



U.S. Department  
of Transportation  
**Federal Aviation  
Administration**

# Advisory Circular

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**Subject:** Airworthiness Approval of  
Positioning and Navigation Systems

**Date:** 9/27/10

**AC No:** 20-138B

**Initiated by:** AIR-130

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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 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.
- Barometric vertical navigation (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 exists to support multi-constellation equipment.

A handwritten signature in blue ink that reads "Susan J. M. Cabler".

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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).
- 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) formerly referred to as special aircraft and aircrew authorization required (SAAAR).

**Note:** RNP AR was previously named RNP SAAAR. The name has been changed to RNP AR for international harmonization, but might not yet be standardized throughout all documents.
- d. Barometric vertical navigation (baro-VNAV) equipment.
- e. This AC does not address new satellite constellations that are planned or currently under construction. This AC will be updated when sufficient documentation exists to support multi-constellation equipment.
- f. This AC incorporates the airworthiness considerations contained in AC 90-101A, *Approval Guidance for RNP Procedures with SAAAR*, and AC 90-105, *Approval Guidance for RNP Operations and Barometric Vertical Navigation in the U.S. National Airspace System*, as a necessary first step to consolidating all the positioning and navigation equipment and RNP airworthiness guidance into one AC. Future AC 90-101 and AC 90-105 revisions will remove the airworthiness guidance. This AC will not replace the operational guidance found in the RNP 90-series ACs. However, this AC does replace the ACs listed in paragraph 1-3 by incorporating and updating the information they contained.
- g. This AC is not mandatory and is not a regulation. This AC describes an acceptable means, but not the only means, to comply with applicable regulations.
- h. This AC provides guidance information intended for new approvals. This AC is not intended to modify, change or cancel existing equipment design or airworthiness approvals.

Equipment with existing approvals can continue to be installed within the provisions of their original design and airworthiness certification.

**i.** The guidance in this AC cannot ensure compliance with all 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. Mandatory terms such as “must” used in this AC are only applicable when following the compliance method outlined.

**j.** 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.

**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.**

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:

- a.** AC 20-129, *Airworthiness Approval of Vertical Navigation (VNAV) Systems for use in the U.S. National Airspace System (NAS) and Alaska.*
- b.** AC 20-130A, *Airworthiness Approval of Navigation or Flight Management Systems Integrating Multiple Navigation Sensors.*
- c.** AC 20-138A, *Airworthiness Approval of Global Navigation Satellite System (GNSS) Equipment.*
- d.** AC 25-4, *Inertial Navigation Systems.*

## 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 type certificates (TC) (major/minor changes to aircraft type design), supplemental type certificates (STC), and TSOAs. The regulations and technical standard orders (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 have been written for positioning and navigation-related equipment and components (see appendix 8 of this AC). New TSO's 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) The design of positioning and navigation equipment has become increasingly more complex and workload intensive with no standardized interface with the pilot. The human factors evaluation of the equipment is subjective.

(3) There is not 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. For example, a decision by the positioning and navigation equipment manufacturer to develop system software to RTCA, Inc. document (RTCA)/(DO)-178B, *Software Considerations in Airborne Systems and Equipment Certification*, dated December 1, 1992, Level C, may limit installation eligibility if that equipment contributes to failure conditions of other systems that perform critical functions to a higher software level.

**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 STCs for installation solely to avionics manufacturers.

c. The installation manual and other data accepted during the TSO process can be used as a source of acceptable data to support an installation airworthiness compliance finding.

### **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-C129(AR)/C196.

a. TSO-C129a, *Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS)*, and TSO-C196, *Airborne Supplemental Navigation Sensors for Global Positioning System Equipment Using Aircraft-Based Augmentation*, both define an acceptable standard for GPS equipment without ground-based or space-based augmentations. Both TSO-C129 all revisions (AR) and TSO-C196 equipment require other positioning and navigation systems appropriate to the operation on-board the aircraft due to equipment limitations.

b. TSO-C196 defines GPS sensor equipment that incorporates many processing improvements found in the GPS/SBAS equipment minimum operational performance standards (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/c, *Airborne Navigation Sensors Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS)*, sensor approved as a TSO-C196 sensor. It is acceptable for these TSO-C196 applicants to take certification credit by re-using data developed during a previous TSO-C145b/c 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 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. RTCA/DO-229D meets or exceeds the performance requirements for TSO-C196. The original RTCA/DO-178B documentation can be re-used if there are no software changes.

(2) Applicants seeking a TSO-C196 TSOA/LODA based on a previously approved TSO-C145b/c sensor must maintain separate part numbers for each unit. It is not acceptable to have both a TSO-C145b/c and TSO-C196 TSOA/LODA simultaneously (see paragraph 3-5.b(4)).

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

(3) It is acceptable for TSOA/LODA applicants with TSO-C145b/c sensors to simply disable the GPS/SBAS tracking loops in their equipment to qualify as a TSO-C196 sensor.

(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 any RTCA/DO-316 requirements not in RTCA/DO-229C; and requirements that are more stringent such as enroute/terminal mode accuracy and the broadband external interference noise environment.

c. There is no plan to withdraw TSO-C129(AR) authorizations or TSO-C129a. Manufacturers can continue production according to their TSOA/LODA or submit new designs for approval according to TSO-C129a and the equipment is still eligible for installation in accordance with the guidance in this AC.

**Note:** TSO-C129/C129a does not provide sufficient performance for all operational applications.

d. It is possible to receive a TSO-C129a Class A incomplete system TSOA/LODA for displays or navigation computers provided they meet the applicable requirements in RTCA/DO-208, with Change 1, *Minimum Operational Performance Standards for Airborne Supplemental Equipment Using Global Positioning System (GPS)*, dated September 21, 1993, as modified by TSO-C129a and are linked by part number to specific GPS sensors in the TSO application documentation.

e. TSO-C129a will take precedence when adding an incomplete system TSO-C129a Class A TSOA/LODA to an FMS with an existing TSO-C115b, *Airborne Area Navigation Equipment Using MultiSensor Inputs*, TSOA/LODA if there are any conflicts between the two TSOs.

**Note:** Paragraph 3-1.e is intended for new applications. There is no intent to invalidate older equipment may have received an incomplete system TSOA/LODA per TSO-C129.

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

a. TSO-C145c/C146c defines an acceptable standard for GPS/SBAS equipment. There is no equipment limitation for GPS/SBAS-equipped aircraft to have other positioning and navigation systems on-board. Additionally, RTCA/DO-229D referenced by the GPS/SBAS TSOs will remain as the MOPS for single-frequency GPS/SBAS equipment. Future multi-frequency/multi-system equipment will have a separate MOPS and TSO.

b. There is no plan to withdraw authorizations to the earlier TSO revisions, so manufacturers of TSO-C145a/C146a or TSO-C145b/C146b 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.

c. 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.

**d.** 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.

**e.** Displays or navigation computers (such as flight management systems (FMSs)) may receive a TSO-C146c Class 1, 2, or 3 (functional Class Gamma) incomplete system TSOA/LODA provided they meet the applicable Class Gamma requirements in RTCA/DO-229D and are linked by part number to specific GPS/SBAS 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.

(1) FMSs are not required to have an incomplete system TSO-C146c Class Gamma TSOA/LODA to provide or process GPS/SBAS navigation functions such as flight path deviation data and GPS/SBAS alerts. It is sufficient to use TSO-C115b plus an alternate method to demonstrate compliance with the applicable RTCA/DO-229D performance requirements. However, an incomplete system TSO-C146c Class Gamma TSOA/LODA provides an established means for the installed FMS to demonstrate navigation computer compliance for credit as a GPS/SBAS system.

**Note 1:** FMSs that do not meet the applicable RTCA/DO-229D Class Gamma performance requirements can still receive Position/Velocity/Time (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 (see paragraphs 5-5.2.b and 5-5.2.c).

**Note 2:** TSOA/LODA applicants may request deviations to TSO-C146c or RTCA/DO-229D performance requirements for the FMS if they demonstrate an equivalent level of safety.

(2) TSO-C146c will take precedence when adding an incomplete system TSO-C146c Class Gamma TSOA/LODA to an FMS with an existing TSO-C115b TSOA/LODA if there are any conflicts between the two TSOs.

(3) FMSs already incorporating GPS and baro-VNAV capability may qualify as TSO-C146c Class Gamma-2 navigation computer systems when receiving inputs from a TSO-C145c Class Beta-2 or Class Beta-3 sensor. The incomplete system TSO-C146c Class Gamma approval would be added to the TSO-C115b approval or replace the TSO-C129(AR) approval if one exists. Applicants are encouraged to seek an incomplete system Class Gamma-2 navigation computer approval for these FMSs (or Class Gamma-1 for FMSs that don’t process vertical deviations) to provide full SBAS-based capability for enroute through lateral navigation (LNAV)/vertical navigation (VNAV).

**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.c, 15-2.a), and 17-5).

(4) 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 11-2.a). Applicants may consider a Class Gamma-3 incomplete system TSOA/LODA to provide LP/LPV navigation computer functions if the FMS incorporates level B software. Otherwise, applicants may consider a Class Delta-4 configuration when integrating LP/LPV capability if the FMS does not incorporate level B software since this configuration doesn't require the FMS to process LP/LPV data (see paragraphs 3-2.e(5) and 3-2.e(6) below). The FMS could still operate as a Class Gamma-2 navigation computer for GPS/SBAS functions other than LP/LPV; or according to its TSO-C115b/C129(AR) authorization.

(5) For Class Delta-4 integrations, FMSs in typical federated avionics architectures do not need an incomplete system TSO-C146c Class Delta-4 TSOA/LODA 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, Class Delta-4 LP/LPV final approach segment capability, and display) will be confirmed at the time of installation.

