. TSO-C145/C146 revision 'b/c' and TSO-C196(AR) equipment already satisfy this parameter by meeting the TSO requirements. TSO-C145a/C146a and TSO-C129(AR) equipment should use this test to demonstrate the HFOM output.

b. The horizontal position output must be calculated using the general least squares position solution of DO-229D appendix J.1 (or any mathematically equivalent linear combination of range measurements). There is no restriction on the choice of the weight matrix W (including non-weighted solutions), and using the LNAV/VNAV, LP, LPV approach weight ($w_i = 1/\sigma_i^2$) is optional.

c. The horizontal position accuracy must be tested using the procedure of DO-229D section 2.5.8.3. The σ_i^2 used to compute the variance d^2_{major} must be greater than or equal to those listed in appendix J when the equipment uses SBAS-provided integrity and greater than or equal to those listed as an acceptable means for FDE-provided integrity in section 2.1.2.2.2.2 when the equipment does not use SBAS-provided integrity. A fixed sigma of 33.3 m is considered a sufficient over-bound when using FDE-provided integrity. For equipment that uses SBAS-provided integrity, testing only in the highest mode attainable for its declared Operational Class as specified in the test itself is acceptable.

d. Performing the test described in paragraphs A4-11.a through A4-11.c confirms that the σ_i and d_{major}, d_{east}, and d_{north} used to compute the HFOM accuracy metric provide a sufficient error over-bound. The accuracy metric must be greater than or equal to 1.96 sqrt($d^2_{east} + d^2_{north}$) or 2.45 d_{major} where d_{major}, d_{east}, and d_{north} are computed using the same σ_i employed during the horizontal accuracy test procedure. This HFOM calculation does not require any specific additional testing.

Note 1: The scaling factors for the horizontal position accuracy metric can be rounded to 2 decimal places but there is no intention to prohibit the use of a more accurate number.

Note 2: The horizontal position accuracy metric listed above is the standard metric used to provide a minimum of 95% containment (varying from 95% to approximately 98.5%) under the assumption that a Gaussian distribution with a sigma of σ_i over-bounds the error of the range measurements. The use of a general least squares position solution (or mathematical equivalent) results in a jointly Gaussian distribution for the components (North, East, Up) of the position error. Any accuracy metric that can be mathematically demonstrated to provide a minimum 95% containment in the position domain under this Gaussian assumption is also acceptable.

A4-12. Demonstrating True Track Angle/True Track Angle Validity.

a. The true track angle/true track validity parameter is intended as a non-critical, optional parameter for airport surface operations. Since most GNSS position sources output some type of track information even during ground operations, it is recommended that GNSS manufacturers output ground track angle as the information can be useful for non-critical ADS-B surface applications. The concern is that below a certain velocity the ground track information becomes invalid, and the velocity at which this occurs is dependent upon the specific GNSS equipment design. GNSS/ADS-B integrations at the aircraft level must stop broadcasting ground track when the GNSS ground track information becomes invalid.

> **Note:** It is possible that future ADS-B surface applications may be defined for critical functions. More stringent GNSS performance requirements and tests than what is described below will have to be developed if and when these new surface applications are defined.

b. GNSS equipment not providing a valid ground track.

GNSS manufacturers may choose to not have their equipment provide a ground track output acceptable for the ADS-B true track angle/true track validity parameter. GNSS manufacturers choosing this option need to include a statement within the equipment limitations section that the ground track information must not be used for ADS-B surface applications.

c. GNSS equipment providing a valid ground track for the true track angle/true track validity parameter.

(1) Appendix H in both RTCA/DO-229D and RTCA/DO-316 provides a recommended output for true ground track angle (ARINC 743 all revisions label 103) for those using ARINC 429 characteristics.

(2) GNSS manufacturers must indicate at what velocity the GNSS track angle 95% accuracy (derived from north/east velocity) exceeds eight degrees variance from the aircraft's actual ground track. GNSS manufacturers must provide this data within the equipment installation instructions for the GNSS/ADS-B integrator.

(3) Optimally, the GNSS equipment will either invalidate or stop outputting the ground track information when it is no longer valid. If the sensor outputs a validity indicator for the velocity, it is sufficient to simply flag the output as invalid if the track accuracy exceeds eight degrees (95%). The GNSS manufacturer must provide information in the installation instructions describing how the sensor outputs the validity indicator if one is provided. Alternately, it is acceptable for the GNSS manufacturer to state in the installation instructions that the track angle does not meet the required accuracy below a specified velocity and indicate the minimum acceptable velocity.

(4) GNSS manufacturers developing data for the minimum valid velocity should consider the following assumptions:

- Surface message is used during taxi, takeoff, and landing ground applications.
- Surface taxi speed is less than 50 knots.
- No turns; only along-track acceleration (0.58g) and jerk (0.25 g/sec).
- Track angle validity is only an issue at taxi speeds.
- Use the GNSS noise environment defined in the velocity test (paragraphs A4-3 through A4-8), or for sensors not originally certified to the latest noise environment standards, use a reduced environmental noise level as described in paragraphs A4-2.d(3) and A4-2d.(4).

Appendix 5. Sample Airplane/Rotorcraft Flight Manual Supplement.

A5-1. Introduction.

a. The intent of this appendix is to provide general guidance for creating an AFM(S)/RFM(S). The information and structure below are not intended to cover all possible aircraft integrations or equipment capabilities and should not be construed to limit the content included in an AFM(S)/RFM(S). Actual AFM(S)/RFM(S) language and structure must be tailored to the actual installation, equipment capabilities, and limitations. AC 25.1581-1 provides flight manual guidance information for transport category airplanes.

b. Section A5-2 contains an example AFM(S)/RFM(S) entry describing operations limitations for the aircraft PBN capabilities and qualification basis that provides easy reference for flightcrews. This is just an example and is not intended as a required format. But, the example could be used as a general template by applicants, modified as needed, when constructing their AFM(S)/RFM(S).

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123 Fourth Street
Anytown, USA

Model XXX
Navigation System

FAA APPROVED AIRPLANE FLIGHT MANUAL SUPPLEMENT
ABC MODEL XXX NAVIGATION AND/OR BARO-VNAV 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 navigation and/or baro-VNAV system when it has been installed in accordance with <*manufacturer's installation manual number and date*>.

For airplanes with an FAA approved airplane flight manual, this document serves as the FAA approved ABC Model XXX GPS, RNAV multi-sensor system, and/or baro-VNAV flight manual supplement. For airplanes that do not have an approved flight manual, this document serves as the FAA approved ABC Model XXX 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.

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____
Title
Office
Federal Aviation Administration
City, State

Sample Airplane/Rotorcraft Flight Manual (Continued)

Installation Center/Repair Station
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Anytown, USA

Model XXX
Navigation System

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SECTION 1 - GENERAL

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

TSO-C115<revision b or later>: The installed ABC system complies with AC 20-138D for IFR navigation using multi-sensor inputs including GPS for enroute, terminal area, and approach RNP operations (as appropriate). *<include appropriate GPS TSO statement below as applicable>*

GPS TSO-C129<appropriate revision>: The installed ABC system complies with AC 20-138D for IFR navigation using GPS for enroute, terminal area, and non-precision approach operations. Non-precision approach operations include those based on conventional navigation aids with "or GPS" in the title and those with "GPS" and "RNAV(GPS)" in the title to "LNAV" minimums.

GPS/SBAS TSO-C145 or C146<appropriate revision> Class 3: The installed ABC equipment complies with AC 20-138D for navigation using GPS and GPS/SBAS (within the coverage of a satellite-based augmentation system complying with ICAO Annex 10) for enroute, terminal area, non-precision approach, and approach procedures with vertical guidance operations. Non-precision approach operations include those based on conventional navigation aids with "or GPS" in the title and those with "GPS" and "RNAV(GPS)" in the title to "LNAV" and "LP" minimums. Approach procedures with vertical guidance includes "RNAV(GPS) to "LNAV/VNAV" and "LPV" minimums.

> **Note 1:** TSO-C145a/C146a Class 3 equipment is not required to perform LP approaches.
>
> **Note 2:** Functional Class Delta equipment is an "ILS look-alike" that only provides LP/LPV capability on the final approach segment.

GPS/SBAS TSO-C145 or C146<appropriate revision> Class 2: The installed ABC equipment complies with AC 20-138D for navigation using GPS and GPS/SBAS (within the coverage of a satellite-based augmentation system complying with ICAO Annex 10) for enroute, terminal area, non-precision approach, and approach procedures with vertical guidance operations. Non-precision approach operations include those based on conventional navigation aids with "or GPS" in the title and those with "GPS" and "RNAV(GPS)" in the title to "LNAV"

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minimums. Approach procedures with vertical guidance includes "RNAV(GPS) to "LNAV/VNAV" minimums.

GPS/SBAS TSO-C145 or C146<appropriate revision Class 1: The installed ABC equipment complies with AC 20-138D for navigation using GPS and GPS/SBAS (within the coverage of a satellite-based augmentation system complying with ICAO Annex 10) for enroute, terminal area, and non-precision approach operations. Non-precision approach operations include those based on conventional navigation aids with "or GPS" in the title and those with "GPS" and "RNAV(GPS)" in the title to "LNAV" minimums.

GPS/GBAS TSO-C161<appropriate revision>: The installed ABC system complies with AC 20-138D for navigation using GPS and GPS/GBAS (within the coverage of a ground-based augmentation system complying with ICAO Annex 10) for GPS/GBAS precision approach procedures to "GLS" minimums.

GPS TSO-C196(AR): The installed ABC system complies with AC 20-138D for IFR navigation using GPS for enroute, terminal area, and non-precision approach operations. Non-precision approach operations include those based on conventional navigation aids with "or GPS" in the title and those with "GPS" and "RNAV(GPS)" in the title to "LNAV" minimums.

<The following statement applies to all types of GNSS stand-alone equipment>:
Navigation information is referenced to the 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-C129(AR), TSO-C145/C146(AR), and TSO-C196(AR) 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 oceanic/remote navigation, when used in conjunction with the ABC prediction program. This does not constitute an operational approval.

<For baro-VNAV equipment:>

The ABC VNAV system has been demonstrated capable of and has been shown to meet the accuracy requirements of:

> VFR/IFR enroute, terminal and approach (if applicable) VNAV operation within the conterminous U.S. and Alaska in accordance with the criteria in AC 20-138D.

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<u>SECTION 2 - LIMITATIONS</u>

1. The system must use at least software version <*insert version identification*> as the minimum version.

2. A valid and compatible database must be installed and contain current data.

<Limitation for TSO-C129(AR) and TSO-C196(AR) equipment:>

3. The aircraft must have other operational, approved navigation equipment installed appropriate to the operation.

<Limitation for all GNSS equipment:>

4. The TSO-C*<insert number and revision>* equipment has a performance limitation necessitating an alternate airport flight planning operational mitigation. In the U.S., refer to sections 1-1-17, 1-1-18, 1-2-3 and 5-4-5 in the Aeronautical Information Manual for specific operational guidance. In other states, refer to their operational guidance for RNAV(GNSS) approaches.

5. The ABC Model XXX Quick Reference 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.

<Limitation for baro-VNAV equipment:>

6. The ABC Model XXX VNAV system Pilot's Guide, P/N <*insert part number*>, dated <*insert date*> must be immediately available to the flight crew whenever navigation is predicated on the use of the system.

7. When using the <insert name> VNAV system, the barometric altimeter must be used as the primary altitude reference for all operations; including instrument approach procedure step-down fixes.

8. Minimum altitude for autopilot coupled VNAV operation is <*insert number*> feet above ground level.

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

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SECTION 3 - EMERGENCY/ABNORMAL PROCEDURES

EMERGENCY PROCEDURES
No change.

ABNORMAL PROCEDURES

1. If ABC Model XXX GPS navigation information is not available or invalid, use 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 or periodically cross-check the GPS guidance to other, approved means of navigation.

<For baro-VNAV equipment:>

If VNAV information is intermittent or lost, disengage VNAV and use the primary barometric altimeter for vertical guidance.

SECTION 4 - NORMAL PROCEDURES

<For GPS equipment:>

1. Normal operating procedures are outlined in the ABC Model XXX GPS Pilot's Guide.

2. *<Describe approach mode sequencing.>*

3. System Annunciators *<applicable to installations with external 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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4. System Switches <*applicable to installations with external 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*>

<For baro-VNAV equipment:>

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

2. Describe each remote annunciator, such as: waypoint (WPT), message (MSG).

3. Describe the function and operation of the various switches used with the system.

4. Describe the pilot's and copilot's display (i.e., CDI, HSI, OBS, etc.)

5. Describe the coupling of VNAV system steering information to the autopilot and/or flight director.

SECTION 5 - PERFORMANCE

No Change

SECTION 6 - WEIGHT AND BALANCE

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

SECTION 7 - SYSTEM DESCRIPTION

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

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A5-2. Sample AFM(S)/RFM(S) PBN Capabilities and Qualification Basis.

Section II Operating Limitations Model XXX

NAVIGATION OPERATIONAL CAPABILITIES

The navigation equipment as installed has been found to comply with the requirements established for the following navigation specifications:

Navigation Specification	Operational Requirements/ Authorizations	Required Equipment	Reference Guidance
Oceanic and Remote Areas of Operation (formerly Class II Navigation).	GNSS FDE availability must be verified prior to flight. Maximum predicted FDE unavailability is 25 minutes. No time limit using GNSS as the primary navigation sensor.	Two *<insert name>* installed systems, operating and receiving usable navigation information from each of the dual GNSS sensors (or one navigation system and one GNSS sensor for those routes requiring only one long range navigation sensor).	Meets the applicable requirements of AC20-138D, AC90-100A, AC91-70, FAA Order 8400.33. This does not constitute an operational approval.
North Atlantic (NAT) Minimum Navigation Performance Specifications (MNPS)	GNSS FDE availability must be verified prior to flight. Maximum predicted FDE unavailability is 25 minutes. No time limit using GNSS as the primary navigation sensor.	Two *<insert name>* installed systems, operating and receiving usable navigation information from each of the dual GNSS sensors (or one FMS and one GNSS sensor for those routes requiring only one long range i ti)	Meets the applicable requirements of AC20-138D, AC91-70, AC91-49. This does not constitute an operational approval.
RNAV-10 RNP-10	GNSS FDE availability must be verified prior to flight. Maximum predicted FDE unavailability is 25 minutes. EPU/ANP does not exceed RNP. No time limit using GNSS as the primary i ti	Two *<insert name>* installed systems, operating and receiving usable navigation information from each of the dual GNSS sensors.	Meets the applicable requirements of AC20-138D FAA Order 8400.128. This does not constitute an operational approval.