(a) The FMS may provide an interface for pilot control of the Class Delta-4 equipment and may host database information such as the Final Approach Segment (FAS) data block 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 description of the database information needed and the data format to establish FMS compatibility as a limitation in the installation manual.

(b) 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. These FMSs will need an incomplete system TSO-C146c 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:** Applicants with non-federated FMS architectures may also consider pursuing incomplete system TSO-C146c Class Gamma approval for the navigation computer functions/components.

(6) An FMS that is part of an aircraft-level TSO-C146c Class Delta-4 integration normally provides the RNAV 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 can also provide RNAV capability for the missed approach segment.



**Note:** RNAV capability for the initial, intermediate, and missed approach segments can be accomplished by the FMS according to its TSO-C115b and/or TSO-C129(AR) 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).

### **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 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 either TSO-C129a, TSO-C145, TSO-C146, or TSO-C196 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 14-8.1).

**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. RNAV Multi-Sensor Equipment.**

**a.** TSO-C115b 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 TSO-C115a. Manufacturers of TSO-C115a equipment can continue production according to their TSOA/LODA. However, integrating GNSS into the multi-sensor navigation equipment is

considered a major change and requires an application for a TSO-C115b TSOA/LODA.

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

(2) Applicants with equipment that has an existing TSO-C115b approval may add an incomplete system TSO-C129a Class A or TSO-C146c Class Gamma TSOA/LODA for the navigation computer functions. The navigation computer requirements in TSO-C129a or TSO-C146c will take precedence if there are any conflicts with the requirements in TSO-C115b (deviations to TSO-C115b need to be approved). See paragraphs 3-1 and 3-2 respectively for additional information on TSO-C129a and TSO-C146c incomplete system TSOA/LODAs.

**b.** Multi-sensor systems must also comply with the appropriate TSO requirements for the individual sensor; for example, 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 United States national airspace system.

**Note:** The multi-sensor navigation system must comply with TSO-C115b (or a later revision) when integrating GNSS sensors. It is not acceptable to use equipment certified to earlier revisions (see paragraph 3-5.b(1)).

### **3-5. 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, 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.

(4) TSO-C196 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 instrument landing system (ILS).

**Note 3:** We recommend that equipment manufacturers provide a means for pilots to inhibit advisory vertical guidance to support nonprecision 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, 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, 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.**

**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 temperature and pressure altitude (i.e., correct altimeter setting) 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. GPS/SBAS Operational Class 2 equipment may not provide advisory vertical guidance on instrument approach procedures with an LNAV line of minima published with LNAV/VNAV and/or LPV lines of minima. The reason is due to potential confusion over advisory versus approved vertical guidance and which line of minima applies. This human factors issue is even more critical when GPS/SBAS equipment “fails-down” to LNAV minima during the final approach segment if vertical guidance is lost during an LNAV/VNAV approach.

**Note:** There is no intent to preclude using baro-VNAV advisory vertical guidance for an LNAV approach provided it is selected prior to the final approach fix. See paragraph 17-5 when integrating baro-VNAV with GPS/SBAS vertical guidance.

**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). GPS/SBAS Operational Class 3 equipment may not provide advisory vertical guidance on instrument approach procedures with an LNAV line of minima published with LNAV/VNAV and/or LPV lines of minima. The reason is due to potential confusion over advisory versus approved vertical guidance and which line of minima applies. This human factors issue is even more critical for GPS/SBAS equipment that has a “fail-down” mode to LNAV minima during the final approach segment.

**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 during approach operations using these lines of minima.

**Note 2:** There is no intent to prevent using baro-VNAV advisory vertical guidance for an LNAV approach provided it is selected prior to the final approach fix. See paragraph 17-5 when integrating baro-VNAV with GPS/SBAS vertical guidance.

**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 (AFMS)/rotorcraft flight manual supplement (RFMS) 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 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 AFMS/RFMS 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 AC23-17, *Systems and Equipment Guide for Certification of Part 23 Airplanes*, AC 25.1329-1, *Approval of Flight Guidance Systems*, AC27-1, *Certification of Normal Category Rotorcraft*, or AC29-2, *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. GNSS 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 publishing 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) 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**

b. 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.

c. TSO-C145b/c, TSO-C146b/c and TSO-C196 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 and RTCA/DO-316 respectively.

**Note:** The respective MOPS and TSOs will be updated with the latest noise standards during the next revision cycle.

d. 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.

e. 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.

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

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

**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 does not permit using TSO-C129(AR) and TSO-C196 equipment on ‘T’ or ‘Q’ routes. However, 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 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 under TSO-C129/C129a will need a new certification if antennas meeting the original requirements are no longer available. Using a different antenna specification constitutes a major design change that requires a new TSOA/LODA.

(1) Either passive or active antennas are acceptable for TSO-C129(AR) and TSO-C196 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, Active Airborne Global Navigation Satellite System (GNSS) Antenna, dated December 13, 2006, 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 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 14-5).

**Note:** TSO-C129(AR) Class A equipment is a sensor/navigation computer combination.

**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 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 equipment is to take advantage of signal processing improvements found in RTCA/DO-229D without the GPS/SBAS requirements. TSO-C196 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 equipment.

**Note 1:** Applicants will have to establish sensor/antenna compatibility when replacing TSO-C129(AR) sensors with either TSO-C196 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, publish aeronautical information, or 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 provides these services through NOTAMs for TSO-C145(AR)/C146(AR) equipment for domestic navigation operations. The FAA plans to provide these services for all GNSS TSO equipment to support

ADS-B out. 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 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 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/Volpe prediction website did not include FDE prediction capability at the time this AC was published. However, the FAA/Volpe website is scheduled to include FDE prediction capability soon.

**e.** The prediction program can be provided on any processing platform (in the GPS equipment or not).

**f.** The prediction program software should be developed in accordance with at least RTCA/DO-178B 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 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 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.

**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  $\pm 15$  minutes computed in intervals of 5 minutes or less about the ETA.

**l.** Prediction programs supporting ADS-B out should meet the requirements in 14 CFR § 91.227. 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 that take advantage of unique antenna performance rather than using the “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 TSO revision ‘c’ (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-C145c defines an acceptable standard for GPS/SBAS sensors (Class Beta) while TSO-C146c defines a complete sensor/navigation computer configuration (Class Gamma) and an “ILS look-alike” (Class Delta). Both TSOs reference RTCA/DO-229D 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 approach to LNAV minimums at the alternate airport rather than a ground-based approach aid (see paragraph 14-6.1). Additionally, GPS/SBAS equipment may be used on RNAV ‘T’ and ‘Q’ routes within the contiguous United States 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.

**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.** GPS/SBAS equipment that complies with the ‘b’ or ‘c’ TSO revision 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 vertical guidance. 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.

### 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. 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 per RTCA/DO-200A, *Standards for Processing Aeronautical Information*, dated September 28, 1998, paragraph 2.4.2, since it changes the reference system but not the actual vertical location.

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 satellite, path, and 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 12-1.d, 14-7, and 20-2.b 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 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-C129(AR) class B1 or C1, TSO-C196, or TSO-C145(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-C129(AR) class B1 or C1, TSO-C196, or TSO-C145(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-C129(AR) class B1 or C1, TSO-C196, or TSO-C145(AR) receiver outputs (i.e., no GPS/GBAS-provided PVT).

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

## **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 14-2.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 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 14-5.

**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.a and 14-5. 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-C146c and the appropriate sections of RTCA/DO-229D as a complete system in the aircraft.

**c.** Using a TSO-C145(AR) or TSO-C196 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 remains TSO-C129(AR). 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 TSO-C129(AR).

**Note:** RTCA/DO-229D 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 when flying outside of the GPS/SBAS service provider's coverage area.

### 5-5.3 GPS/SBAS Upgrade.

It is possible to upgrade TSO-C196 equipment to TSO-C145c 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-C145c/C146c compliance. Proposed upgrades for this equipment to TSO-C145c/C146c 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 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-C145b/C146b/C145c/C146c 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-C145b/C146b/C145c/C146c 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-C129/C129a<br>Combined Rec/Ant | TSO-C129/C129a<br>All Classes | TSO-C196<br>GPS | TSO-C145a/C146a<br>All Classes | TSO-C145b/C146b/<br>C145c/C146c<br>Opn'l Class 1 | TSO-C145b/C146b/<br>C145c/C146c<br>Opn'l Class 2,3,4 |
|--|---------------|------------------------------------|-------------------------------|-----------------|--------------------------------|--|--|
| TSO-C144(AR)<br>Passive                          |               | X                                  | X                             | X               | X                              |  |  |
| TSO-C144<br>Active                               |               | X                                  | X                             | X               | X                              | See Note   |  |
| TSO-C190   |               | X                                  | X                             | X               | X                              | X  |  |
| TSO-C129 TSOA<br>Antenna/Receiver<br>Combination | X             |                                    |                               |                 |                                |  |  |

**Table 2. Acceptable Standard Antennas**

**Note :** An active TSO-C144 antenna may be acceptable for TSO-C145b/C146b/C145c/C146c Operational Class 2, 3, & 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 to TSO-C145c 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.**

For all combined sensor/navigator GNSS equipment, the navigation database is an essential component for the equipment to perform its intended function. Guidelines pertaining to the navigation database can be found in AC 20-153 (latest revision). Particular attention should be paid to the specification of the data quality requirements as described in RTCA/DO-200A, appendix B.

##### **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 AFMS/RFMS.

##### **5-6.2 Database Process.**

The RNAV multi-sensor equipment manufacturer is usually the last link in the aeronautical data processing chain, as the format for the data loaded in the final database is typically proprietary. The applicant for a TSOA/LODA must identify an aeronautical data process accessible to the equipment users. AC 20-153 (latest revision), *Acceptance of Data Processes and associated Navigation Databases*, provides an acceptable method for this aeronautical data process. The approval of the process is included as part of the TSOA/LODA for GNSS equipment.