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SECTION II - OPERATING LIMITATIONS

MODEL XXX

NAVIGATION OPERATIONAL CAPABILITIES (Continued)

Navigation Specification	Operational Requirements/ Authorizations	Required Equipment	Reference Guidance
B-RNAV/RNAV-5 RNP-5.	EPU/ANP does not exceed RNP. No time limit using GNSS as the primary navigation sensor.	At least one *<insert name>* installed system is receiving usable navigation information from one or more of the following sensors: 1. Multiple DMEs, or 2. GNSS sensor.	Meets the applicable requirements of AC20-138D, AC90-96A, AC90-100A, EASA AMC 20-4.
RNP-4 Oceanic and Remote Area Operations.	GNSS FDE availability must be verified prior to flight. Maximum predicted FDE unavailability is 25 minutes. EPU/ANP does not exceed RNP. No time limit using GNSS as the primary navigation sensor.	Two *<insert name>* installed RNP navigation systems, operating and receiving usable navigation information from each of the dual GNSS sensors.	Meets the applicable requirements of AC20-138D, FAA Order 8400.33. This does not constitute an operational approval.
RNAV-2 RNAV-1 P-RNAV RNAV Routes (DPs, STARS, Q and T Routes) RNP-2 RNP-1	GNSS is required for takeoff in P-RNAV airspace. GNSS FDE availability must be verified prior to flight for DPs that require GNSS. EPU/ANP does not exceed RNP. No time limit using GNSS as the primary navigation sensor.	At least one *<insert name>* installed system is receiving usable navigation information from one or more of the following sensors: 1. Multiple DMEs, or 2. GNSS sensor (required for takeoff in P-RNAV airspace and some DPs).	Meets the applicable requirements of AC20-138D, AC90-105, AC90-96A, AC90-100A, JAA TGL 10. This does not constitute an operational approval.

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SECTION II - OPERATING LIMITATIONS **MODEL XXX**

NAVIGATION OPERATIONAL CAPABILITIES (Continued)

Navigation Specification	Operational Requirements/ Authorizations	Required Equipment	Reference Guidance
RNP-APCH [titled RNAV (GPS) or RNAV (GNSS)] -including RNP procedures to a minimum value of RNP-0.3 (LNAV minimums) *<include LPV minimums if appropriate>*. RNP AR-APCH procedures, and approach procedures with RF legs are NOT authorized. *<Include a separate entry if RNP AR-APCH or advanced RNP capability such as RF legs ARE approved.>*	All instrument approach procedures that are retrieved from the navigation system database are authorized. GNSS is required to initiate RNAV (GPS) approach procedures. For RNAV(GPS) approach procedures, a missed approach is required if both GNSS sensors become unavailable EPU/ANP does not exceed RNP (except during a missed approach procedure following loss of GNSS navigation). Maximum predicted RAIM outage is 5 minutes. For ILS, LOC, LOC-BC, LOA, and SDF approach procedures, the active navigation source must be LOC or BC (green needles) prior to crossing the final approach fix.	At least one *<insert name>* installed system is receiving usable navigation information from a GNSS sensor (required for RNAV (GPS) approach procedures)	Meets the applicable requirements of, AC20-138D, AC90-105, EASA AMC 20-27. This does not constitute an operational approval.
Enroute, Terminal and Approach Vertical Navigation (VNAV)	Use of Vertical Glidepath (GP) guidance to a published DA is approved.	The selected navigation system is receiving usable information for a baro-VNAV (or SBAS, if applicable) solution.	Meets the applicable requirements of AC20-138D, AC90-100A, AC90-105, EASA AMC 20-27.

Appendix 6. Installation of GNSS Equipment for VFR Use Only.

A6-1. Introduction.

This appendix provides guidelines for the installation of stand-alone GNSS systems used for VFR navigation only.

A6-2. General.

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) including EMI/EMC. Loss of or misleading VFR navigation information is considered a minor hazard failure condition; therefore, it is acceptable to have development assurance level D for software per RTCA/DO-178B or ‘C’, and electronic hardware, per RTCA/DO-254. A readable placard must be installed in clear view of the pilot stating that the equipment is only to be used for VFR operations, unless the equipment automatically displays this message on start-up and pilot action is required to clear the message. An AFMS/RFMS is not required since the placard or display contains the equipment limitation.

A6-3. Applicability.

This appendix applies to all un-pressurized aircraft less than 6000 pounds where the modification is classified as a minor alteration.

A6-4. Technical Instructions.

Install the GPS as follows:

a. The GPS equipment should be located in a position which is viewable and accessible to the pilot from his/her normally seated position. The installed GPS equipment should not:

(1) Restrict access to or view of any control, display or indicator;

(2) Restrict movement of the flight controls;

(3) Interfere with the pilot’s vision along the flight path; or

(4) Restrict pilot/passenger egress.

b. The installation should be carried out in accordance with the equipment manufacturer’s installation manual/instructions, the aircraft maintenance manual and the guidelines in AC 43.13-2 (latest revision). The installation should conform to the following requirements:

(1) Equipment manufacturer-supplied or standard parts should be used.

(2) If a 'non-standard' method of installation is used, the equipment manufacturer's recommended procedures should be followed.

(3) The GPS mounting should be tested to ensure that it will be restrained throughout the flight envelope.

(4) Where a modification is required to the aircraft structure to show compliance with paragraph A6-4.b(3) of this appendix, the modification is to be carried out in accordance with the aircraft maintenance manual and the guidelines in the latest revisions of AC 43.13-1 and AC 43.14-2.

c. If required, install a remote GPS antenna as follows:

(1) Determine a suitable location for the GPS antenna on the upper fuselage. Particular care should be taken to ensure that at least the minimum separation is maintained between the GPS antenna and VHF communications and ELT antennas.

(2) Install the equipment manufacturer-approved GPS antenna in accordance with the equipment manufacturer's installation manual/instructions, the aircraft maintenance manual and the guidelines in AC 43.13-2 (latest revision). The GPS antenna installation should be tested to ensure that it would be restrained throughout the flight envelope.

(3) If using an internally mounted, equipment manufacturer-supplied remote antenna, install the antenna in accordance with the equipment manufacturer's installation manual/instructions. Ensure that the antenna and associated cable will not interfere with pilot's vision, aircraft controls or displays, or pilot/passenger egress.

d. Install and placard an appropriately rated circuit breaker or fuse.

e. If required, install a remote GPS indicator as follows:

(1) Determine a suitable location for the GPS indicator. The indicator should be located in the instrument panel and readily viewable to the pilot from his/her normally seated position.

(2) Install the indicator in accordance with the equipment manufacturer's installation manual/instructions, the aircraft maintenance manual and the guidelines in AC 43.13-2 (latest revision).

(3) Interconnect the GPS, power supply, indicator and antenna (as required) in accordance with the equipment manufacturer's installation manual/instructions.

f. Unless the equipment automatically displays a message on start-up and pilot action is required to clear the message, install the following placard in the vicinity of the GPS and in clear view of the pilot: GPS APPROVED FOR VFR USE ONLY.

g. Close the GPS circuit breaker or install the fuse.

h. Carry out a functional test of the GPS installation in accordance with the equipment manufacturer's installation/operation instructions. Checks are also to be carried out to determine satisfactory operation of all disturbed systems, that there is no interference between GPS and other systems, no effect on the aircraft compass system and that there is no interference with the aircraft flight controls.

Appendix 7. RF leg Demonstration Templates

A7-1. Introduction.

a. Airworthiness applicants must demonstrate the aircraft's capability to perform all types of RF legs that can be published on instrument procedures per the procedure design criteria. This appendix provides templates that are an acceptable method to demonstrate an aircraft's capability to perform RF legs. Applicants may use engineering simulations and/or aircraft for the flight test demonstrations. The templates depict the various RF legs procedure designers might use when constructing actual initial, intermediate, or missed approach segments for RNAV (GPS) or RNAV (RNP) approaches along with SIDs and STARs. Applicants can use the templates to create one or more approach procedures at the desired airport for flight test demonstration purposes only in visual meteorological conditions. The intent is to streamline the airworthiness approval for conducting RF legs.

> **Note 1:** Simply completing an RF leg demonstration does not imply or confer any approval or qualification to conduct any procedure requiring RNP AR. See appendix 2 for guidance on aircraft qualification and the latest revision of AC 90-101 for guidance on operational approval.

> **Note 2:** These templates are acceptable for both RNP AR and non-RNP AR demonstrations. When demonstrating RNP AR or non-RNP AR capability it is acceptable to label the test procedures as RNAV (RNP) RWY XX or RNAV (GPS) RWY XX respectively.

b. The demonstration procedures applicants create need to include the depicted RF leg types shown in paragraph A7-2. To increase flight test efficiency, it is acceptable for applicants to link the individual RF legs depicted in the figures using straight segments to create "mega procedures" for demonstrating aircraft capability. However, the reflex curve legs ('S' turns) and decreasing radius turns must not have a straight segment between the path terminators (see Figure 4 for an example). The point is to demonstrate the aircraft is capable of flying the various types of turns including turns of minimum radius.

> **Note:** Figure 4 is only an example and is not intended as the only possible combination for creating efficient flight profiles.

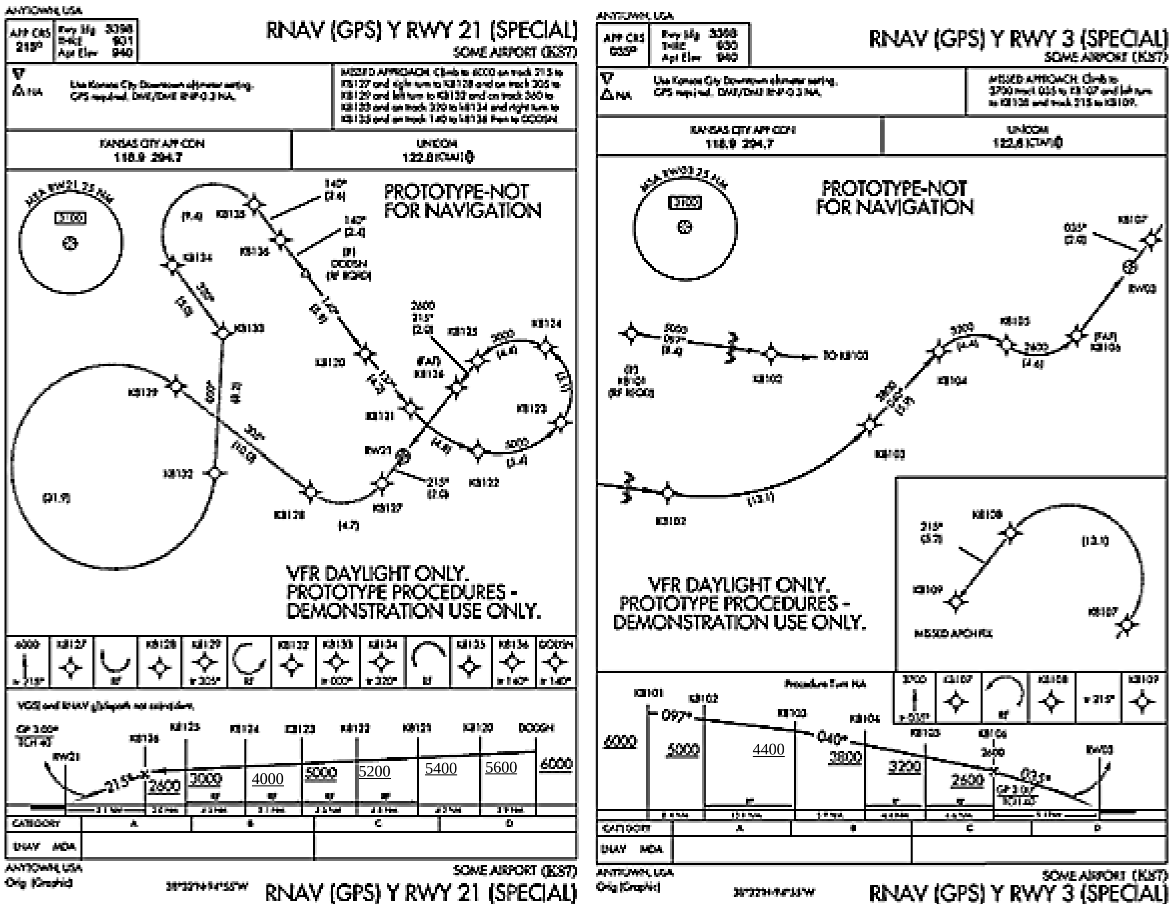

Figure 4. Example Procedure Profiles

c. It should be noted that the templates are designed for use on both RNP AR (e.g., RNAV (RNP)) and non-RNP AR (e.g., RNAV (GPS)) procedures with RF legs. Therefore, the procedures created from the templates will provide "stressing" situations because some license was taken with the procedure design criteria. For example, RF legs on RNAV (GPS) approaches currently terminate at least 2 NM prior to the final approach fix, not at the final approach fix (refer to the 'S' turn in Figure 4). Another example is that several RF leg radii were intentionally reduced to approach the 25 degree RNP AR flight guidance system bank angle limits given the design wind criteria and category C/D aircraft speeds.

d. Paragraph A7-2 provides a basic description, illustration, and waypoint information for the RF legs. A Test Guide in paragraph A7-3 lists a recommended testing regimen and considerations for test conduct, but the applicant can tailor the test regimen as needed. The procedures were designed using criteria set forth in FAA Orders with some exceptions as noted in paragraph A7-1.c.

e. The test instrument procedures are designed and located at an airport with an elevation of approximately 1500 ft MSL. All turn radii were computed using expected ground speeds and altitudes based upon the 1500 ft MSL airport elevation. The turn radii were adjusted so that the required bank angle, given the adverse wind input, would approach the bank angle limitation noted in the procedure design criteria. The waypoint and navigation leg data is provided so that the procedures can be "translated" to another location suitable to the applicant. However, the new airport elevation should be within the range of 1000 - 2000 ft MSL to ensure that the designed turn radii and bank angles do not change significantly. If the airport used has an elevation outside of the 1000 - 2000 ft MSL range, it is the applicant's responsibility to ensure the procedures offer adequate obstacle clearance and meet the bank angle limits in the RF leg design criteria.

A7-2. Test Procedures Description.

Each of the procedures is described in this section along with an image for illustration.

A7-2.1. Departures.

a. Design criteria for departures are currently being developed. Subsequently, two procedures were designed using known criteria in addition to criteria features that are likely to be incorporated. One of the procedures mimics a conventional design at Boston Logan that has proven difficult for some high performance aircraft to use. Because of environmental restrictions on the ground track, the previous conventional procedure incorporates a series of short track-to-fix (TF) legs that when viewed from a larger perspective "looks" like a series of RF legs when considering that each of the waypoints are "fly-by." However, in the conventional format, some FMSs have difficulty with the short leg segments and therefore annunciate an inability to capture a subsequent leg. The resolution to this issue is the RF leg or a series of RF legs that ensure conformance to the desired ground path. The "Alpha Departure" shown in Figure 5 incorporates an RF leg shortly after takeoff followed by a straight climbing segment to a series of two back-to-back RF legs with reducing radii. Waypoint information is shown in Table 14.

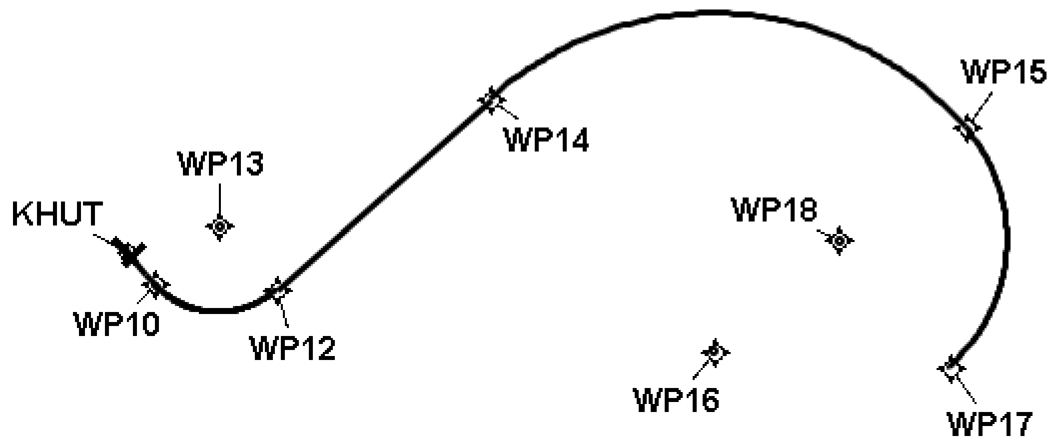

Figure 5. Alpha Departure

Runway Transition Data - Northwest1 DEP

DB	Waypoint	Distance	Leg	FO/FB	Latitude	Longitude	TC	MC	Altitude	Speed	MEA	Arc Center Lat (D° M' S.ss")	Arc Center Lon (D° M' S.ss")	Arc Radius (NM)
NACO: FULL	*DER RW13*				N38 03 35.48	W097 51 17.61								
	WP10 WP	1.00	CF	FB	N38 02 50.65	W097 50 27.06	138.28	132.28	+2043					
	WP12 WP	4.71	RF		N38 02 36.01	W097 45 05.27						N38 04 50.54	W097 47 36.91	3.00
	WP14 WP	10.03	TF	FB	N38 09 15.81	W097 35 35.10	48.37	42.37		230				
	WP15 WP	18.36	RF		N38 08 14.76	W097 14 40.04						N38 00 29.33	W097 25 46.14	11.70
	WP17 WP	9.23	RF		N37 59 56.88	W097 15 19.74				250		N38 04 21.38	W097 20 14.52	5.87

Waypoint Data

DB	Waypoint	Arc Center	Lat-Long (DMS.S)	Latitude (Deg)	Longitude (Deg)	Latitude (D°, M.mm')	Longitude (D°, M.mm')	Latitude (D° M' S.ss")	Longitude (D° M' S.ss")
	WP10 WP		380250.65N-0975027.06W	N 38.0474016	W 97.8408493	N38 02.844	W97 50.451	N38 02 50.65	W097 50 27.06
	WP12 WP		380236.01N-0974505.27W	N 38.0433368	W 97.7514634	N38 02.600	W97 45.088	N38 02 36.01	W097 45 05.27
	WP13 WP	Y	380450.54N-0974736.91W	N 38.0807058	W 97.7935850	N38 04.842	W97 47.615	N38 04 50.54	W097 47 36.91
	WP14 WP		380915.81N-0973535.10W	N 38.1543916	W 97.5930830	N38 09.263	W97 35.585	N38 09 15.81	W097 35 35.10
	WP15 WP		380814.76N-0971440.04W	N 38.1374327	W 97.2444558	N38 08.246	W97 14.667	N38 08 14.76	W097 14 40.04
	WP16 WP	Y	380029.33N-0972546.14W	N 38.0081485	W 97.4294845	N38 00.489	W97 25.769	N38 00 29.33	W097 25 46.14
	WP17 WP		375956.88N-0971519.74W	N 37.9991334	W 97.2554842	N37 59.948	W97 15.329	N37 59 56.88	W097 15 19.74
	WP18 WP	Y	380421.38N-0972014.52W	N 38.0726064	W 97.3373679	N38 04.356	W97 20.242	N38 04 21.38	W097 20 14.52

No FAA checks included.

Database Effective Dates

Database	Date
NFDC	10/20/2011
JEPPESEN	N/A
IFP_OFFLINE	N/A
AVNIS	12/15/2011
benefits	N/A
NACO	N/A

Table 14. Alpha Departure Waypoints

b. The "Bravo Departure" shown in Figure 6, consists of an RF leg shortly after takeoff followed by a brief straight segment, then two back-to-back RF legs with a turn direction reversal. The turn radii also vary as the aircraft climbs and increases performance. Waypoint information is shown in Table 15.

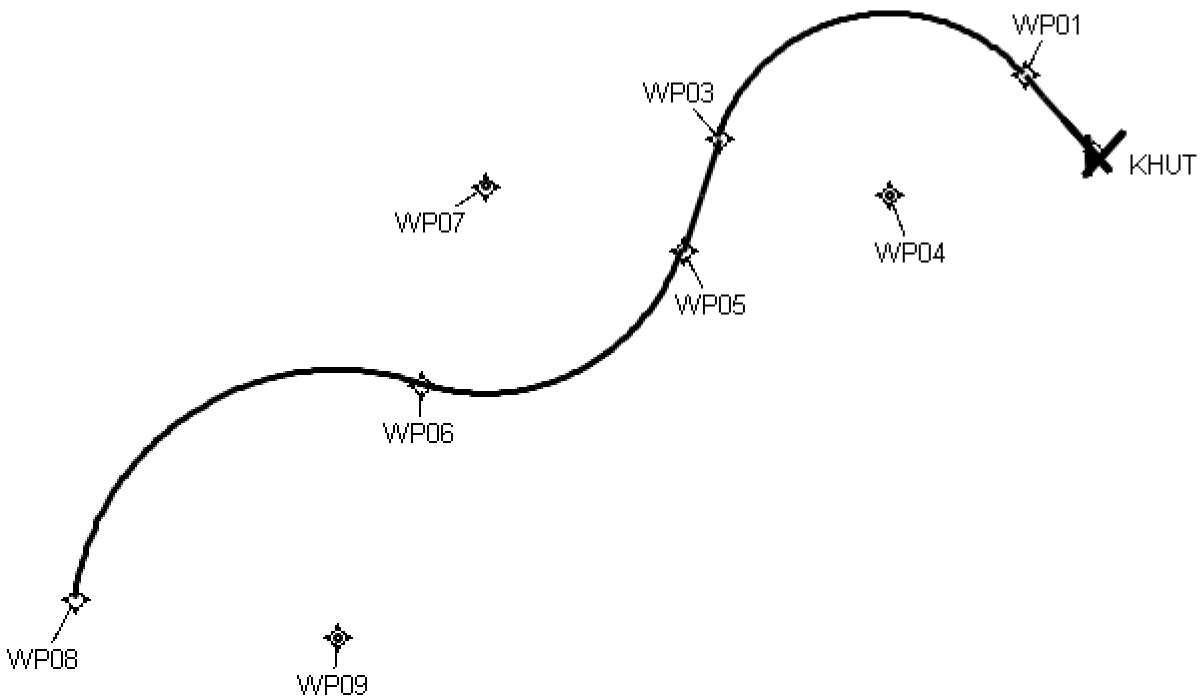

Figure 6. Bravo Departure

Runway Transition Data - Southwest1 DEP

DB	Waypoint	Distance	Leg	FO/FB	Latitude	Longitude	TC	MC	Altitude	Speed	MEA	Arc Center Lat (D° M' S.ss")	Arc Center Lon (D° M' S.ss")	Arc Radius (NM)
NACO: FULL	***DER RW31***				N38 04 27.15	W097 52 15.90								
	WP01 WP	1.00	CF	FB	N38 05 11.97	W097 53 06.49	318.27	312.27	+2043					
	WP03 WP	6.40	RF		N38 04 07.23	W097 59 40.21						N38 03 09.74	W097 55 59.72	3.06
	WP05 WP	2.00	TF	FB	N38 02 13.13	W098 00 27.73	198.23	192.23						
	WP06 WP	5.53	RF		N37 59 58.37	W098 06 05.17				230		N38 03 19.16	W098 04 41.65	3.52
	WP08 WP	7.86	RF		N37 56 19.81	W098 13 30.08				250		N37 55 41.30	W098 07 51.90	4.50

Waypoint Data

DB	Waypoint	Arc Center	Lat-Long (DMS.S)	Latitude (Deg)	Longitude (Deg)	Latitude (D°, M.mm')	Longitude (D°, M.mm')	Latitude (D° M' S.ss")	Longitude (D° M' S.ss")
	WP01 WP		380511.97N-0975306.49W	N 38.0866586	W 97.8851359	N38 05.200	W97 53.108	N38 05 11.97	W097 53 06.49
	WP03 WP		380407.23N-0975940.21W	N 38.0686757	W 97.9945032	N38 04.121	W97 59.670	N38 04 07.23	W097 59 40.21
	WP04 WP	Y	380309.74N-0975559.72W	N 38.0527067	W 97.9332567	N38 03.162	W97 55.995	N38 03 09.74	W097 55 59.72
	WP05 WP		380213.13N-0980027.73W	N 38.0369801	W 98.0077039	N38 02.219	W98 00.462	N38 02 13.13	W098 00 27.73
	WP06 WP		375958.37N-0980605.17W	N 37.9995476	W 98.1014351	N37 59.973	W98 06.086	N37 59 58.37	W098 06 05.17
	WP07 WP	Y	380319.16N-0980441.65W	N 38.0553211	W 98.0782353	N38 03.319	W98 04.694	N38 03 19.16	W098 04 41.65
	WP08 WP		375619.81N-0981330.08W	N 37.9388359	W 98.2250232	N37 56.330	W98 13.501	N37 56 19.81	W098 13 30.08
	WP09 WP	Y	375541.30N-0980751.90W	N 37.9281393	W 98.1310840	N37 55.688	W98 07.865	N37 55 41.30	W098 07 51.90

No FAA checks included.

Database Effective Dates

Database	Date
NFDC	10/20/2011
JEPPESEN	N/A
IFP_OFFLINE	N/A
AVNIS	12/15/2011
benefits	N/A
NACO	N/A

SW DEPARTURE

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Created : Thu Dec 15 13:22:48 EST 2011 TARGETS 4.8 Beta 12/15/2011 (r23657)

A single arrival was designed which is similar to a previously studied design at Fargo, ND. As the aircraft descends and decelerates, it follows a path consisting of a series of RF legs with a turn direction reversal after the first. The second directional turn consists of two back-to-back RF legs with decreasing radii. The arrival is shown in Figure 7 and waypoint information is shown in Table 16.