#### **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 equipment. Each type of GNSS equipment described in chapter 5 is acceptable as an input to TAWS 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.

For area navigation equipment, the navigation database is an essential component for the equipment to perform its intended function. Guidelines pertaining to the navigation database can be found in AC 20-153 (latest revision). Particular attention should be paid to the specification of the data quality requirements as described in RTCA/DO-200A, appendix B.

#### 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.

The RNAV multi-sensor equipment manufacturer is usually the last link in the aeronautical data processing chain, as the format for the data loaded in the final database is typically proprietary. The applicant for a TSOA/LODA must identify an aeronautical data process accessible to the equipment users. AC 20-153 (latest revision), *Acceptance of Data Processes and associated Navigation Databases*, provides an acceptable method for this aeronautical data process.

### 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 5-4.2 for GPS/GBAS. The GNSS position sensor should be installed in accordance with guidelines provided in chapters 11 through 15 and 18 through 21.

**Note:** See paragraphs 14-6.8 and 14-8.16 for GNSS installation considerations regarding ground proximity warning system (GPWS) or TAWS alerting functions.

**b.** See paragraph 3-2 for TSO 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 17-5 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 United States airspace meet International Civil Aviation Organization (ICAO) standards. These could include non-United States 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) Require 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.

## (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. A flight technical error (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:

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

*Single facility reference, where:*

$$\sigma_{sis} = 0.05 \text{ NM}$$

$$\sigma_{air} \text{ is MAX } \{ (0.085 \text{ NM}, (0.125\% \text{ of distance})) \}$$

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

**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.

**Note 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.

**Note 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 United States 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 (x<sub>tk</sub>) and along track (a<sub>tk</sub>) 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 above table 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:** The above table is a result of the root-sum-square combination of the error elements shown below in Table 5. The accuracy table 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.

| <b>GROUND EQUIPMENT ERROR</b> | <b>AIRBORNE EQUIPMENT ERROR</b>  |
|-------------------------------|----------------------------------|
| 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.**

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.

**Note:** Paragraph 6-6 applies to both “stand-alone” and loosely coupled integrations.

#### **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, RTCA/DO-229D, appendix R, provides INS/IRU – GNSS integration requirements. The GNSS/inertial hybrid outputs of the IRU should meet the equipment requirements of RTCA/DO-229D, appendix R.

**c.** The FAA assumes that there is a limitation on the use of the GPS/inertial position data output to support enroute through LNAV approach only. Using this data for operations requiring higher precision would require other integrity and accuracy enhancements such as GPS/SBAS or GPS/GBAS. Since hybrid vertical position and integrity has not been addressed by RTCA/DO-229D, any use should be identified and resolved as part of the non-TSO function

approval process.

**Note 1:** RTCA/DO-316, appendix R contains the same information found in RTCA/DO-229D, appendix R.

**Note 2:** 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.'

**Note 3:** 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 10, 17, and 22 describe baro-VNAV performance and installation considerations.

**d.** Tightly coupled equipment must be demonstrated to be equivalent to either TSO-C129(AR), TSO-C196, or TSO-C145(AR) as described in chapter 3. Any discrepancies should be identified and resolved as part of the TSO approval. 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.

**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 (ESV) 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 7-9 and 16 along with appendix 2 and 3 is to provide the airworthiness information found in AC 90-101A and AC 90-105 in this AC. The information is taken directly from AC 90-101A and AC 90-105, but contains some necessary minor changes due to formatting and grammar considerations. The information from AC 90-101A and AC 90-105 has not changed other than to recognize TSO-C196 equipment and, in some places, add minor clarification information or correct mistakes. This is a necessary first step to consolidate all the positioning and navigation equipment airworthiness guidance and RNP airworthiness guidance into one AC. The plan is for future AC 90-101 and AC 90-105 revisions to remove the airworthiness guidance. Information on special characteristics of RNP operations and advantages of GPS/SBAS and GPS/GBAS for RNP operations incorporating vertical guidance is provided below.

b. Chapter 8 is specific to the equipment performance considerations for RNP approach procedures; and, chapter 9 is specific to the equipment performance considerations for RNP terminal operations. Airworthiness guidance for RNP (AR), including installation considerations, is addressed in appendix 2 of this AC while appendix 3 of this AC describes advanced features (radius to fix (RF) leg types) for RNP systems. Chapter 16 describes installation considerations for RNP. 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.

c. GPS/SBAS and GPS/GBAS sensors can be approved on FMS-equipped aircraft without baro-VNAV to provide vertical path guidance for RNP 0.3 operations and RNP AR operations as low as RNP 0.1 with no change to existing RNP criteria, GPS/SBAS, or GPS/GBAS performance standards. However, all aircraft and FMS requirements for RNP and RNP AR operations still apply. Refer to chapters 14 and 16 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.

d. 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 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.** GPS 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).

#### **b. Unique Features and Requirements of RNP Approaches.**

(1) RNP approaches normally include at least two lines of minima: LNAV and LNAV/VNAV. The LNAV/VNAV minima are based on using systems meeting the performance criteria for baro-VNAV systems in chapter 15.

(2) RF legs are discussed in Advanced Features, appendix 3.

(3) Unless the pilot has in sight the visual references required to continue the approach, the procedure must be discontinued if any of the following conditions occur:

(a) The navigation display is flagged invalid.

(b) Loss of integrity alerting function.

(c) The integrity alerting function is activated before passing the FAF.

**Note:** Discontinuing the procedure may not be necessary for a GNSS fail-down condition to LNAV only; or, for a multi-sensor RNP system that includes demonstrated RNP capability without GPS. Aircraft and/or equipment manufacturer documentation should be examined against functional and performance requirements to determine the extent the system may be used in such a configuration.

### **7-3. Special Characteristics of RNP 1 Operations.**

**a.** Operation on RNP obstacle departure procedures (ODPs), standard instrument departures (SIDs), and STARs.

(1) Pilots are not required to monitor ground-based navigation facilities used in position updating unless required by the AFMS/RFMS.

(2) The navigation performance needed to fly RNP 1 procedures must be clearly designated on all appropriate charts.

**b. Requirements for Navigation Infrastructure.**

(1) If DME is used, the DME navigation infrastructure supporting the design of a procedure must be assessed and validated by the FAA or an FAA authorized third-party service provider. This includes a computer model assessment and an analysis by FAA flight inspection assets. DME coverage may use expanded service volume for select DME facilities so there is no requirement to use VOR, LOC, NDB, or AHRS during normal operation of the DME/DME RNP system. Expanded Service Volume facilities require a satisfactory flight inspection prior to use.

(2) DME signals must meet signal-in-space accuracy tolerances everywhere the signals are received in that procedure.

(3) For DME-based RNP operations where reliance is placed upon the IRU/Inertial Reference System (IRS), some aircraft systems revert to VOR/DME-based navigation before reverting to inertial coasting. When the VOR is within 40 NM from the procedure and there is insufficient DME/DME navigation infrastructure, the impact of VOR radial accuracy must be evaluated by the FAA and determined to not affect aircraft position accuracy.

(4) The FAA must monitor the navigation infrastructure and issue timely warnings of outages (NOTAM).

(5) All RNP 1 procedures must be flown by aircraft meeting the performance requirements in this AC using DME/DME/IRU and/or GPS.

(6) If any critical DME facilities exist, they must be identified within the relevant United States Flight Information Publications. All DME ground stations used to define the availability of these ODPs, SIDs, and STARs must comply with applicable ICAO standards.

## Chapter 8. Equipment Performance - RNP Approach.

### 8-1. Introduction.

This chapter provides guidance on the performance and functional requirements 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 10. 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 Requirements.

The notes below apply to the entire paragraph.

**a.** Aircraft with approval to conduct RNAV (GPS) or GPS approaches meet the performance and functional requirements in this AC for RNP instrument approaches without RF legs.

**b.** Aircraft with a statement of compliance with the criteria in this AC in their airplane flight manual (AFM)/rotorcraft flight manual, AFMS/RFMS, pilot operating handbook (POH), or the operating manual for their avionics meet the performance and functional requirements for RNP instrument approaches. This presumes compliance with the operational guidance in AC 90-105.

**c.** Aircraft with a statement from the manufacturer documenting compliance with the criteria in this AC meet the performance and functional requirements for RNP instrument approaches. These statements should include the airworthiness basis for compliance. Compliance with the sensor requirements will have to be determined by the equipment or aircraft manufacturer while compliance with the functional requirements in this chapter and chapter 14 may be determined by the manufacturer or by inspection by the operator, but must presume compliance with operational guidance in AC 90-105.

**d.** GPS stand-alone systems should be approved in accordance with TSO-C129(AR) Class A1 or TSO-C146(AR) Class 1, 2 or 3 and meet the applicable functionality and performance requirements of chapter 5, this chapter, and chapter 9. These systems should be installed for instrument flight rules (IFR) use in accordance with this AC.

**e.** GPS sensors used in multi-sensor system equipment (e.g., FMS) should be approved in accordance with TSO-C129(AR) Class B1, C1, B3, C3, TSO-C196, or TSO-C145(AR) Class 1, 2 or 3 and meet the performance and functionality requirements of chapter 5, this chapter, and chapter 9. These systems should be installed for IFR use in accordance with this AC.

**f.** Multi-sensor systems should be approved in accordance with TSO-C115b, but may also have incomplete system TSO-C129(AR) Class A or TSO-C146(AR) Class Gamma approvals (see paragraphs 3-1.d and 3-2.e). Those systems using GPS equipment should comply with the applicable GPS equipment chapters and chapters 6, 11-13, 15, 18-19, and 21 of this AC. These systems should also meet the performance and functionality requirements in

this chapter.

**Note 1:** GPS equipment approved to TSO-C129(AR) must meet the system functions specified in this chapter. In addition, integrity should be provided by RAIM. It is recommended that GPS receivers include the pseudo-range step detection and health word checking functions if those functions were not specifically required for TSO approval (see appendix 1 for additional information).