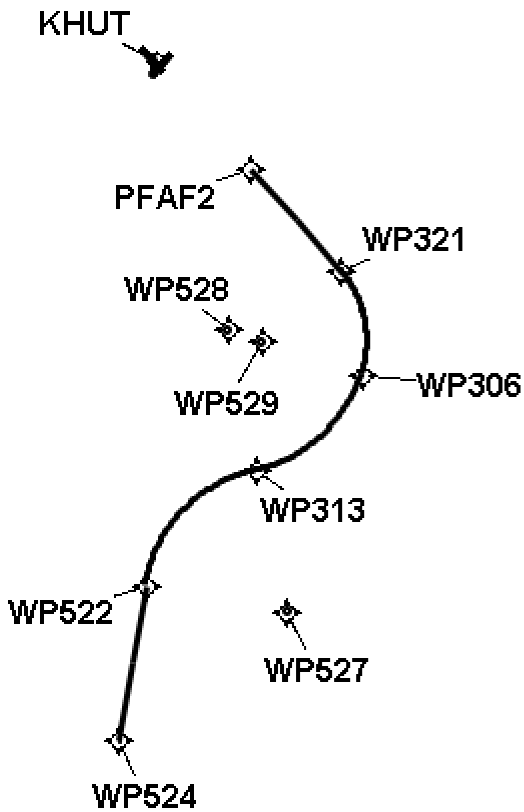

Figure 7. Arrival

Runway Transition Data - South RNAV STAR

DB	Waypoint	Distance	Leg	FO/FB	Latitude	Longitude	TC	MC	Altitude	Speed	MEA	Arc Center Lat (D° M' S.ss")	Arc Center Lon (D° M' S.ss")	Arc Radius (NM)
	WP524 WP		IF		N37 40 27.46	W097 53 15.62								
	WP522 WP	5.40	TF	FB	N37 45 46.51	W097 52 03.10	10.23	4.23						
	WP313 WP	5.91	RF		N37 49 46.57	W097 47 09.39						N37 44 52.99	W097 45 51.24	5.00
	WP306 WP	5.19	RF		N37 53 05.51	W097 42 30.19						N37 54 37.47	W097 48 27.02	4.95
	PFAF2 WP	3.86	RF		N37 56 42.35	W097 43 28.16						N37 54 14.09	W097 46 56.16	3.69
	WP321 WP	4.70	TF	FB	N38 00 12.21	W097 47 26.74	318.04	312.04						

Waypoint Data

DB	Waypoint	Arc Center	Lat-Long (DMS.S)	Latitude (Deg)	Longitude (Deg)	Latitude (D°, M.mm')	Longitude (D°, M.mm')	Latitude (D° M' S.ss")	Longitude (D° M' S.ss")
	PFAF2 WP		375642.35N-0974328.16W	N 37.9450982	W 97.7244900	N37 56.706	W97 43.469	N37 56 42.35	W097 43 28.16
	WP306 WP		375305.51N-0974230.19W	N 37.8848637	W 97.7083862	N37 53.092	W97 42.503	N37 53 05.51	W097 42 30.19
	WP313 WP		374946.57N-0974709.39W	N 37.8296033	W 97.7859430	N37 49.776	W97 47.157	N37 49 46.57	W097 47 09.39
	WP321 WP		380012.21N-0974726.74W	N 38.0033911	W 97.7907609	N38 00.203	W97 47.446	N38 00 12.21	W097 47 26.74
	WP522 WP		374546.51N-0975203.10W	N 37.7629185	W 97.8675290	N37 45.775	W97 52.052	N37 45 46.51	W097 52 03.10
	WP524 WP		374027.46N-0975315.62W	N 37.6742955	W 97.8876734	N37 40.458	W97 53.260	N37 40 27.46	W097 53 15.62
	WP527 WP	Y	374452.99N-0974551.24W	N 37.7480540	W 97.7642320	N37 44.883	W97 45.854	N37 44 52.99	W097 45 51.24
	WP528 WP	Y	375437.47N-0974827.02W	N 37.9104090	W 97.8075046	N37 54.625	W97 48.450	N37 54 37.47	W097 48 27.02
	WP529 WP	Y	375414.09N-0974656.16W	N 37.9039145	W 97.7822680	N37 54.235	W97 46.936	N37 54 14.09	W097 46 56.16

No FAA checks included.

No TERPS Surfaces included.

Database Effective Dates

Database	Date
NFDC	10/20/2011
JEPPESEN	N/A
IFP_OFFLINE	N/A
AVNIS	12/15/2011
benefits	N/A
NACO	N/A

Table 16. Arrival Waypoints

A7-2.3. Approaches.

a. Four approaches are provided to assess avionics guidance capability through a series of RF leg approach designs. The first three templates are acceptable for both RNP AR and non-RNP AR demonstrations. The fourth template is applicable to RNP AR only. It is acceptable to label the test procedures RNAV (RNP) when demonstrating RNP AR capability. When demonstrating non-RNP AR capability it is acceptable to label the test procedures as RNAV (GPS).

b. As shown in Figure 8, Approach 1 is a teardrop procedure that incorporates a descending RF right turn to final, rolling out at the final approach fix. Note that there is no straight segment 2 NM prior to the final approach fix which will be stressing for RNAV (GPS) final approach guidance due to the reduced scaling transition from terminal mode to approach mode. This path requires the aircraft to descend, decelerate, and then configure for landing all during the RF leg. The missed approach also contains an RF leg en route to the missed approach hold. Waypoint information is shown in Table 17 and vertical error budget information is shown in Table 18.

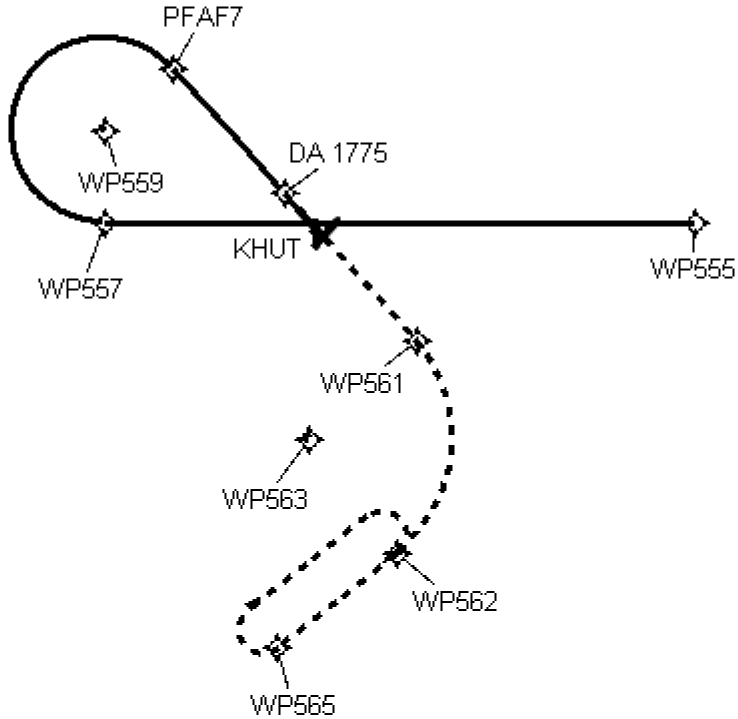

Figure 8. Approach 1

Leg Table 1

Segment	Leg Type	Start	End	Turn Type	Glide Path End Alt	Min Obs./ ATC End Alt	Max End Alt	Turn Radius Comp Alt	Descent Grad	Climb Grad	End Spd	Turn Radius Comp Spd	RNP	Turn Dir
Intermediate	IF	*WP555*	*WP555*	FB	10129			10129.22	0.0			300.0	1.0	
Intermediate	TF	*WP555*	*WP557*	FB	6235			6235.10				165.0	1.0	LEFT
Final	RF	*WP557*	*PFAF7*	FB	3172			6235.10				165.0	0.3	RIGHT
Final	TF	*PFAF7*	*KHUT:RW13:AER*	FB	1580			1580.00				165.0	0.3	
Missed	TF	DA 1775	*WP561*	FB				4337.40				265.0	1.0	RIGHT
Missed	RF	*WP561*	*WP562*	FB				4873.04				265.0	1.0	RIGHT
Missed	TF	*WP562*	*WP565*	FB				6881.69				265.0	1.0	
Missed	HM	*WP565*	*WP565*	FB				8890.33				265.0	1.0	RIGHT

Leg Table 2

Segment	Leg Type	Start	End	Turn Type	Leg Length (NM)	Leg Length (FT)	Start Course Magnetic	End Course Magnetic	Course Change	RF/Flyby Leg Radius	RF/Flyby Turn Bank Angle	Tailwind	RF Leg Arc Center
Intermediate	IF	*WP555*	*WP555*	FB	0.00	0.00000							
Intermediate	TF	*WP555*	*WP557*	FB	15.58	94644.27202	264.04	263.84					
Final	RF	*WP557*	*PFAF7*	FB	9.62	58427.49136	263.86	131.96	228.10	2.4156	19.95	59.35	WP559
Final	TF	*PFAF7*	*KHUT:RW13:AER*	FB	5.00	30380.57743	131.96	132.00	0.00		n/a	30.00	
Missed	TF	DA 1775	*WP561*	FB	5.22	31746.48819	131.96	132.00					
Missed	RF	*WP561*	*WP562*	FB	6.30	38255.73029	132.00	226.20	94.20	3.8294	24.89	56.65	WP563
Missed	TF	*WP562*	*WP565*	FB	4.02	24409.52927	226.16	226.12					
Missed	HM	*WP565*	*WP565*	FB	4.02	24409.52927	226.16						

Waypoint Data

DB	Waypoint	Latitude (Deg)	Longitude (Deg)	Latitude (Deg, Decimal Min)	Longitude (Deg, Decimal Min)	Latitude (D° M' S.ss")	Longitude (D° M' S.ss")
	PFAF7 WP	N 38.1361836	W 97.9417593	N38 8.171	W97 56.506	N38 08 10.26	W097 56 30.33
	WP555 WP	N 38.0691650	W 97.6507673	N38 4.150	W97 39.046	N38 04 08.99	W097 39 02.76
	WP557 WP	N 38.0688801	W 97.9795143	N38 4.133	W97 58.771	N38 04 07.97	W097 58 46.25
	WP559 WP	N 38.1091856	W 97.9796419	N38 6.551	W97 58.779	N38 06 33.07	W097 58 46.71
	WP561 WP	N 38.0170377	W 97.8059367	N38 1.022	W97 48.356	N38 01 01.34	W097 48 21.37
	WP562 WP	N 37.9237951	W 97.8164481	N37 55.428	W97 48.987	N37 55 25.66	W097 48 59.21
	WP563 WP	N 37.9742701	W 97.8659231	N37 58.456	W97 51.955	N37 58 27.37	W097 51 57.32
	WP565 WP	N 37.8826581	W 97.8832395	N37 52.959	W97 52.994	N37 52 57.57	W097 52 59.66

PFAF

	LAT	LON
LTP/FTP	N38 04 27.15	W097 52 15.90
Runway True Bearing	138.00	
FAF Altitude	6235.10	
LTP/FTP Elevation	1525.00	
TCH	55.00	
Glidepath Angle	3.00	
GPI	1049.46	
FAF Distance From LTP/FTP	88808.07 Feet	
	14.62 NM	
	LAT	LON
PFAF	N38 04 07.97	W097 58 46.25

RNP Value	0.30
LTP MSL Elevation	1525.00
Distance (ft) LTP to PFAF	88808.07
MSL PFAF Altitude	6235.10
Glidepath Angle	3.00
TCH	55.00
Delta ISA (dISA)	0.00
Semispan	131.00

Max Glidepath Angle	3.50	
PFAF Elevation	6235.10	
LTP Elevation	1525.0	
ACT	0.00	
Min Glidepath Angle	3.10	
NA Below	11.95 (C)	53.51 (F)
NA Above	46.85 (C)	116.32 (F)

Dist (ft) LTP to OCS ORIGIN	3324.78
OCS Slope (run:rise)	19.15:1
VEB ROC @ PFAF	72.14

Error Components	(Enter Bank Angle, WPR, FTE, and ATIS values below)		@ 250 ft	@ PFAF
ISAD	(dh x dISA)/288 + dISA - 0.5 x .00198 x [dh+h])		0.00	0.00
BG	40.48	semispan x sin (Bank Angle)	40.48	40.48
ANPE	1.225 x rnp x tan(a)		117.03	117.03
VAE	D x (tan(a) - tan(a - .01)) D=250/tan(a)		0.83	15.73
WPR	60.00	WPR x tan(a)	3.14	3.14
FTE	75.00		75.00	75.00
ASE	-8.8 x 10^-8 x (h + D x tan(a))^2 + 6.5 x 10^-3 x (h + D x tan(a)) + 50		61.26	87.11
ATIS	20.00		20.00	20.00

Table 18. Approach 1 Vertical Error Budget

c. Approach 2, as shown in Figure 9, is also a descending right turn to final but has a series of four RF legs with differing radii. Similar to Approach 1 in Figure 8, this path will require the aircraft to descend and decelerate during the RF leg. Waypoint information is shown in Table 19 and vertical error budget information is included in Table 20.

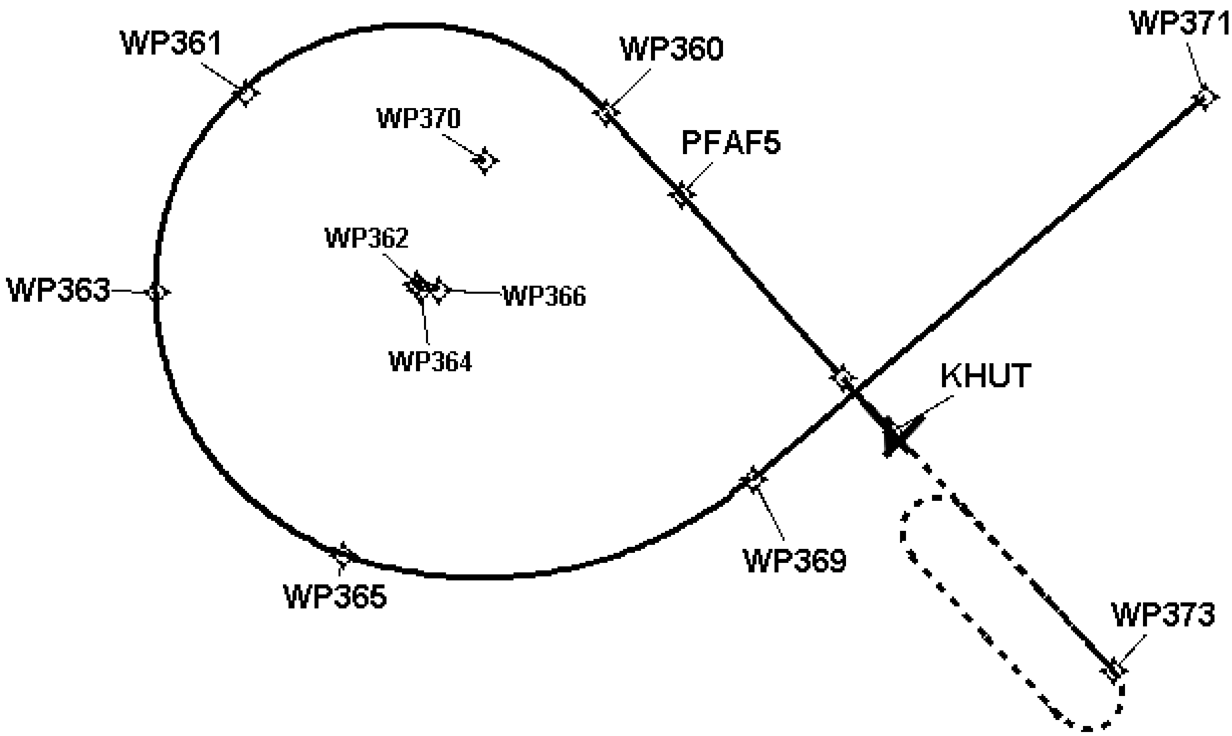

Figure 9. Approach 2

Leg Table 1

Segment	Leg Type	Start	End	Turn Type	Glide Path End Alt	Min Obs./ ATC End Alt	Max End Alt	Turn Radius Comp Alt	Descent Grad	Climb Grad	End Spd	Turn Radius Comp Spd	RNP	Turn Dir
Intermediate	IF	*WP371*	*WP371*	FB	12677			12676.98	0.0			300.0	1.0	
Intermediate	TF	*WP371*	*WP369*	FB	10009			10009.28				300.0	1.0	RIGHT
Intermediate	RF	*WP369*	*WP365*	FB	8044			10009.28				300.0	1.0	RIGHT
Intermediate	RF	*WP365*	*WP363*	FB	6499			8043.55				250.0	1.0	RIGHT
Intermediate	RF	*WP363*	*WP361*	FB	5486			6499.25				250.0	1.0	RIGHT
Intermediate	RF	*WP361*	*WP360*	FB	3672			5486.00				250.0	1.0	RIGHT
Intermediate	TF	*WP360*	*PFAF5*	FB	3172			3172.36				165.0	1.0	RIGHT
Final	TF	*PFAF5*	*KHUT:RW13:AER*	FB	1580			1580.00				165.0	0.3	
Missed	TF	DA 1775	*WP373*	FB				5312.04				265.0	1.0	
Missed	HM	*WP373*	*WP373*	FB				3725.00				265.0	1.0	RIGHT