**Note 2:** Multi-sensor systems that use DME/DME or DME/DME/IRU as the only means of RNP compliance are not authorized to conduct RNP approaches. However, operators still retain the option to develop special RNP approaches using these systems.

### **8-3. Performance and Functional Requirements for RNP Systems.**

#### **a. Accuracy.**

(1) The aircraft must comply with RTCA/DO-236B, *Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation*, dated October 28, 2003, paragraph 2.1.1.

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

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

(4) To satisfy the accuracy requirement, the FTE should not exceed 0.5 NM on the initial, intermediate and missed approach segments of an RNP approach procedure. The FTE should not exceed 0.25 NM on the final approach segment of the approach.

**Note 1:** This requirement is considered satisfied as long as the TSE for each segment is not exceeded where the navigation system provides for RNP performance monitoring and alerting and where the integration of operational modes and configurations account for accuracy and FTE.

**Note 2:** Using 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 is an acceptable means of compliance.

**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 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 0.6 NM is greater than  $10^{-5}$ .

**e. Signal in Space.**

During 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 operations on the final approach segment, the aircraft navigation equipment must provide an alert if the probability of signal-in-space errors causing a navigation system 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.

**f. Path Definition.**

Aircraft performance is evaluated around the path defined by the published procedure and RTCA/DO-236B, paragraph 3.2.5.4.1.

**Note:** The guidance in this paragraph provides equivalent performance to the intent in AC 90-105 for basic RNP approach. AC 90-105 references RTCA/DO-236B, paragraph 3.2.5.4.2, Fixed-Radius Transitions, which is more closely associated with RNP Advanced Features in appendix 3.

**g.** Functional Requirements for Navigation Displays.

(1) The following navigation displays and functions are required, as installed in accordance with this AC or equivalent system installation advisory material. 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.

(2) 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:

(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  $\pm 1$  NM for the initial, intermediate, and missed approach segments and  $\pm 0.3$  NM for the final segment is acceptable.

(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 requirements and be located in the primary field of view.

**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 flightcrew 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) Along track distances between waypoints;
- (d) Active navigation sensor type;
- (e) The identification of the active (To) waypoint;
- (f) The ground speed or time to the active (To) waypoint; and
- (g) 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/DO-236B and RTCA/DO-201A, *Standards for Aeronautical Information*, dated April 19, 2000.

**Note 2:** Numeric values for tracks 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 navigation system error (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 automatic pilot from the RNP system is mandatory for approaches.

**j.** Database Integrity.

The navigation database suppliers must comply with RTCA/DO-200A. A Type 2 Letter of Acceptance (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 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 requirements in paragraph 8-2 are eligible for RNP instrument approach operations. Aircraft qualified by any revision of AC 90-101 for RNP AR are considered qualified for RNP approach operations without further examination.

**c.** System Eligibility for RNP Approach Operations.

(1) LNAV line of minima qualification.

(a) Stand-alone systems meeting TSO-C129(AR) Class A1 or TSO-C146(AR) Class 1, 2, or 3 meet the aircraft qualification requirements for RNP instrument approach operations using the LNAV line of minima provided the systems and IFR installations were performed in accordance with this AC.

(b) Multi-sensor systems using TSO-C129(AR) Class B1, B3, C1, or C3 sensors; TSO-C196 sensors; TSO-C145(AR) Class 1, 2, or 3 sensors; or, TSO-C161a sensors using GBAS positioning service meet the aircraft qualification requirements for RNP instrument approach operations using the LNAV line of minima, provided the installations are in accordance with this AC and the associated FMS complies with TSO-C115b.

**Note:** Multi-sensor systems may also have incomplete system TSO-C129(AR) Class A or TSO-C146(AR) Class Gamma approvals (see paragraphs 3-1.d and 3-2.e).

(2) LNAV/VNAV line of minima qualification.

(a) Stand-alone TSO-C146(AR) Class 2 or 3 systems meet the aircraft qualification requirements for RNP instrument approach operations using the LNAV/VNAV line of minima provided that the installations are in accordance with this AC. Systems meeting TSO-C129(AR) Class A1 with baro-VNAV can be used for RNP approaches using the LNAV/VNAV line of minima if the criteria in chapters 13 and 15 are met and the systems are installed in accordance with this AC.

(b) Multi-sensor systems using TSO-C145(AR) Class 2 or 3 sensors meet the aircraft qualification requirements for RNP instrument approach operations using the LNAV/VNAV line of minima provided that the installations are in accordance with this AC and the associated FMS complies with TSO-C115b.

**Note:** Multi-sensor systems may also have incomplete system TSO-C129(AR) Class A or TSO-C146(AR) Class Gamma approvals (see paragraphs 3-1.d and 3-2.e).

(c) Multi-sensor systems using TSO-C129(AR) Class B1, B3, C1, or C3 sensors with baro-VNAV; TSO-C196 sensors with baro-VNAV; or, TSO-C161a sensors using the GBAS positioning service with baro-VNAV can be used for RNP approaches using the LNAV/VNAV line of minima if the criteria in chapters 13 and 15 are met and the systems are

installed in accordance with this AC. The associated FMS must comply with TSO-C115b.

**Note:** Multi-sensor systems may also have incomplete system TSO-C129(AR) Class A or TSO-C146(AR) Class Gamma approvals (see paragraphs 3-1.d and 3-2.e).

## Chapter 9. Equipment Performance - RNP Terminal.

### 9-1. Introduction.

This chapter provides guidance on the performance and functional requirements for RNP 1 operations in the terminal area. RNP Terminal terminology is used in the AC 90-105, appendix 2 title, and is synonymous with RNP 1. The equipment can be used to conduct RNP instrument departure procedures (including RNP ODPs and SIDs) and RNP STARs within the United States NAS where domestic air traffic control procedures are applied.

### 9-2. Aircraft and System Requirements for RNP Terminal Operations.

The notes below apply to the entire paragraph.

**a.** Aircraft with a statement of compliance with the criteria in this AC in their AFM/RFM, AFMS/RFMS, POH, or the operating manual for their avionics meet the performance and functional requirements for RNP terminal operations. This presumes compliance with the operational guidance in AC 90-105.

**b.** Aircraft with a statement from the manufacturer documenting compliance with the criteria in this AC meet the performance and functional requirements for RNP terminal operations. These statements should include the airworthiness basis for compliance. Compliance with the sensor requirements will have to be determined by the equipment or aircraft manufacturer while compliance with the functional requirements in this chapter may be determined by the manufacturer or by inspection by the operator, but must presume compliance with operational guidance in AC 90-105.

**c.** GPS stand-alone equipment should be approved in accordance with TSO-C129(AR) Class A1 or TSO-C146(AR) Class 1, 2, or 3, and meet the applicable performance and functional requirements of chapter 5 and this chapter. These systems should be installed for IFR use in accordance with this AC.

**d.** GPS sensors used in multi-sensor system equipment (e.g., FMS) should be approved in accordance with TSO-C129(AR) Class B or C, TSO-C196, or TSO-C145(AR) Class 1, 2, or 3 and meet the applicable performance and functional requirements of chapter 5 and this chapter. These systems should be installed for IFR use in accordance with this AC.

**e.** Multi-sensor systems should be approved in accordance with TSO-C115b, but may also have incomplete system TSO-C129(AR) Class A or TSO-C146(AR) Class Gamma approvals (see paragraphs 3-1.d and 3-2.e). Those systems using GPS equipment should comply with the applicable GPS equipment chapters and chapters 6, 11-13, 15, 18, 19, and 21 of this AC. These systems should also meet the performance and functionality requirements in this chapter.

**f.** Aircraft/equipment with approval under AC 90-100A (or later revision) to use GPS is approved under this AC for RNP 1 operations.

**g.** RNP aircraft with P-RNAV approval based on GPS capability meet the functional requirements of this AC for RNP 1 operations, such as RNP DPs, RNP SIDs, and RNP STARS.

**Note 1:** RNP 1 operations are based on GPS positioning and, if adequate coverage is available, DME/DME/IRU. 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:** TSO-C145(AR) or TSO-C146(AR) equipment may also be authorized to conduct RNP operations in United States airspace where domestic ATC procedures are applied (Class I Navigation operations) without an airworthiness limitation for other navigation equipment on the aircraft. This authorization includes operations outside the navigational service volume of ICAO standard ground-based NAVAIDs.

### **9-3. System Performance Monitoring and Alerting.**

#### **a.** Accuracy.

(1) The aircraft must comply with RTCA/DO-236B, paragraph 2.1.1.

(2) During operations in airspace or on routes designated as RNP 1, the lateral TSE must be within  $\pm 1$  NM for at least 95 percent of the total flight time. The along-track error must also be within  $\pm 1$  NM for at least 95 percent of the total flight time. To satisfy the accuracy requirement, the 95 percent, FTE should not exceed 0.5 NM (see chapter 16).

**Note:** Using a lateral deviation indicator with 1 NM full-scale deflection is an acceptable means of compliance. Using an autopilot or FD is also an acceptable means of compliance, 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 if the operator can revert to a different navigation system and proceed to a suitable airport.

**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 2 NM is greater than  $10^{-5}$  for RNP 1 operations.

**e. Path Definition.**

RNP systems should provide lateral guidance so aircraft remain within the lateral boundaries of the fly-by transition area as defined in RTCA/DO-236B, paragraph 3.2.5.4.1.

**f. Signal-in-Space.**

If using GPS, 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 for RNP 1 operations.

**g. Functional Requirements of Navigation Data Displays.**

(1) If using this AC as the means of compliance, then the following navigation displays and functions are required and must be 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:

(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, 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 required total system accuracy.

(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 terminal area 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 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 requirements and be located in the primary field of view.

**h. System Capabilities.**

The following system capabilities are required as a minimum within any RNP 1 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) Capability to load from the database into the RNP 1 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 distance and bearing to the active (To) waypoint; and
  - (d) The ground speed or time 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 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, or their equivalent:

- (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-236B and DO-201A.

(11) The aircraft must have the capability to automatically execute leg transitions consistent with heading to altitude (VA), heading to manual (VM) and heading to intercept (VI) ARINC 424 path terminators. An alternate acceptable method is the capability to manually fly the aircraft on a heading to intercept a course or to go direct to another fix after reaching a procedure-specified altitude.

(12) The aircraft must have the capability to automatically execute leg transitions consistent with course to altitude (CA) and from a fix to manual termination (FM) ARINC 424 path terminators. An alternate acceptable method is the RNP system must permit the pilot to readily designate a waypoint and select a desired course to or from a designated waypoint.

(13) The capability to load a RNP 1 procedure from the database, by procedure name, into the area navigation system.

(14) The capability to display an indication of the RNP 1 system failure in the pilot’s primary field of view.

**i. Database Integrity.**

The navigation database suppliers must comply with RTCA/DO-200A. A Type 2 LOA, issued by the appropriate regulatory authority, demonstrates compliance with this criteria. Type 2 LOAs issued prior to this AC are considered compliant.

**9-4. System Eligibility and Approval for RNP 1 Operations.**

**a. Eligibility for RNP Terminal Area Operations.**

The following systems meet the criteria defined in this AC. This equipment still requires evaluation by the manufacturer against all the functional and performance requirements in this AC.

(1) Aircraft with a TSO-C129(AR) Class A1 system (without deviation from the functionality in chapter 14) or a TSO-C146(AR) Class 1, 2, or 3 system (without deviation from the functionality in chapter 14) that are installed for IFR use in accordance with this AC.

(2) Aircraft with TSO-C129(AR) Class B or C sensors, TSO-C196 sensors, or TSO-C145(AR) Class 1, 2, or 3 sensors installed according to this AC in an FMS that meets the requirements of TSO-C115b.

**Note:** Multi-sensor systems may also have incomplete system TSO-C129(AR) Class A or TSO-C146(AR) Class Gamma approvals (see paragraphs 3-1.d and 3-2.e).

**b. System Eligibility for RNP 1 Operations.**

(1) Standalone TSO-C129(AR) Class A1 or A2 systems (without deviation from the functionality in chapter 14), or TSO-C146(AR) Class 1, 2, or 3 systems (without deviation from the functionality in chapter 14) meet the aircraft qualification requirements for RNP 1 operations. GPS systems must be installed in accordance with this AC.

(2) Multi-sensor systems using (without deviation from the functionality in chapter 14) TSO-C129(AR) Class B or Class C sensors, TSO-C196 sensors, or TSO-C145(AR) Class 1, 2, or 3 sensors meet the aircraft qualification requirements for RNP 1 operations provided that the installations comply with the criteria in this AC. RNP systems must be installed in accordance with this AC and the associated FMS must comply with TSO-C115b.

**Note:** Multi-sensor systems may also have incomplete system TSO-C129(AR) Class A or TSO-C146(AR) Class Gamma approvals (see paragraphs 3-1.d and 3-2.e).



(3) Multi-sensor systems that rely on ground-based NAVAIDS. Multi-sensor systems that require the use of ground-based NAVAIDS, such as DME/DME, can be used to conduct RNP 1 operations provided that the AFM/RFM or AFMS/RFMS shows the aircraft is approved for RNP instrument flight operations, the aircraft meets the functional and performance criteria in this chapter (e.g., RNP performance monitoring and alerting), and the criteria of chapter 6 appropriate to the ground-based NAVAIDS and/or inertial systems used.

## Chapter 10. Equipment Performance - Baro-VNAV.

### 10-1. General Limitations for Operations under IFR.

**a.** A baro-VNAV system may be approved for enroute, terminal, and approach use within the contiguous United States, Alaska, and Hawaii. However, unless compensated for temperature, baro-VNAV equipment can only be used within the limitations for temperature published on approach procedure charts.

**b.** Systems providing temperature compensation to the barometric VNAV guidance must comply with RTCA/DO-236B, appendix H.2. 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 outside of the final approach segment if the equipment includes a method for the flightcrew to inhibit the compensation function.

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

(3) 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.

(4) Baro-VNAV performance has not been shown to be adequate for vertical guidance on LPV or GLS approaches.

### 10-2. 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-236B, paragraph 2.1.2).

**Note:** GPS/SBAS Class 2 and 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.

| <b>Altitude Region (MSL)</b> | <b>Level Flight Segments &amp; Climb/Descent Intercept of Clearance Altitudes</b> | <b>Flight Along Specified Vertical Profile</b> |
|------------------------------|---|--|
| 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.<br>(See Note 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.

**Note 2:** For aircraft type designs prior to January 1, 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:** Baro-VNAV equipment error includes all errors resulting from the vertical guidance equipment installation. This includes errors of the altimeter system and along-track or horizontal coupling error.

**Note 4:** 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.

**c. Flightcrew 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 descent 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.

**d. System Displays.**

(1) The system displays should give no operationally misleading information.

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

|                               | <b>Enroute/Terminal (feet)</b> | <b>Approach (feet)</b> |
|-------------------------------|--------------------------------|------------------------|
| Minimum Full-Scale Deflection | $\geq 500$                     | $\geq 150$ (see note)  |
| Readability                   | $\leq 100$                     | $\leq 30$              |
| Minimum Discernable Movement  | $\leq 10$                      | $\leq 5$               |

**Table 7. Vertical Path Deviations**

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

(3) 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.

**e.** 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.

**f.** Additional Constraints.

(1) The baro-VNAV equipment should indicate the aircraft vertical path position to the accuracy specified in paragraph 10-2.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 10-2.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 10-2 throughout the range of environmental conditions that will be encountered in actual service. Exposing the equipment to the environmental test conditions of TSO-C115b 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 flightcrew to determine system status prior to flight.

(6) The equipment should provide the navigation accuracy specified in paragraph 10-2.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 flightcrew prior to arrival at a waypoint for anticipating necessary vertical maneuvering. This indicator 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.

(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 10-2.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.

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

**Chapter 11. General Installation Considerations.**

**11-1. Introduction.**

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

**11-2. 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 GNSS Category I 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/Nonprecision Approach (LNAV or RNP 0.3) | Nonprecision Approach with Vertical Guidance (LNAV/VNAV) | LP/LPV Approach | GNSS Precision Approach (Cat. I) |
|------------------------|----------------------------|---|--|-----------------|----------------------------------|
| Loss of Navigation     | No Effect                  | Major   | Major  | Major           | Major                            |
| Misleading Information | Minor                      | Major   | Major  | Hazardous       | Hazardous                        |

**Table 8. Typical Hazard Classifications**

**Note:** 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.

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 14-2.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.

### **11-3. Software Considerations.**

AC 20-115 (latest revision) *Radio Technical Commission for Aeronautics, Inc. Document RTCA/DO-178B*, defines an acceptable means of qualifying software. The applicant is encouraged to submit the Plan for Software Aspects of Certification (PSAC) early in the software development process. Early submittal will allow timely resolution of issues such as partitioning and 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.

### **11-4. 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.

### **11-5. 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.

### **11-6. 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?

#### **11-7. 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.

#### **11-8. 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.

**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.

(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, 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.

## Chapter 12. General Installation Considerations - Antennas.

### 12-1. Antenna placement.

Paragraphs (a) through (f) below are specific to GNSS antennas.

**a.** Typically, a GNSS antenna is located forward or aft of the wings on the top of the fuselage.

**b.** 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. **Shadowing by aircraft structure (and in some cases by rotorcraft blades) can adversely affect the operation of the GNSS equipment.**

**c.** The 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). This includes consideration of antenna location with respect to blockage from airframe components, airframe structures, engine components, or other antennas with the aircraft at typical level cruising attitude. The antenna should also be located to minimize the effects of aircraft shadowing during typical maneuvers.

**d.** The antenna should be separated as much as practical from transmitting antennas (e.g., VHF and high frequency radio, satellite communications (SATCOM), DME, direction finder, emergency locator transmitter, and traffic and collision alerting system). For small aircraft, the antenna should also be separated as much as practical from the windscreen to prevent case-to-antenna coupling.

**e.** 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.

**f.** 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.

**g.** For installations on rotorcraft, the effects of the rotor blades on antenna performance should be considered. This may require additional equipment functional flight evaluation or analytical evaluation to confirm the antenna location is suitable.

**h.** 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).

### **12-2. 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 manual/instructions. 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.

### **12-3. Antenna Cables.**

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

### **12-4. 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.

## **Chapter 13. General Installation Considerations - Sensors.**

### **13-1. 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).

### **13-2. 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.

### **13-3. 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 flightcrew 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 flightcrew. 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.

#### **13-4. Dual Positioning and Navigation Installations.**

**a.** Paragraph 13-4 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 workload associated with manually updating both equipment sets to maintain consistency between them should not be too burdensome.

(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).

#### **13-5. 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.

### **13-6. Interface to FGS.**

**a.** Paragraph 13-6 describes guidelines for interfacing the positioning and navigation equipment with a FGS. When used in paragraph 13-6, 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.

**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 for engagement. 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 input should meet the performance criteria in this AC, as appropriate, to meet the SVS or EVS intended function.

### **13-7. 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 United States. However, aviation authorities in other countries might use true heading as the primary heading reference in areas of extreme latitude.

### **13-8. 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.

### **13-9. 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 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.

### **13-10. 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.

### **13-11. 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, 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-C151b and the latest revisions of AC 23-18, and AC 25-23.

(2) Electronic map displays, see TSO-C165 and the latest revisions of AC 20-159, AC 23.1311-1, and AC 25-11.

(3) 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 14. Installation Considerations - GNSS.