Leg Table 2

Segment	Leg Type	Start	End	Turn Type	Leg Length (NM)	Leg Length (FT)	Start Course Magnetic	End Course Magnetic	Course Change	RF/Flyby Leg Radius	RF/Flyby Turn Bank Angle	Tailwind	RF Leg Arc Center
Intermediate	IF	*WP371*	*WP371*	FB	0.00	0.00000							
Intermediate	TF	*WP371*	*WP369*	FB	10.67	64836.91202	223.80	223.70					
Intermediate	RF	*WP369*	*WP365*	FB	7.86	47776.01926	223.70	283.59	59.89	7.5100	19.36	66.82	WP370
Intermediate	RF	*WP365*	*WP363*	FB	6.18	37533.45966	283.59	353.36	69.76	5.0700	19.68	62.93	WP366
Intermediate	RF	*WP363*	*WP361*	FB	4.05	24626.59378	353.36	42.16	48.81	4.7600	19.79	59.87	WP364
Intermediate	RF	*WP361*	*WP360*	FB	7.25	44079.45700	42.16	132.22	90.05	4.6200	19.65	57.86	WP362
Intermediate	TF	*WP360*	*PFAF5*	FB	2.00	12152.23097	132.22	132.23	0.02		n/a	30.00	
Final	TF	*PFAF5*	*KHUT:RW13:AER*	FB	5.00	30380.57743	132.23	132.28	1.16		n/a	30.00	
Missed	TF	DA 1775	*WP373*	FB	7.17	43590.52964	131.07	131.14					
Missed	HM	*WP373*	*WP373*	FB	4.00	24304.46194	131.07						

Waypoint Data

DB	Waypoint	Latitude (Deg)	Longitude (Deg)	Latitude (Deg, Decimal Min)	Longitude (Deg, Decimal Min)	Latitude (D° M' S.ss")	Longitude (D° M' S.ss")
	PFAF5 WP	N 38.1364523	W 97.9413803	N38 8.187	W97 56.483	N38 08 11.23	W097 56 28.97
	WP360 WP	N 38.1613379	W 97.9695326	N38 9.680	W97 58.172	N38 09 40.82	W097 58 10.32
	WP361 WP	N 38.1673998	W 98.1073560	N38 10.044	W98 6.441	N38 10 02.64	W098 06 26.48
	WP362 WP	N 38.1099519	W 98.0422797	N38 6.597	W98 2.537	N38 06 35.83	W098 02 32.21
	WP363 WP	N 38.1073598	W 98.1408183	N38 6.442	W98 8.449	N38 06 26.50	W098 08 26.95
	WP364 WP	N 38.1082105	W 98.0403093	N38 6.493	W98 2.419	N38 06 29.56	W098 02 25.11
	WP365 WP	N 38.0285723	W 98.0696613	N38 1.714	W98 4.180	N38 01 42.86	W098 04 10.78
	WP366 WP	N 38.1082629	W 98.0337635	N38 6.496	W98 2.026	N38 06 29.75	W098 02 01.55
	WP369 WP	N 38.0510922	W 97.9138308	N38 3.066	W97 54.830	N38 03 03.93	W097 54 49.79
	WP370 WP	N 38.1466107	W 98.0164594	N38 8.797	W98 0.988	N38 08 47.80	W098 00 59.25
	WP371 WP	N 38.1661249	W 97.7418454	N38 9.967	W97 44.511	N38 09 58.05	W097 44 30.64
	WP373 WP	N 37.9941400	W 97.7766721	N37 59.648	W97 46.600	N37 59 38.90	W097 46 36.02

PFAF

	LAT	LON
LTP/FTP	N38 04 27.15	W097 52 15.90
Runway True Bearing	138.00	
FAF Altitude	3172.36	
LTP/FTP Elevation	1525.00	
TCH	55.00	
Glidepath Angle	3.00	
GPI	1049.46	
FAF Distance From LTP/FTP	30380.58 Feet	
	5.00 NM	
	LAT	LON
PFAF	N38 08 11.23	W097 56 28.97

Table 19. Approach 2 Waypoints

RNP Value	0.30
LTP MSL Elevation	1525.00
Distance (ft) LTP to PFAF	30380.58
MSL PFAF Altitude	3172.36
Glidepath Angle	3.00
TCH	55.00
Delta ISA (dISA)	0.00
Semispan	131.00

Max Glidepath Angle	3.50	
PFAF Elevation	3172.36	
LTP Elevation	1525.0	
ACT	0.00	
Min Glidepath Angle	3.10	
NA Below	11.95 (C)	53.51 (F)
NA Above	45.68 (C)	114.23 (F)

Dist (ft) LTP to OCS ORIGIN	3324.90
OCS Slope (run:rise)	19.15:1
VEB ROC @ PFAF	216.86

Error Components	(Enter Bank Angle, WPR, FTE, and ATIS values below)		@ 250 ft	@ PFAF
ISAD	(dh x dISA)/288 + dISA - 0.5 x .00198 x [dh+h])		0.00	0.00
BG	25.00	semispan x sin (Bank Angle)	25.00	25.00
ANPE	1.225 x rnp x tan(a)		117.03	117.03
VAE	D x (tan(a) - tan(a - .01)) D=250/tan(a)		0.83	5.50
WPR	60.00	WPR x tan(a)	3.14	3.14
FTE	75.00		75.00	75.00
ASE	-8.8 x 10^-8 x (h + D x tan(a))^2 + 6.5 x 10^-3 x (h + D x tan(a)) + 50		61.26	69.73
ATIS	20.00		20.00	20.00

Table 20. Approach 2 Vertical Error Budget

d. Approach 3 is shown in Figure 10. This procedure uses an RF leg early in the procedure followed by a brief straight segment, then two back-to-back RF legs with a turn direction reversal. The second RF leg terminates at the final approach fix. As on the other approaches, the aircraft will be required to descend, decelerate and configure for landing during the series of RF legs. The missed approach also includes an RF leg to the missed approach hold. Waypoint information is shown in Table 21 and vertical error budget information is included in Table 22.

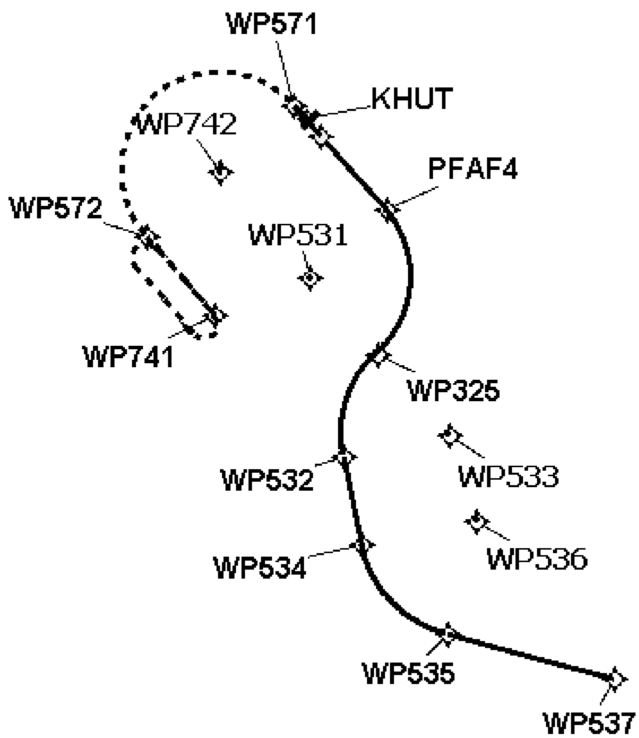

Figure 10. Approach 3

Leg Table 1

Segment	Leg Type	Start	End	Turn Type	Glide Path End Alt	Min Obs./ ATC End Alt	Max End Alt	Turn Radius Comp Alt	Descent Grad	Climb Grad	End Spd	Turn Radius Comp Spd	RNP	Turn Dir
Intermediate	IF	*WP537*	*WP537*	FB	10584			10583.57	0.0			300.0	1.0	
Intermediate	TF	*WP537*	*WP535*	FB	8641			8641.47				250.0	1.0	RIGHT
Intermediate	RF	*WP535*	*WP534*	FB	7193			8641.47				250.0	1.0	RIGHT
Intermediate	TF	*WP534*	*WP532*	FB	6193			6192.56				250.0	1.0	RIGHT
Intermediate	RF	*WP532*	*WP325*	FB	4937			6192.56				250.0	1.0	RIGHT
Intermediate	RF	*WP325*	*PFAF4*	FB	3162			4936.79				250.0	1.0	LEFT
Final	TF	*PFAF4*	*KHUT:RW31:AER*	FB	1570			1570.00				165.0	0.3	
Missed	TF	DA 1765	*WP571*	FB				2615.00				265.0	0.5	LEFT
Missed	RF	*WP571*	*WP572*	FB				8536.36				265.0	1.0	LEFT
Missed	TF	*WP572*	*WP741*	FB				10854.65				265.0	1.0	LEFT
Missed	HM	*WP741*	*WP741*	FB				13172.95				265.0	1.0	RIGHT

Leg Table 2

Segment	Leg Type	Start	End	Turn Type	Leg Length (NM)	Leg Length (FT)	Start Course Magnetic	End Course Magnetic	Course Change	RF/Flyby Leg Radius	RF/Flyby Turn Bank Angle	Tailwind	RF Leg Arc Center
Intermediate	IF	*WP537*	*WP537*	FB	0.00	0.00000							
Intermediate	TF	*WP537*	*WP535*	FB	7.77	47201.70006	278.82	278.72					
Intermediate	RF	*WP535*	*WP534*	FB	5.80	35214.94480	278.72	342.26	63.54	5.2220	19.55	64.11	WP536
Intermediate	TF	*WP534*	*WP532*	FB	4.00	24304.46194	342.26	342.25					
Intermediate	RF	*WP532*	*WP325*	FB	5.02	30520.94148	342.25	42.26	60.00	4.7980	19.44	59.26	WP533
Intermediate	RF	*WP325*	*PFAF4*	FB	7.10	43126.52487	42.26	312.31	89.95	4.5209	19.67	56.77	WP531
Final	TF	*PFAF4*	*KHUT:RW31:AER*	FB	5.00	30380.57743	312.31	312.27	0.00		n/a	30.00	
Missed	TF	DA 1765	*WP571*	FB	1.80	10937.00787	312.31	312.29					
Missed	RF	*WP571*	*WP572*	FB	13.64	82894.71614	312.29	133.02	179.27	4.3623	24.99	63.90	WP742
Missed	TF	*WP572*	*WP741*	FB	4.64	28172.46233	133.02	133.06					
Missed	HM	*WP741*	*WP741*	FB	4.64	28172.46233	133.02						

Waypoint Data

DB	Waypoint	Latitude (Deg)	Longitude (Deg)	Latitude (Deg, Decimal Min)	Longitude (Deg, Decimal Min)	Latitude (D° M' S.ss")	Longitude (D° M' S.ss")
	PFAF4 WP	N 37.9975785	W 97.7847137	N37 59.855	W97 47.083	N37 59 51.28	W097 47 04.97
	WP325 WP	N 37.8911180	W 97.7924249	N37 53.467	W97 47.545	N37 53 28.02	W097 47 32.73
	WP531 WP	N 37.9473859	W 97.8558480	N37 56.843	W97 51.351	N37 56 50.59	W097 51 21.05
	WP532 WP	N 37.8151083	W 97.8240457	N37 48.906	W97 49.443	N37 48 54.39	W097 49 26.56
	WP533 WP	N 37.8313647	W 97.7252214	N37 49.882	W97 43.513	N37 49 52.91	W097 43 30.80
	WP534 WP	N 37.7497614	W 97.8069336	N37 44.986	W97 48.416	N37 44 59.14	W097 48 24.96
	WP535 WP	N 37.6831652	W 97.7273613	N37 40.990	W97 43.642	N37 40 59.39	W097 43 38.50
	WP536 WP	N 37.7674351	W 97.6994648	N37 46.046	W97 41.968	N37 46 02.77	W097 41 58.07
	WP537 WP	N 37.6501154	W 97.5696846	N37 39.007	W97 34.181	N37 39 00.42	W097 34 10.86
	WP571 WP	N 38.0746550	W 97.8715595	N38 4.479	W97 52.294	N38 04 28.76	W097 52 17.61
	WP572 WP	N 37.9784995	W 98.0097230	N37 58.710	W98 0.583	N37 58 42.60	W098 00 35.00
	WP741 WP	N 37.9200757	W 97.9456813	N37 55.205	W97 56.741	N37 55 12.27	W097 56 44.45
	WP742 WP	N 38.0262098	W 97.9402549	N38 1.573	W97 56.415	N38 01 34.36	W097 56 24.92