### 14-1. Introduction.

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.

### 14-2. 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 11-2.a classifies misleading information during GNSS CAT I and LP/LPV approaches as a hazardous failure condition; and paragraph 11-2.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 14-2.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 11-2.a, 11-2.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.

### **14-3. 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 14-3.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.

#### **14-4. 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 (PVT) 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, 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.

#### **14-5. 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 AFMS/RFMS. 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 that it is not acceptable to flight plan based on a GPS approach at the alternate airport. The alternate airport must be flight planned using an available ground-based approach aid. However, once at the alternate airport, the pilot may perform a GPS approach if the equipment indicates integrity is available to support the approach.

**d.** The limitations can provide further reference to the Airman's Information Manual for additional information.

**Note 1:** The performance limitation for other navigation equipment appropriate to the operation must be unambiguously stated in the installation documentation and AFMS/RFMS.

**Note 2:** See appendix 1 for methods to remove the limitation for other navigation equipment in oceanic and remote areas.

**Note 3:** The performance limitations in paragraphs 14-5.b and 14-5.c do not have to use the specific language above (see appendix 5 for examples). The intent is to indicate the equipment has a performance limitation and adequately capture that limitation in the AFMS/RFMS.

## **14-6. 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).

### **14-6.1 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 that it is not acceptable to flight plan an alternate airport based on an RNAV(GPS) LP/LPV or LNAV/VNAV approach. The alternate airport



must be flight planned using an LNAV approach or available ground-based approach aid. However, once at the alternate airport, the pilot may perform an RNAV(GPS) LP/LPV or LNAV/VNAV approach if the equipment indicates integrity is available to support the approach.

**b.** The limitation can provide further reference to the Airman's Information Manual for additional information.

**Note:** The performance limitation in 14-6.1a does not have to use the specific language above (see appendix 5 for examples). The intent is to indicate the equipment has a performance limitation and adequately capture that limitation in the AFMS/RFMS.

#### **14-6.2 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 14-6.2a is not intended for equipment updated by the manufacturer.

#### **14-6.3 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. 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.

#### **14-6.4 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).

### 14-6.5 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.

### 14-6.6 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 17-5).

#### **14-6.7 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).

#### **14-6.8 GPWS/TAWS Glideslope Warning.**

Aircraft with ILS capability that is interfaced to GPWS or Class A TAWS with a glideslope warning function (Mode 5 GPWS alert) must also include the glideslope warning function during a GPS/SBAS LPV approach.

**Note:** There is no intent to differentiate between LPV approaches using a 35m VAL or 50m VAL in the FAS datablock. The guidance above is intended **for all** LPV approaches.

#### **14-7. 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).

##### **14-7.1 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.

#### **14-7.2 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.

#### **14-7.3 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 108.000 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).

#### **14-8. 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).

##### **14-8.1 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:** 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.

**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 and/or TSO-C129a 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.

#### **14-8.2 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.

### **14-8.3 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).

### **14-8.4 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).

### **14-8.5 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.

### **14-8.6 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.

### **14-8.7 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.

### **14-8.8 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.

### **14-8.9 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).

#### **14-8.10 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.

#### **14-8.11 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.

#### **14-8.12 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.

#### **14-8.13 GPS/GBAS GPWS/TAWS Glideslope Warning.**

Aircraft with ILS capability that is interfaced to GPWS or Class A TAWS with a glideslope warning function (Mode 5 GPWS alert) must also include the glideslope warning function during a GPS/GBAS precision approach.



**14-9. 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 25-10 (latest revision) provides additional guidance on miscellaneous, non-required equipment installations.

## **Chapter 15. Installation Considerations - RNAV Multi-Sensor Equipment.**

### **15-1. Introduction.**

When installing GNSS as part of a multi-sensor system, the installation issues of chapter 14 apply and will take precedence if any conflicts with this chapter arise.

### **15-2. 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:

**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:

#### **15-2.1 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:

(1) The distance to 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.

### **15-2.2 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.)

### **15-3. 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.

**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:** 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.

#### **15-4. Unique Software Considerations.**

**a.** If software was developed using RTCA/DO-178A procedures (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 pertinent airworthiness requirements is to comply with pertinent portions of the requirements contained in RTCA/DO-178B, 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-178B, as referenced in AC 20-115B (or later revision) to show that the software aspects of a system comply with pertinent airworthiness requirements. For software developed prior to the availability of RTCA/DO-178B, paragraph 12.1.4 of RTCA/DO-178B 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-178B.

## Chapter 16. Installation Considerations - RNP.

### 16-1. Introduction.

This chapter contains installation consideration guidance for basic RNP. RNP AR installation considerations are in appendix 2 of this AC.

### 16-2. Flight Technical Error.

The aircraft manufacturer should verify maintenance of FTE (95% of the flying time) during straight path segments per table 9 below. The FTE should be demonstrated in each phase of flight, both with and without autopilot and/or FD as applicable. The FTE values below are also acceptable for curved path segments only with an autopilot and/or FD. Manual flight operation on curved path segments will require a separate FTE evaluation.

| RNP | FTE  | FTE Basis                     |
|-----|------|-------------------------------|
| 0.3 | 0.25 | Flight Director and Autopilot |
| 1.0 | 0.5  | Flight Director and Autopilot |
|     | 0.8  | Manual CDI operation          |
| 2.0 | 1.0  | Manual CDI operation          |
| 4.0 | 2.0  | Manual CDI operation          |

**Table 9. RNP FTE Performance**

**Note:** Navigation systems providing RNP performance monitoring and alerting (such as GNSS) can satisfy this FTE requirement. These systems must ensure the TSE for each segment is not exceeded; and, the integration of operational modes and configurations accounts for accuracy and FTE.

### 16-3. Radius to Fix (RF) Legs.

**a.** Paragraph 16-3 applies to equipment intended to support procedures with RF legs (see appendix 3). If a moving map display is included with or interfaced to the positioning and navigation equipment, the map display should be capable of depicting the curved, RF leg segments without discontinuities on both active and inactive leg segments. 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.

**b.** It could be possible for applicants to provide mitigations for moving map displays that are not capable of depicting RF leg segments. The applicant needs to substantiate during the installation approval that FTE is monitored and controlled during the entire RNP operation,

including the RF legs. For example, moving map display deficiencies may be mitigated by an aircraft equipped with an automatically slaved course selector and a sufficiently capable autopilot with a limitation for autopilot coupling during RNP operations with RF legs. Other solutions may be possible; but, any solution must be documented in the installation instructions along with any limitations.

c. Positioning and navigation equipment that does not support RF leg capability must have an AFMS/RFMS limitation stating the equipment cannot be used for RNP procedures containing RF legs.

#### **16-4. Interface to FGS.**

Verify acceptable autopilot response to an RNP fault by 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 17. Installation Considerations - Baro-VNAV.

### 17-1. 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.

### 17-2. Manufacturer's Instructions.

Baro-VNAV equipment should be installed in accordance with instructions and limitations provided by the manufacturer of the equipment.

### 17-3. 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).

### 17-4. 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-C115b (or earlier revision) 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. Software changes in TSO approved equipment must be reported, as required, to the appropriate ACO. If the equipment displays a software identifier to the flightcrew, 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.

**17-5. Integration with GNSS-Provided Vertical Guidance.**

**a.** Many aircraft integrations have implemented baro-VNAV for use in all phases of flight, and can be used for vertical guidance on an LNAV/VNAV approach. 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 17-5.a(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; 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.

## **Chapter 18. Installed Performance - Data Submittal.**

### **18-1. 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.

### **18-2. 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.

### **18-3. 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 to the design assurance levels 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-C146c 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 Level C would state the following:

“This TSO-C146c 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 or part 23 Class IV aircraft unless the LPV approach mode is disabled through the following equipment configuration setting: ....”

**18-4. 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 11 through 22 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, 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.

**18-5. 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.

#### **18-6. 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.

#### **18-7. 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.

#### **18-8. Database.**

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 FAA to its application in the equipment, for those navigation systems that comply with the latest revisions of ACs 90-100, 90-101, or 90-105. Verify a navigation database type 2 LOA exists with reference to RTCA/DO-200A as recognized in AC 20-153 (latest revision).

#### **18-9. 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 14-4 for additional documentation considerations specific to GNSS.

#### **18-10. 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.

**18-11. 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 18 through 22), regulatory compliance, and EMI/EMC testing.

## **Chapter 19. Installed Performance - Test (General).**

### **19-1. 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.

### **19-2. Power Supply.**

Assess all switching and transfer functions, including electrical bus switching, pertaining to the positioning and navigation installation.

### **19-3. 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.

### **19-4. 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.

## Chapter 20. Installed Performance - Test (GNSS).

### 20-1. Ground Test - GPS, GPS/SBAS, and GPS/GBAS.

#### 20-1.1 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 35 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.

#### 20-1.2 Antenna to Aircraft Navigation Reference Offset.

RTCA/DO-229D, 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.

### **20-1.3 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 13 and 14.

### **20-1.4 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 11, 13, and 14 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 11, 13, and 14 of this AC.

## **20-2. Flight Test - GPS, GPS/SBAS, and GPS/GBAS**

### **20-2.1 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.** 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.



**d.** 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 pulling the circuit breaker for the GNSS equipment. This test should be done in all of the GNSS enroute and approach modes.

#### **20-2.2 LPV and Precision Approaches.**

**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.** If the equipment uses barometric altitude input, verify that the equipment properly interprets the barometer reading. For equipment that requires manual entry of barometric correction, the entry should be accomplished during an approach to evaluate the crew workload.
- 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, including those non-normal procedures that can be evaluated in flight.

### **20-2.3 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 21. Installed Performance - Test (RNAV Multi-Sensor Equipment).

### 21-1. Ground Test.

Refer to TSO-C115b and RTCA/DO-187 (or later revisions) for RNAV Multi-Sensor Equipment ground test information.

### 21-2. 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 20-2). 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 from RTCA/DO-283A 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.).
- 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.

**21-2.1 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 pulling the circuit breaker for the equipment. This test should be done in each of the sensor modes, if applicable.

#### **21-2.2 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 22. Installed Performance - Test (Baro-VNAV).**

### **22-1. Introduction.**

Paragraphs 22-2 and 22-3 describe the installed performance test considerations for an initial approval. Subsequent installations are addressed in paragraph 22-4. 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.

### **22-2. Ground Test.**

#### **22-2.1 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.

**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).

#### **22-2.2 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 of the 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.

### **22-3. Flight Test.**

#### **22-3.1 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.
- f. Assess all switching and transfer functions pertaining to the baro-VNAV equipment including high-power electrical loads and electrical bus switching.
- g. Evaluate whether magnetic or radio frequency interference exists between the baro-VNAV equipment installation and other onboard equipment, or vice versa.

**h.** Evaluate the accessibility of all controls pertaining to the baro-VNAV system installation.

**i.** 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.

**j.** Analyze crew workload when operating the baro-VNAV equipment.

### **22-3.2 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:

(1) Theodolite observation;

(2) Comparison against ILS, GPS/SBAS LPV or LNAV/VNAV, or GPS/GBAS GLS glide path signals;

(3) By equivalent measuring techniques.

**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.

**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 10-2.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.



**22-4. 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 22-2.2 for baro-VNAV initial approval.

**c.** Conduct flight evaluations similar to the flight tests outlined in paragraph 22-3.1 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 or 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 AC 20-138A, appendix 1 are still eligible for oceanic and remote operation and need not be re-evaluated.

**b.** TSO-C196 and TSO-C145/C146(AR) equipment are inherently capable of supporting this operation without further evaluation if the operator obtains a 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 provide an acceptable barometric aiding implementation method for TSO-C196 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.

### 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 2 and 3 of this appendix.

(4) The failure of the long-range navigation function is a major failure condition. For many oceanic/remote operations, this requires equipping the airplane with at least two (or more) independent (i.e., dual control display unit, dual GPS antenna, dual power sources, dual GPS sensors, etc.) navigation 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 Class II oceanic and 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:** The term "primary means" is obsolete. This updated AFMS/RFMS language is a clarification of previous guidance.

**c. Operational Approval.**

The applicant should be aware that an operational approval must be obtained before conducting Class II navigation (remote/oceanic). Applicants should contact the appropriate flight standards district office to seek operational approval.

**A1-3. Equipment Performance.**

**a. TSO-C129(AR).**

The GPS equipment must meet the criteria of TSO-C129(AR).

**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 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 required navigation performance authorization required approaches. The aircraft qualification information is presented here as a convenient necessary first step to consolidate all the positioning and navigation equipment and RNP AR airworthiness guidance into one AC. The information presented in this appendix has some necessary minor changes due to formatting and grammar along with some additional clarification information. But, the basic information from AC 90-101A has not changed other than to recognize TSO-C196 equipment. The plan is for future AC 90-101 revisions to remove the airworthiness guidance. 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.** 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 and RTCA/DO-236B, paragraph 3.2 define the path the aircraft must use to evaluate performance. The aircraft's navigation system will also define all vertical paths in the final approach segment by a flight path angle (RTCA/DO-236B, paragraph 3.2.8.4.3) and as a straight line emanating to a fix and altitude.

#### **b. Lateral Accuracy.**

The aircraft must comply with paragraph 2.1.1 of RTCA/DO-236B.

**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):

$$\sqrt{((6076.115)(1.225)\mathbf{RNP} \cdot \tan\theta)^2 + (60\tan\theta)^2 + 75^2 + ((-8.8 \cdot 10^{-8})(\mathbf{h} + \Delta\mathbf{h})^2 + (6.5 \cdot 10^{-3})(\mathbf{h} + \Delta\mathbf{h}) + 50)^2}$$

where  $\theta$  is the vertical navigation path angle,  $h$  is the height of the local altimetry reporting station and  $\Delta h$  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) RNAV 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-236B. The requirement in RTCA/DO-236B 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.**

RTCA/DO-236B provides additional information concerning many of the required functions for RNP AR aircraft qualification.

**a.** 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 10 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 (GPS/SBAS or GPS/GBAS) 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 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 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 inertial reference system 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 announcement 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:

$$ASE = -88 \cdot 10^{-8} \cdot H^2 + 65 \cdot 10^{-3} \cdot H + 50 \text{ (ft)}$$

where H is the true altitude of the aircraft.

## (7) Temperature compensation systems.

Temperature compensation systems with an airworthiness approval providing corrections to the baro-VNAV guidance must comply with RTCA/DO-236B, appendix H.2. This criterion applies to the final approach segment. 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.

**b. 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-236B 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 4 of this appendix. EUROCAE ED-75A/RTCA DO-236B 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-236B 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 when there is no requirement for RNP containment.

| Turn Height Above<br>Airport (Feet) | Standard Tailwind<br>Component (Knots)* |                     |
|-------------------------------------|---|---------------------|
|                                     | Standard                                | AFS-400<br>Approval |
| 500                                 | 25                                      |                     |
| 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.

(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.

**c.** Demonstration of Path Steering Performance.

The applicant must complete the demonstration in accordance with AC 120-29 (latest revision), paragraphs 5.19.2.2 and 5.19.3.1 when the demonstration of RNP capability includes a demonstration of the aircraft's path steering performance (i.e., flight technical error).

**d.** 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.

(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  $\pm 100$  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.a(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.

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:** The flight crew can use this display for operational contingency procedures. Flight crew procedures may mitigate the need for this display if the applicant and/or operator can demonstrate the flight crew workload is acceptable.

e. Design Assurance.

(1) The system design assurance 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 design assurance 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.e 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.

**f.** 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.

**g.** 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.**

This paragraph defines additional requirements to conduct approaches with RF legs. The AFM/RFM or aircraft qualification guidance should identify whether or not this capability is provided.

**a.** The navigation system must have the capability to execute leg transitions and maintain tracks consistent with an RF leg between two fixes.

**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.

**b.** The aircraft must have an electronic map display of the selected procedure.

**c.** The flight management computer, the FD system and autopilot must be capable of

commanding a bank angle up to 30 degrees above 400 feet above ground level (AGL) and up to 8 degrees below 400 feet AGL.

**d.** Upon initiating a go-around or missed approach (through activation of take-off/go around (TOGA) or other means), the flight guidance mode should remain in LNAV.

**Note:** 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.

#### **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 design assurance 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 to avoid obstacles or terrain while executing an approach.

**Note:** The applicant should document systems designed consistent with this effect, and this documentation may eliminate the need for application of operational mitigations for the aircraft.

**c.** The system design assurance 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 to avoid obstacles or terrain while executing an approach.

**Note 1:** The AFM/RFM should document systems designed consistent with this effect. This documentation should describe the specific aircraft configurations or modes of operation achieving RNP values less than 0.3.

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 paragraph A2-5.b 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 ( $1^\circ$ ) 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.

**Note:** Since loss of GNSS is unlikely, one means of compliance for this requirement is to show when GNSS is lost (i.e., when annunciation of loss of RNP capability occurs prior to the aircraft reaching the DA):

1) The conditional probability the aircraft exits the final approach obstacle clearance volume should be less than 0.001 (one in a thousand). This will ensure that 999 times out of 1000 the aircraft can complete an RNP AR approach should a loss of GNSS occur; and

2) The conditional probability the aircraft exits the missed approach obstacle clearance volume should be 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 should a loss of GNSS occur. Since executing a missed approach is unlikely under normal weather conditions, this conditional

probability is less stringent than the requirement for the final approach segment.

#### **A2-6. Requirements for Approaches with a Missed Approach Less Than RNP 1.**

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. 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).

**a.** No single-point-of-failure can cause the loss of guidance compliant 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 design assurance must be consistent with at least a major failure condition for the loss of lateral guidance on an RNP AR approach when the missed approach procedure requires RNP less than 1.0 to avoid obstacles or terrain.

(2) For RNP AR missed approach operations requiring less than 1.0 to avoid obstacles or terrain, the loss of the lateral guidance display is a hazardous (severe-major) failure condition.

**Note:** The AFM/RFM should document systems designs consistent with this effect. This documentation should describe the specific aircraft configurations or modes of operation achieving RNP values less than 1.0 during a missed approach procedure. Meeting this requirement can substitute for the general requirement for dual equipment (described above).