PFAF

	LAT	LON
LTP/FTP	N38 03 35.48	W097 51 17.61
Runway True Bearing	318.00	
FAF Altitude	3162.36	
LTP/FTP Elevation	1515.00	
TCH	55.00	
Glidepath Angle	3.00	
GPI	1049.46	
FAF Distance From LTP/FTP	30380.58 Feet	
	5.00 NM	
	LAT	LON
PFAF	N37 59 51.28	W097 47 04.97

Table 21. Approach 3 Waypoints

RNP Value	0.30
LTP MSL Elevation	1515.00
Distance (ft) LTP to PFAF	30380.58
MSL PFAF Altitude	3162.36
Glidepath Angle	3.00
TCH	55.00
Delta ISA (dISA)	0.00
Semispan	131.00

Max Glidepath Angle	3.50	
PFAF Elevation	3162.36	
LTP Elevation	1515.0	
ACT	0.00	
Min Glidepath Angle	3.10	
NA Below	11.97 (C)	53.55 (F)
NA Above	45.70 (C)	114.27 (F)

Dist (ft) LTP to OCS ORIGIN	3324.27
OCS Slope (run:rise)	19.15:1
VEB ROC @ PFAF	216.83

Error Components	(Enter Bank Angle, WPR, FTE, and ATIS values below)		@ 250 ft	@ PFAF
ISAD	(dh x dISA)/288 + dISA - 0.5 x .00198 x [dh+h])		0.00	0.00
BG	25.00	semispan x sin (Bank Angle)	25.00	25.00
ANPE	1.225 x rnp x tan(a)		117.03	117.03
VAE	D x (tan(a) - tan(a - .01)) D=250/tan(a)		0.83	5.50
WPR	60.00	WPR x tan(a)	3.14	3.14
FTE	75.00		75.00	75.00
ASE	-8.8 x 10^-8 x (h + D x tan(a))^2 + 6.5 x 10^-3 x (h + D x tan(a)) + 50		61.20	69.68
ATIS	20.00		20.00	20.00

Table 22. Approach 3 Vertical Error Budget

e. Approach 4 is shown in Figure 11. This procedure is intended for RNP AR operations only. The procedure is unique and incorporates an RF leg beginning at the missed approach point. This configuration will require the aircraft to begin the missed approach and track the RF leg while climbing and accelerating. The initial RF leg is followed consecutively by two additional RF legs each with increasing radii. Waypoint information is shown in Table 23.

> **Note:** At the AC publication date, approach 4 was only intended for future RNP AR operations. This does not impact previous recognition of RF leg capability.

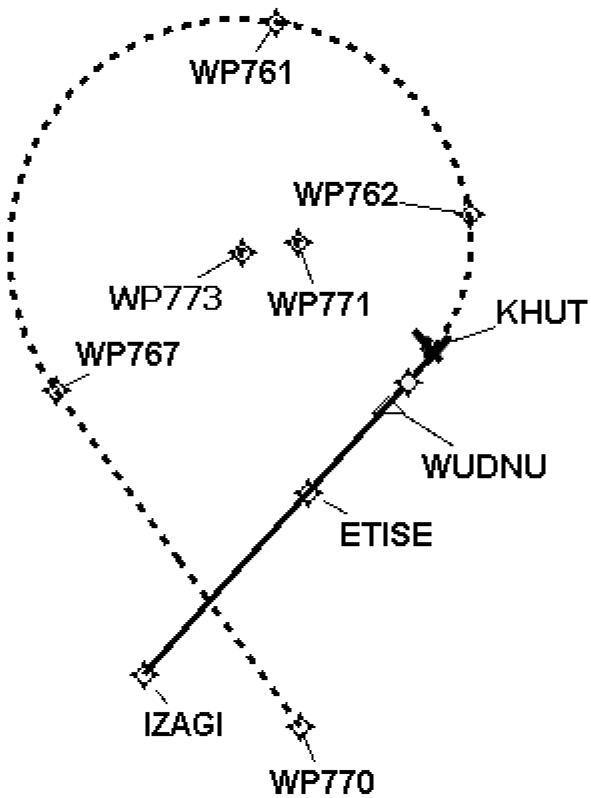

Figure 11. Approach 4

Path From IZAGI Leg Table 1/2

Segment	Leg Type	Start	End	Turn Type	RNP	Min End Fix Alt	Max End Fix Alt	Leg Length (NMI)	Leg Length (FT)	Start Course True	End Course True	Course Change	Turn Dir
INTERMEDIATE	IF	IZAGI [NFDC]	IZAGI [NFDC]	FB	1.0		3400.00	0.0000	0.00000				
INTERMEDIATE	TF	IZAGI [NFDC]	ETISE [NFDC]	FB	1.0			7.0859	43054.72936	42.3130	42.3748	0.0008	RIGHT
FINAL	TF	ETISE [NFDC]	WUDNU [NFDC]	FB	0.3			3.4141	20744.41667	42.3756	42.4055	0.0032	
FINAL	TF	WUDNU [NFDC]	KHUT:RW04:AER	FB	0.3			1.7000	10329.45409	42.4022	42.4172		
MISSED_APPROACH	RF	KHUT:RW04:AER	WP762	FB	1.0			4.5803	27830.28432	42.4186	350.3648	52.0539	LEFT
MISSED_APPROACH	RF	WP762	WP761	FB	1.0			8.3775	50902.81282	350.3648	278.4359	71.9289	LEFT
MISSED_APPROACH	RF	WP761	WP767	FB	1.0			15.6858	95308.95821	278.4359	143.8122	134.6236	LEFT
MISSED_APPROACH	TF	WP767	WP770	FB	1.0			12.0000	72913.38583	143.8120	143.9038		

Path From IZAGI Leg Table 2/2

Segment	Leg Type	Start	End	Turn Type	End Fix Speed Restriction	RF Leg Radius	Flyby Turn Bank Angle Override	Tailwind Component Override	RF Leg Arc Center	Reduced ROC
INTERMEDIATE	IF	IZAGI [NFDC]	IZAGI [NFDC]	FB						
INTERMEDIATE	TF	IZAGI [NFDC]	ETISE [NFDC]	FB						
FINAL	TF	ETISE [NFDC]	WUDNU [NFDC]	FB						
FINAL	TF	WUDNU [NFDC]	KHUT:RW04:AER	FB						
MISSED_APPROACH	RF	KHUT:RW04:AER	WP762	FB		5.0400			WP771	
MISSED_APPROACH	RF	WP762	WP761	FB		6.6800			WP772	
MISSED_APPROACH	RF	WP761	WP767	FB		6.6800			WP773	
MISSED_APPROACH	TF	WP767	WP770	FB						

Waypoint Data

DB	Waypoint	Latitude (Deg)	Longitude (Deg)	Latitude (Deg, Decimal Min)	Longitude (Deg, Decimal Min)	Latitude (D° M' S.ss")	Longitude (D° M' S.ss")
NFDC	ETISE	N 37.99630	W 97.93545	N37 59.77783	W97 56.12717	N37 59 46.67000	W097 56 7.63000
NFDC	IZAGI	N 37.90891	W 98.03603	N37 54.53467	W98 2.16167	N37 54 32.08000	W098 02 9.70000
	WP761 WP	N 38.22164	W 97.95474	N38 13.29863	W97 57.28419	N38 13 17.91791	W097 57 17.05128
	WP762 WP	N 38.13013	W 97.83636	N38 7.80785	W97 50.18133	N38 07 48.47124	W097 50 10.87986
	WP767 WP	N 38.04564	W 98.08928	N38 2.73849	W98 5.35700	N38 02 44.30923	W098 05 21.41989
	WP770 WP	N 37.88395	W 97.94012	N37 53.03696	W97 56.40730	N37 53 2.21756	W097 56 24.43804
	WP771 WP	N 38.11601	W 97.94129	N38 6.96055	W97 56.47760	N38 06 57.63311	W097 56 28.65604
	WP772 WP	N 38.11139	W 97.97543	N38 6.68363	W97 58.52586	N38 06 41.01778	W097 58 31.55178
	WP773 WP	N 38.11139	W 97.97543	N38 6.68362	W97 58.52587	N38 06 41.01708	W097 58 31.55191
NFDC	WUDNU	N 38.03837	W 97.88691	N38 2.30217	W97 53.21450	N38 02 18.13000	W097 53 12.87000

PFAF

	LAT	LON
LTP/FTP	N38 03 33.52	W097 51 45.78
Runway True Bearing	42.43	
FAF Altitude	3200.00	
LTP/FTP Elevation	1516.30	
TCH	55.00	
Glidepath Angle	3.00	
GPI	1049.46	
FAF Distance From LTP/FTP	31073.87 Feet	
	5.11 NM	
	LAT	LON
PFAF	N37 59 46.67	W097 56 07.63

Table 23. Approach 4 Waypoints

A7-3. Test Guide.

a. Paragraph A7-3 provides guidance that may be used to conduct development and/or airworthiness RF leg testing for new equipment hardware/software, or updates to existing equipment hardware/software. The guidance is designed to be used in collaboration with the templates described in paragraph A7-2 to create "FOR TEST ONLY" terminal area instrument procedures (departures, arrivals and approaches). The intent of this regimen is to provide a set of rigorous instrument procedures that the applicant can use to demonstrate meeting the RF leg airworthiness approval criteria.

b. The test instrument procedures are designed and located at an airport with an elevation of approximately 1500 ft MSL. The waypoint and navigation leg data is provided so that the procedures can be "translated" to another location suitable to the applicant. However, the new airport elevation should be within the range of 1000 - 2000 ft MSL to ensure that the designed turn radii and bank angles do not change significantly (see paragraph A7-1.e). The applicant will be required to obtain a navigation database for their respective navigation system that contains the test procedures.

c. The information in the following paragraphs describes test conditions such as generic aircraft performance parameters, desired atmospheric conditions, and considerations to assist the applicant with creating a detailed test plan. Applicants are encouraged to use these recommended guidelines. However, amendments may be made as required to accommodate unique equipment designs, test environment, testing methods or other considerations.

A7-3.1. Initial Set-Up.

a. Configure the aircraft for individual trials using two gross weight conditions:

(1) Nominal heavy weight resulting in lower accelerations to climb speed and higher speeds on approach.

(2) Nominal light weight resulting in higher accelerations to climb speed and lower speeds on approach.

b. Verify that a navigation database with the FAA "FOR TEST ONLY" terminal procedures is loaded in the FMS.

c. Verify desired data parameters will be recorded (if data recording capability is available).

> **Note:** In addition to the desired data parameters, the lateral path definition (desired path) and lateral path "cross-track error" (distance from path centerline) should be included in the recorded data parameters to monitor/review path maintenance performance.

d. Configure the simulation (if practical) for trials using two atmospheric conditions:

(1) Standard day, standard lapse rate.

(2) 35^{o} C outside air temperature, with standard lapse rate.

e. If practical, simulated wind direction should be set to a tailwind for each turn entry. The wind velocity for the respective altitude should approximate those values shown below.

Use linear interpolation to obtain wind values for altitudes that fall between the values listed below. For altitudes greater than 15,000 ft, use the formula: V_{KTW} = 0.00198 x (altitude) + 47.

Note: If the simulator cannot model variable winds and various levels, select the wind direction and velocity that will most effectively simulate the worst case tailwind for the procedure.

≤ 2000 ft = 30 kts
3000 ft = 53 kts
4000 ft = 55 kts
5000 ft = 57 kts
6000 ft = 59 kts
7000 ft = 61 kts
8000 ft = 63 kts
9000 ft = 65 kts
10,000 ft = 67 Kts
11,000 ft = 69 kts
12,000 ft = 71 kts
13,000 ft = 73 kts
14,000 ft = 75 kts
15,000 ft = 77 kts

A7-3.2. Airborne Test Conditions.

a. Record aircraft configuration.

(1) Verify that the simulation is "conformed" with correct avionics hardware and software.

(2) Record aircraft performance parameters (gross weight, etc.) and configuration.

b. Select the procedure to be tested, load the procedure into the route of flight and verify the procedure is in the active route.

Note: Approach 1 and Approach 3 (Figure 8 and Figure 10) have the RF leg connecting to the final approach segment at the final approach fix. These configurations are more demanding than required for an RNAV (GPS) final segment which may affect capture.

c. Ensure the correct RNP values are used for the respective flight phase. Use either the FMS default value or a manually entered RNP value.

- Departure RF legs: 1.0 NM.
- Arrival RF legs: 1.0 NM.
- RNAV (GPS) initial, intermediate, and missed approach segments: 1.0 NM.

- RNP AR initial, intermediate, and missed approach segments: 1.0 – 0.1 NM.

Note: RNP AR initial, intermediate, and missed approach segment RNP values can be as low as 0.1 NM but the typical value is 1.0 NM.

d. Prior to takeoff, verify that data recording is activated and data is recording.

e. Position the aircraft for the respective procedure.

f. Engage lateral and vertical path guidance if practical.

Note: For departure, if lateral guidance cannot be armed/engaged prior to takeoff, engage as soon as practical after takeoff to begin path tracking.

g. Engage autopilot/flight director (as soon as practical after takeoff) and verify the autopilot/flight director is providing guidance to the lateral path.

Note: Executing the procedures with autopilot engaged is desired. The test directors should also consider manually flying the procedures with flight director only if the respective test vehicle is capable.

h. Fly the programmed route and observe that the lateral cross track deviation does not exceed the FTE for the respective RNP level.

RNP	FTE	FTE Basis
1.0	0.5 NM	Flt Director and/or Autopilot
0.3	0.25 NM	Flt Director or,
	0.125 NM	Autopilot
<0.3	FTE to achieve TSE ≤ 1* RNP value	

i. Repeat A7-3.2.b through A7-3.2.h as required for each of the aircraft configurations and instrument procedures.

Appendix 8. non-U.S. Constellations with GPS-Based GNSS.

A8-1. Introduction.

a. RTCA SC-159 is developing standards to support aviation use of non-U.S. core constellations in accordance with their approved terms of reference. RTCA is working with the constellation service providers to secure the necessary information for manufacturers to create suitable performance standards for GPS/GLONASS and dual-frequency/multi-constellation (DFMC) avionics.

b. This appendix provides preliminary information for manufacturers that wish to add GLONASS or other constellation(s) capabilities to their GPS, GPS/SBAS, or GPS/GBAS equipment, including single-constellation dual-frequency (L5/E5a) capability. No FAA TSO exists for GLONASS, GPS/GLONASS, multi-constellation or dual-frequency avionics. Therefore, adding capability for any other constellation or dual-frequency capability must be accomplished as a non-TSO function until appropriate TSOs are available. Adding other constellation or frequency capability according to the guidance provided in this appendix does not ensure compatibility or compliance with future TSO requirements. Manufacturers may only enable additional constellations or frequencies when they are declared operational for aviation use by the constellation operator.

> **Note:** GLONASS SARPs are included in the latest edition of *ICAO Aeronautical Telecommunications, Annex 10, Volume 1 (Radio Navigation Aids)*. However, these SARPs do not include equipment performance and test standards and may not represent the latest GLONASS configuration envisioned by the Russian Federation. Draft SARPS for Galileo and Beidou are in work, and GPS L5 will be introduced to support DFMC capability.

c. Manufacturers that include non-U.S. constellation or second frequency capabilities must ensure those capabilities are integrated on a non-interference basis and that any non-U.S. constellation’s failures, errors, or alerts do not affect GPS, GPS/SBAS, or GPS/GBAS capability. GPS, GPS/SBAS, and GPS/GBAS equipment must continue to meet the requirements of its TSOA and all of the criteria for GPS, GPS/SBAS, or GPS/GBAS equipment as described in this AC. Non-U.S. constellations or other frequencies must not be used to supplement or aid GPS, GPS/SBAS, GPS/GBAS performance requirements or GPS RAIM prediction requirements. Additionally, the loss of non-U.S. constellation functions or other frequencies must not affect the GPS, GPS/SBAS, or GPS/GBAS functions or performance.

d. No operational credit should be expected for the use of non-U.S. constellations or other frequencies and the installation instructions must include appropriate language for an AFM(S)/RFM(S) limitation. Future TSOs and operational credit for non-U.S. constellations depends upon system and service provider performance capabilities, published constellation performance commitments, and operational support commitments (e.g. international NOTAMS).

e. Manufacturers that have equipment with a TSO-C196(AR), TSO-C145(AR), TSO-C146(AR) or TSO-C161(AR) TSOA may add non-U.S. constellation capability or additional frequencies as a non-TSO function. Adding non-U.S. constellation or GPS L5 functionality is considered a new and novel major change to the TSOA that will require coordination with the ACO and FAA Headquarters. The applicant must present a data package detailing proposed performance, intended function, and limitations. Applicants should consider concurrently applying for airworthiness approval when submitting data to add a non-U.S. constellation or GPS L5 as a non-TSO function.

> **Note:** TSO-C129a has been cancelled. Adding non-U.S. constellation capability to TSO-C129a is a major change that requires an upgrade to a new TSO. Applicants should contact their ACO.

f. Receive-only mobile earth station equipment "operating with" non-U.S. licensed radionavigation-satellite service (RNSS) satellites require compliance with the applicable Federal Communications Commission rules. Title 47 Code of Federal Regulations (C.F.R.) Part 25.131 and Part 25.137 address requests for licensing, additions to the "permitted space station list" and waivers for non-Federal, receive-only equipment operating with foreign satellite systems, including receive-only mobile earth stations operating with non-U.S. licensed RNSS satellites.

Appendix 9. Definitions and Acronyms.

A9-1. Definitions.

a. Advisory Vertical Guidance. Vertical path deviation guidance indications generated by any means, but for no operational credit. See chapter 4.

b. All Revisions (AR). An all-inclusive reference for TSOs with multiple versions that remain applicable.

c. Aircraft-Based Augmentation System (ABAS). A generic term for an algorithm on the aircraft that verifies GNSS position output integrity. That algorithm can use RAIM or RAIM-equivalent methods, and in the future may use advanced techniques to provide an integrity-assured position solution.

d. Approved Vertical Guidance. Vertical path deviation guidance indications generated by certified means to use for operational credit on charted approach procedures that contain a TERPS-protected glidepath (e.g., LNAV/VNAV, LPV, GLS, ILS).

e. Area Navigation (RNAV). A method of navigation that permits aircraft operation on any desired flight path within the coverage of station-referenced navigation aids; within the capability limits of self-contained aids; or a combination of these. For the purposes of this AC, the specified RNAV accuracy must be met 95% of the flight time.

f. Display. Within the context of this AC, a display is a device mounted in the aircraft instrument panel to convey course guidance navigation information to the aircrew for controlling the aircraft along the intended route. Displays may also be used to convey other information as well.

g. Design Eye Position. The position at each pilot's station from which a seated pilot achieves the required combination of outside visibility and instrument scan. The design eye position is a single point selected by the applicant that is normally a point fixed in relation to the aircraft structure (neutral seat reference point) at which the midpoint of the pilot’s eyes should be located when seated at the normal position.

h. Fault Detection and Exclusion (FDE). A receiver autonomous integrity monitoring algorithm that can automatically detect and exclude a faulty satellite from the position solution when a sufficient number of redundant satellite measurements are available.

i. Galileo. Galileo is a European satellite-based radio navigation system being developed that will provide a global positioning service. Galileo will provide two levels of service: an open service for non-critical applications, and a fee-based service for safety-of-life applications. However, the two-level structure hasn’t been irrevocably set. The Galileo open service will provide two signals that are interoperable with, but will be independent from, GPS for aviation applications.

j. Global Navigation Satellite System (GNSS). GNSS is a generic term for satellite-based navigation, including GPS, GPS/SBAS, GPS/GBAS, GLONASS, Galileo and any other satellite navigation or augmentation system suitable for aviation use within the Aeronautical Radio Navigation Service (ARNS) frequency band.

k. Global Positioning System (GPS). GPS is a U.S. satellite-based radio navigation system that provides a global positioning service. The service provided by GPS for civil use is defined in the September 2008 GPS Standard Positioning System Performance Standard, 4th edition available at http://pnt.gov/public/docs/2008/spsps2008.pdf.

l. GLONASS. GLONASS is a Russian Federation satellite-based radio navigation system providing a global positioning service. GLONASS has 24 operational satellites in their designated orbital slots. But, GLONASS is not yet approved for IFR operations in the U.S. National Airspace System.

m. Ground-Based Augmentation System (GBAS). GBAS is a localized coverage augmentation system to GPS that calculates integrity and correction data and broadcasts the data to GPS/GBAS users directly from a ground-based transmitter. International GBAS standards are defined in ICAO Annex 10.

n. Letter of Design Approval (LODA). An FAA design approval that is issued only to a foreign (non-U.S.) manufacturer of an appliance that the FAA has found meets a specific TSO. A LODA is not a production approval and does not confer an installation approval. The civil aviation authority for the manufacturer's country approves and oversees the quality control system and production of the appliance under the provisions of the bilateral agreement with the U.S..

o. Local Area Augmentation System (LAAS). LAAS is the legacy term for the U.S. implementation of GPS/GBAS.

p. Navigation Computer. Within the context of this AC, navigation refers to any function used to direct the course of an aircraft. A navigation computer as addressed in this AC provides the functions of position estimation, path definition, path steering, and situation indications and alerting to the flight crew.

q. Normal Line of Sight. Established at 15 degrees below the horizontal plane referenced to the design eye position for fixed-wing aircraft (see AC 25-11 latest revision). For rotorcraft, reference the visibility requirements defined in the latest revisions of AC 27-1 and 29-2.

r. Primary Field of View. The vertical and horizontal visual fields relative to the design eye reference point that can be viewed with eye rotation only using foveal or central vision. The values for the horizontal (relative to the normal line of sight) are +/-15 degrees optimum, with +/- 35 degrees maximum. The values for the vertical (relative to normal line of sight) are +/-15 degrees optimum, with + 40 degrees up and -20 degrees down maximum (see AC 25-11 latest revision). The primary field of view definition should be broad enough to include the center radio stack on 14 CFR part 23 airplanes with "classic", analog basic 'T' instrumentation. For rotorcraft, reference the visibility requirements defined in the latest revisions of AC 27-1 and 29-2.

s. Primary Optimum Field of View. For the purpose of this AC related to RNP AR, the primary optimum field of view is within +/-15 degrees horizontal and vertical relative to the pilot's normal line of sight.

t. Receiver Autonomous Integrity Monitoring (RAIM). Any algorithm that verifies the integrity of the position output using redundant GPS measurements, or using GPS measurements and barometric aiding, is considered a RAIM algorithm. An algorithm that uses additional information (e.g., multi-sensor system with inertial reference system) to verify the integrity of the position output may be acceptable as a RAIM-equivalent.

u. Required Navigation Performance (RNP). RNP is a statement of the total aircraft navigation performance necessary for operation within a defined airspace.

v. RNAV Multi-Sensor Equipment. This type of navigation system computes and displays one independent or blended position and other navigation data combined from one or more navigation sensors, which provide independent positions.

w. Satellite-Based Augmentation System (SBAS). SBAS is a wide coverage augmentation system to GPS that calculates integrity and correction data on the ground and uses geostationary satellites to broadcast the data to GPS/SBAS users. In the U.S., this is referred to as Wide Area Augmentation System (WAAS).

x. Sensor. Within the context of this AC, a sensor is a device on the aircraft that receives signals from an appropriate antenna to calculate an output supplied to a navigation computer.

y. Stand-alone. Stand-alone as addressed in this AC refers to navigation equipment incorporating both a GNSS position sensor and a navigation computer function in a single unit so that the equipment provides path deviations relative to a selected path.

z. Time of Arrival Control (TOAC). TOAC is a system capability that determines the necessary and available adjustments to aircraft speed and vertical profile necessary to satisfy a required time of arrival (RTA) at a fix.

aa. Wide Area Augmentation System (WAAS). WAAS is the U.S. implementation of GPS/SBAS.

A9-2. Acronyms.

14 CFR	Title 14 of the Code of Federal Regulations
ABAS	Aircraft-Based Augmentation System
AC	Advisory Circular
ACO	Aircraft Certification Office
ADAHRS	Air Data Attitude Heading Reference System
ADS-B	Automatic Dependent Surveillance - Broadcast

AF/D	Airport/Facilities Directory
AFM	Airplane Flight Manual
AFMS	Airplane Flight Manual Supplement
AGL	Above Ground Level
AHRS	Attitude Heading Reference System
AIRAC	Aeronautical Information Regulation and Control
AML	Approved Model List
APCH	Approach
(AR)	All Revisions
ARNS	Aeronautical Radio Navigation System
ASI	Aviation Safety Inspector
ATIS	Automated Traffic Information System
atk	Along Track
baro-VNAV	Barometric Vertical Navigation
CA	Course to Altitude termination per ARINC 424
CAT I	Category I precision approach
CDI	Course Deviation Indicator
CDU	Control Display Unit
CF	Course to Fix per ARINC 424
CFR	Code of Federal Regulations
$\mathbf{D_{MAX}}$	Maximum Use Distance
DA	Decision Altitude
dB	Decibel
dBc	Decibels Relative to Carrier Power
dBm	Decibels Referenced to one Milliwatt
D/D/I	DME/DME/Inertial Reference Unit
DER	Designated Engineering Representative
DER	Designated End of Runway (for RNP AR only)
DF	Direct to Fix per ARINC 424
DME	Distance Measuring Equipment
DOD	Department of Defense
DOT	Department of Transportation
DP	Departure Procedure
EHSI	Electronic Horizontal Situation Indicator
ELT	Emergency Locator Transmitter
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EVS	Enhanced Vision System
FA	Fix to Altitude termination per ARINC 424
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FAS	Final Approach Segment
FD	Flight Director
FDE	Fault Detection and Exclusion
FGS	Flight Guidance System
FHS	Functional Hazard Assessment
FM	Fix to Manual termination per ARINC 424

FMS	Flight Management System
FOM	Figure of Merit
FRP	Federal Radionavigation Plan
FRT	Fixed Radius Transition
FSTD	Flight Simulation Training Device
FTE	Flight Technical Error
FTP	Fictitious Threshold Point
GBAS	Ground-Based Augmentation System
GEO	Geostationary Orbit Satellite
GNSS	Global Navigation Satellite System
GLS	GBAS Landing System
GNSS	Global Navigation Satellite System
GPA	Glide Path Angle
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
HAL	Horizontal Alert Limit
HAT	Height Above Terrain
HDOP	Horizontal Dilution of Precision
HFOM	Horizontal Figure of Merit
$HFOM_V$	Horizontal Figure of Merit (velocity)
HMI	Hazardously Misleading Information
HPL	Horizontal Protection Level
HSI	Horizontal Situation Indicator
HTAWS	Helicopter Terrain Awareness and Warning System
HUL	Horizontal Uncertainty Level
Hz	Hertz
ICAO	International Civil Aviation Organization
IF	Initial Fix per ARINC 424
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
INS	Inertial Navigation System
IRS	Inertial Reference System
IRU	Inertial Reference Unit
LAAS	Local Area Augmentation System
LNAV	Lateral Navigation
LNAV/VNAV	Lateral Navigation/Vertical Navigation
LOA	Letter of Acceptance
LOC	Localizer
LODA	Letter of Design Approval
LP	Localizer Performance without Vertical Guidance
LPV	Localizer Performance with Vertical Guidance
LTP	Landing Threshold Point
MAG	Magnetic
MEMS	Micro-Electro-Mechanical System
MLS	Microwave Landing System
MMR	Multi-Mode Receiver

MNPS	Minimum Navigation Performance Standards
MOPS	Minimum Operational Performance Standards
MSL	Mean Sea Level
NAC_V	Navigation Accuracy Category (velocity)
NAS	National Airspace System
NAVAID	Navigation Aid
NDB	Non-Directional Beacon
NM	Nautical Mile
NOTAM	Notice to Airmen
NSE	Navigation System Error
NTAP	Notices to Airman Publication
OBS	Omni Bearing Selector
ODP	Obstacle Departure Procedure
OEM	Original Equipment Manufacturer
PAN	Precision and Navigation
PAPI	Precision Approach Path Indicator
PBN	Performance-based Navigation
PHAC	Plan for Hardware Aspects of Certification
POH	Pilot Operating Handbook
PSAC	Plan for Software Aspects of Certification
PVT	Position, Velocity, Time
RAIM	Receiver Autonomous Integrity Monitoring
RF	Radius to Fix per ARINC 424
RFM	Rotorcraft Flight Manual
RFMS	Rotorcraft Flight Manual Supplement
RNAV	Area Navigation
RNP	Required Navigation Performance
RNP APCH	RNP Approach
RNP AR .	RNP Authorization Required
RTA	Required Time of Arrival
SAAAR	Special Aircraft and Aircrew Authorization Required
SAPT	Service Availability Prediction Tool
SATCOM	Satellite Communications
SBAS	Satellite-Based Augmentation System
SFAR	Special Federal Aviation Regulation
SID	Standard Instrument Departure
STAR	Standard Terminal Arrival Route
STC	Supplemental Type Certificate
STC-AML	Supplemental Type Certificate Approved Model List
SVS	Synthetic Vision System
TACAN	Tactical Air Navigation
TAWS	Terrain Awareness and Warning System
TC	Type Certificate
TF	Track to Fix per ARINC 424
TOAC	Time of Arrival Control
TOGA	Take-Off Go Around
TSE	Total System Error

TSO	Technical Standard Order
TSOA	Technical Standard Order Authorization
VA	Heading to Altitude termination per ARINC 424
VAL	Vertical Alert Limit
VASI	Visual Approach Slope Indicator
VDB	Very High Frequency Data Broadcast
VDOP	Vertical Dilution of Precision
VFOM	Vertical Figure of Merit
$VFOM_V$	Vertical Figure of Merit (velocity)
VFR	Visual Flight Rules
VHF	Very High Frequency
VI	Heading to Intercept per ARINC 424
VM	Heading to Manual termination per ARINC 424
VNAV	Vertical Navigation
VOR	Very High Frequency Omni-Directional Range
VPL	Vertical Protection Level
VSWR	Voltage Standing Wave Ratio
URA	User Range Accuracy
WAAS	Wide Area Augmentation System
xtk	Cross Track

Appendix 10. Related Documents.

A10-1. FAA Advisory Circulars.

a. AC 20-107B, *Composite Aircraft Structure*.

b. AC 20-115C, *Airborne Software Assurance.*

c. AC 20-152, *RTCA, Inc., Document RTCA/DO-254, Design Assurance Guidance for Airborne Electronic Hardware.*

d. AC 20-153B, *Acceptance of Data Processes and Associated Navigation Databases.*

e. AC 20-159, *Obtaining Design and Production Approval of Airport Moving Map Display Applications Intended for Electronic Flight Bag Systems.*

f. AC 20-163, *Displaying Geometric Altitude Relative to Mean Sea Level.*

g. AC 20-165A, *Airworthiness Approval of Automatic Dependent Surveillance - Broadcast (ADS-B) Out Equipment for Operation in the National Airspace System (NAS).*

h. AC 20-167, *Airworthiness Approval of Enhanced Vision System, Synthetic Vision System, Combined Vision System, and Enhanced Flight Vision System Equipment.*

i. AC 20-168, *Certification Guidance for Installation of Non-Essential, Non-Required Aircraft Cabin Systems and Equipment.*

j. AC 20-169, *Guidance and Certification of Military and Special Mission Modifications and Equipment for Commercial Derivative Aircraft (CDA).*

k. AC 20-170, *Integrated Modular Avionics Development, Verification, Integration, and Approval Using RTCA/DO-297 and Technical Standard Order-C153.*

l. AC 20-174, *Development of Civil Aircraft and Systems.*

m. AC 21-16F, *RTCA Document DO-160 versions D, E, and F, Environmental Conditions and Test Procedures for Airborne Equipment.*

n. AC 21-40A, *Application Guide for Obtaining a Supplemental Type Certificate.*

o. AC 21-46, *Technical Standard Order Program.*

p. AC 21-50, *Installation of TSOA Articles and LODA Appliances.*

q. AC 23-8B, *Flight Test Guide for Certification of Part 23 Airplanes.*

r. AC 23-13A, *Fatigue, Fail-Safe, and Damage Tolerance Evaluation of Metallic Structure for Normal, Utility, Acrobatic, and Commuter Category Airplanes.*

s. AC 23-17, *Systems and Equipment Guide for Certification of Part 23 Airplanes.*

t. AC 23-18, *Installation of Terrain Awareness and Warning System (TAWS) Approved for Part 23 Airplanes.*

u. AC 23-21 with Change 1, *Airworthiness Compliance Checklists Used to Substantiate Major Alterations for Small Airplanes.*

v. AC 23-22, *Guidance for Approved Model List (AML) Supplemental Type Certificate (STC) Approval for Part 23 Airplane Avionics Installations.*

w. AC 23.1309-1E, *Equipment, Systems, and Installations in Part 23 Airplanes.*

x. AC 23.1311-1C, *Installation of Electronic Displays in Part 23 Airplanes.*

y. AC 23.1419-2D, *Certification of Part 23 Aircraft for Flight in Icing Conditions.*

z. AC 25-7C, *Flight Test Guide for Certification of Transport Category Airplanes.*

aa. AC 25-11A, *Transport Category Airplane Electronic Display Systems.*

bb. AC 25-15, *Approval of Flight Management Systems in Transport Category Airplanes.*

cc. AC 25-23, *Airworthiness Criteria for the Installation Approval of a Terrain Awareness and Warning System (TAWS) for Part 25 Airplanes.*

dd. AC 25-1309-1A, *System Design and Analysis.*

ee. AC 25.1329-1, *Approval of Flight Guidance Systems.*

ff. AC 25.1419-1A, *Certification of Part 25 Aircraft for Flight in Icing Conditions.*

gg. AC 25.1529-1A, *Instructions for Continued Airworthiness of Structural Repairs on Transport Airplanes.*

hh. AC 27-1, *Certification of Normal Category Rotorcraft.*

ii. AC 29-2C, *Certification of Transport Category Rotorcraft.*

jj. AC 43.9-1F, *Instructions for Completion of FAA Form 337.*

kk. AC 43.13-1B, *Acceptable Methods, Techniques and Practices – Aircraft Inspection and Repair*.

ll. AC 43.13-2B, *Acceptable Methods, Techniques and Practices – Aircraft Alterations.*

mm. AC 90-96A, *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).*

nn. AC 90-100, *U.S. Terminal and Enroute Area Navigation (RNAV) Operations.*

oo. AC 90-101A, *Approval Guidance for RNP Procedures with AR.*

pp. AC 90-105, *Approval Guidance for RNP Operations and Barometric Vertical Navigation in the U.S. National Airspace System.*

qq. AC 91-49 with Change 1, *General Aviation Procedures for Flight in North Atlantic Minimum Navigation Performance Specification Airspace.*

rr. AC 120-28D, *Criteria for Approval of Category III Weather Minima for Takeoff, Landing, and Rollout.*

ss. AC 120-29A, *Criteria for Approval of Category I and Category II Weather Minima for Approach*

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

A10-2. FAA Technical Standard Orders.

a. TSO-C66c, *Airborne Distance Measuring Equipment (For Air Carrier Aircraft).*

b. TSO-C115d, *Required Navigation Performance (RNP) Equipment Using Multi-Sensor Inputs*.

c. TSO-C129a, *Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS).*

> **Note:** TSO-C129a has been cancelled but is referenced here for historical purposes because manufacturers may still produce the equipment according to an existing TSOA and the equipment is still eligible for installation.

d. TSO-C144a, *Passive Airborne Global Navigation Satellite System (GNSS) Antenna*.

e. TSO-C145d, *Airborne Navigation Sensors Using the Global Positioning System (GPS) Augmented by the Satellite-Based Augmentation System (SBAS).*

f. TSO-C146d, *Stand-Alone Airborne Navigation Equipment Using the Global Positioning System (GPS) Augmented by the Satellite Based Augmentation System (SBAS)*.

g. TSO-C151c, *Terrain Awareness and Warning System.*

h. TSO-C154c, *Universal Access Transceiver (UAT) Automatic Dependent Surveillance-Broadcast (ADS-B) Equipment.*

i. TSO-C161a, *Ground Based Augmentation System Positioning and Navigation Equipment.*

j. TSO-C162a*, Ground Based Augmentation System Very High Frequency Data Broadcast Equipment.*

k. TSO-C165a, *Electronic Map Display Equipment for Graphical Depiction of Aircraft Position.*

l. TSO-C166b, *Extended-Squitter Automatic Dependent Surveillance-Broadcast (ADS-B) and Traffic Information.*

m. TSO-C190*, Active Airborne Global Navigation Satellite System (GNSS) Antenna.*

n. TSO-C194*, Helicopter Terrain Awareness and Warning System.*

o. TSO-C196b, *Airborne Supplemental Navigation Sensors for Global Positioning System Equipment Using Aircraft-Based Augmentation.*

p. TSO-C204, *Circuit Card Assembly Functional Sensors using Satellite-Based Augmentation System (SBAS) for Navigation and Non-Navigation Position/Velocity/Time Output.*

q. TSO-C205, *Circuit Card Assembly Functional Class Delta Equipment Using the Satellite-Based Augmentation System For Navigation Applications.*

r. TSO-C206, *Circuit Card Assembly Functional Sensors using Aircraft-Based Augmentation for Navigation and Non-Navigation Position/Velocity/Time Output.*

A10-3. RTCA, Inc. Documents (RTCA/DO) documents.

a. RTCA/DO-160G, *Environmental Conditions and Test Procedures for Airborne Equipment*.

b. RTCA/DO-178B, *Software Considerations in Airborne Systems and Equipment Certification*.

c. RTCA/DO-178C, *Software Considerations in Airborne Systems and Equipment Certification*.

d. RTCA/DO-187, *Minimum Operational Performance Standards For Airborne Area Navigation Equipment Using Multi-Sensor Inputs*.

e. RTCA/DO-189, *Minimum Performance Standard for Airborne Distance Measuring Equipment (DME) Operating Within the Radio Frequency Range of 960-1215 Megahertz*.

f. RTCA/DO-201A, *Standards for Aeronautical Information*.

g. RTCA/DO-228 with Change 1, *Minimum Operational Performance Standards For Global Navigation Satellite System (GNSS) Airborne Antenna Equipment*.

h. RTCA/DO-229D, Change 1, *Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System(GPS/WAAS) Airborne Equipment*.

i. RTCA/DO-235B, *Assessment of Radio Frequency Interference Relevant to the GNSS L1 Frequency Band*.

j. RTCA/DO-236C, Change 1, *Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation*.

k. RTCA/DO-246D, *GNSS Based Precision Approach Local Area Augmentation System (LAAS) Signal-in-Space Interface Control Document (ICD)*.

l. RTCA/DO-253C, *Minimum Operational Performance Standards for GPS Local Area Augmentation System Airborne Equipment*.

m. RTCA/DO-254, *Design Assurance Guidance for Airborne Electronic Hardware*.

n. RTCA/DO-260B, *Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance-Broadcast (ADS-B) and Traffic Information Services-Broadcast (TIS-B).*

o. RTCA/DO-257A, *Minimum Operational Performance Standards for the Depiction of Navigation Information on Electronic Maps*.

p. RTCA/DO-282B, *Minimum Operational Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance-Broadcast (ADS-B).*

q. RTCA/DO-283B, *Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation*.

r. RTCA/DO-301, *Active Airborne Global Navigation Satellite System (GNSS) Antenna*.

s. RTCA/DO-316, *Minimum Operational Performance Standards for Global Positioning System/Aircraft-Based Augmentation System Airborne Equipment*.

A10-4. Other Documents.

a. ARINC Specification 424-19, Navigation Systems Database, December 19, 2008. Copies of this document may be requested from Aeronautical Radio Inc., 2551 Riva Road, Annapolis, Md. 21401-7435.

b. The FAA and Industry Guide to Product Certification, September 2004. Copies of this document may be obtained at: http://www.faa.gov/aircraft/air_cert/design_approvals/media/CPI_guide_II.pdf.

c. GPS Standard Positioning Service Performance Standard, 4th edition, September, 2008. Copies of this document and general information related to GPS may be requested at http://pnt.gov/public/docs/2008/spsps2008.pdf.

d. Department of Defense IS-GPS-200D, Navstar GPS Space Segment/Navigation User Interface. Copies of 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/gps/geninfo/default.htm.

e. FAA Specification Wide Area Augmentation System (WAAS), FAA-E-2892C, July 29, 2009. This document is available on-line at http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/library/documents/.

A10-5. How to Get Related Documents.

a. Order copies of 14 CFR parts from the Superintendent of Documents, Government Printing Office (GPO), P.O. Box 979050, St. Louis, MO 63197. For general information, telephone (202) 512-1800 or fax (202) 512-2250. You can also get copies online at the GPO electronic CFR Internet website at www.gpoaccess.gov/cfr/.

b. Order copies of RTCA documents from RTCA Inc., 1828 L Street NW, Suite 805, Washington, D.C. 20036-4007. For general information, telephone (202) 833-9339 or fax (202) 833-9434. You can also order copies online at www.rtca.org.

c. You can find copies of ACs on the FAA website at http://www.faa.gov/regulations_policies/advisory_circulars/, or www.airweb.faa.gov/rgl.

d. You can find a current list of technical standard orders on the FAA Regulatory and Guidance Library at www.airweb.faa.gov/rgl. You will also find the TSO Index of Articles on the same site.