**b.** 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:

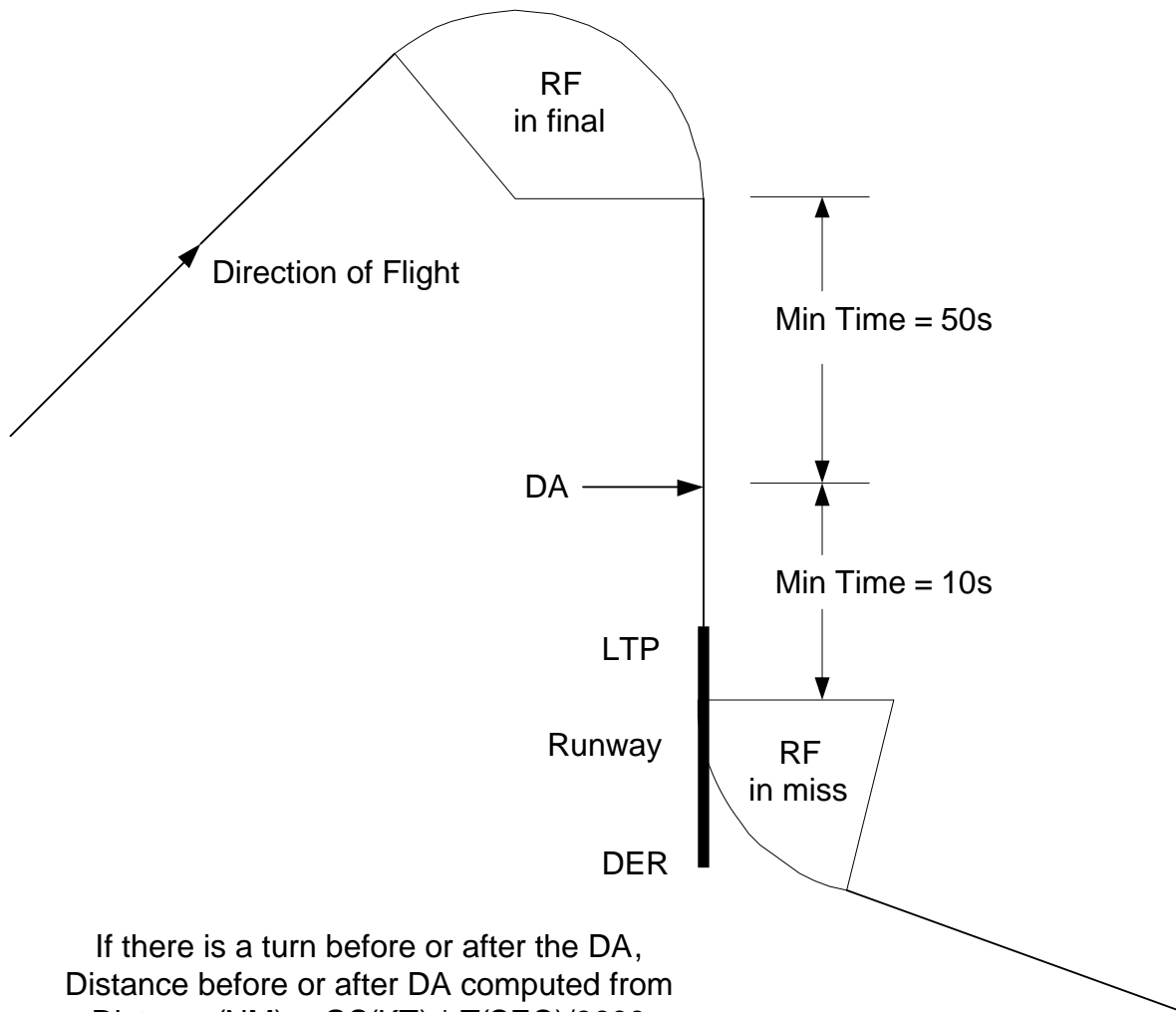
(1) If the aircraft supports RF legs, the lateral path after initiating a go-around (TOGA) (given a minimum 50 second straight segment between the RF end point and the DA) must be within 1 degree of the track defined by the straight segment through the DA point (see figure 1). The prior turn can be of 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.

**c.** 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.

## Public RNP AR Procedures Minimum Straight Segments between Turns and Decision Altitude



If there is a turn before or after the DA,  
Distance before or after DA computed from  
 $Distance(NM) = GS(KT) * T(SEC) / 3600$   
 where  
 $GS = Category\ Speed + 15\ kt$

**Figure 1. 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 8260-10, 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/](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 United States 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. An LOA recognizes the data supplier as one whose data quality, integrity and quality management practices are consistent with the criteria of DO-200A. The aircraft operator's supplier (e.g., FMS company) 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:** If the manufacturer documents the modification has no effect on the navigation database or path computation, the operator need not perform this additional confirmation.

**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 open software problem reports are resolved that exist within the aircraft or other equipment that could directly or indirectly affect the RNP approval. Open software problems or changes that could effect 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).

(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 2-6 in RTCA/DO-283A. 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 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. RNP Advanced Features.

#### A3-1. Introduction.

This appendix provides guidance on the performance and functional requirements for RNP systems containing radius to fix capability. **This appendix does not apply to RNP AR; see appendix 2 for all RNP AR guidance.**

#### 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 (terminal).

**Note:** RF legs will not be used in the final approach segment of an RNP approach.

##### a. System Requirements.

###### (1) Path Definition.

The RNP lateral accuracy requirement is evaluated around the path defined by the published procedure and RTCA/DO-236B, paragraph 3.2.3.3.

**Note 1:** Industry standards for paths can be found in RTCA/DO-236B.

**Note 2:** The guidance in this paragraph clarifies the intent in AC 90-105 for RNP Advanced Features. AC 90-105 mistakenly references RTCA/DO-236B paragraphs 3.2.5.4.1, Fly-By Transitions, and 3.2.5.4.2, Fixed-Radius Transitions, rather than paragraph 3.2.3.3, RF legs.

###### (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 RTCA/DO-283A, the applicant must complete the demonstration in accordance with AC 120-29A, paragraphs 5.19.2.2 and 5.19.3.1.

**Note:** The applicant may use AC 120-29A, paragraphs 5.19.2.2 and 5.19.3.1 to compute accepted FTE values.

(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 flightcrew’s primary field of view when loss of navigation capability and/or loss of integrity are experienced.

**b. Functional Requirements.**

(1) Autopilot and Flight Director.

RNP procedures with RF legs require using an autopilot or FD with at least “roll-steering” capability that is driven by the RNP system. 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 25 degrees above 400 feet AGL.

(3) Electronic Map Display.

The aircraft must have an electronic map display depicting the RNP computed path of the selected procedure including RF legs.

(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:** For missed approaches with an RF Leg, the flightcrew must be able to couple the autopilot or FD to the RNP system (engage LNAV) by 500 feet AGL.

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 requirements 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 requirements). 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.

## Appendix 4. GNSS Velocity Tests to Support ADS-B.

### A4-1. Introduction.

The information in this appendix describes a bench test procedure that can be used as an acceptable means to establish the velocity accuracy output of GNSS equipment.

### A4-2. Velocity Accuracy and Velocity Figure of Merit Tests.

a. The following velocity tests are only required if the equipment manufacturer chooses to have their equipment provide inputs to ADS-B equipment.

b. AC 20-165, paragraph 7d, states that installations with a position source capable of providing velocity accuracy should have the navigation accuracy category - velocity ( $NAC_V$ ) 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.

### 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<br><i>Note 1</i> | 0.xx<br><i>Note 1</i> | 0    | 0.25  | 0.xx<br><i>Note 1</i> | 0.xx<br><i>Note 1</i> | 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<br><i>Note 1</i> | 0.xx<br><i>Note 1</i> | 0    | 0.2   | 0.xx<br><i>Note 1</i> | 0.xx<br><i>Note 1</i> | 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<br><i>Note 1</i> | 0.xx<br><i>Note 1</i> | 0    | 0.25  | 0.xx<br><i>Note 1</i> | 0.xx<br><i>Note 1</i> | 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:

$$h_i = \sqrt{(V_i^{east\_truth} - V_i^{east})^2 + (V_i^{north\_truth} - V_i^{north})^2}$$

#### 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<sub>V</sub>) data shall be used to determine the percentage of samples bounded by the HFOM<sub>V</sub> as shown below. The test passes if TSh,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 NACV = 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<br><i>Note 1</i> | 0.xx<br><i>Note 1</i> | 0                     | 0.25  | 0.xx<br><i>Note 1</i> | 0.xx<br><i>Note 1</i> | 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<br><i>Note 1</i> | 0.25  | 0                     | 0                     | 0.xx<br><i>Note 1</i> | 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<br><i>Note 1</i> | 0.25  | 0                     | 0                     | 0.xx<br><i>Note 1</i> | 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:

$$v_i = |V_i^{vertical\_truth} - V_i^{vertical}|$$

#### 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

$$b_{v,i} = \begin{cases} 1 & v_i \leq VFOM_V \\ 0 & v_i > VFOM_V \end{cases}$$

**A4-9. Additional Tests to Demonstrate Accuracy Commensurate with NACV = 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 (NACV=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:

$$T_{non\_acc} = 2 * \sqrt{\frac{\sum_{i=1}^{N_{non\_acc}} \left( \frac{1.5(h_{i\_non\_acc})}{HDOP_{i\_non\_acc}} \right)^2}{N_{non\_acc}}}$$

Where:

$HDOP_{i\_non\_acc}$  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.

**Appendix 5. Sample Airplane/Rotorcraft Flight Manual Supplement.****A5-1. Introduction.**

The intent of this appendix is to provide general guidance for creating an AFMS/RFMS. 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 AFMS/RFMS. Actual AFMS/RFMS language and structure must be tailored to the actual installation, equipment capabilities, and limitations.

Installation Center/Repair Station  
123 Fourth Street  
Anytown, USA

Model XXX GPS  
Navigation System

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

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

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

For airplanes with an FAA approved airplane flight manual, this document serves as the FAA approved ABC Model XXX GPS flight manual supplement. For airplanes that do not have an approved flight manual, this document serves as the FAA approved ABC Model XXX GPS supplemental flight manual.

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

FAA APPROVED

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Title  
Office  
Federal Aviation Administration  
City, State

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**Sample Airplane/Rotorcraft Flight Manual (Continued)**

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Model XXX GPS  
Navigation System

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Navigation System

**SECTION 1 - GENERAL**

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

*GPS TSO-C129<appropriate revision>*: The installed ABC system complies with AC 20-138B 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 20-138B 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 20-138B 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” minimums. Approach procedures with vertical guidance includes “RNAV(GPS) to “LNAV/VNAV” minimums.

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*GPS/SBAS TSO-C145 or C146* <appropriate revision Class 1>: The installed ABC equipment complies with AC 20-138B 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-C161a* <appropriate revision>: The installed ABC system complies with AC 20-138B 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*: The installed ABC system complies with AC 20-138B 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 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.

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Navigation System

SECTION 2 - LIMITATIONS

1. The ABC Model XXX GPS 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.

2. The system must use at least software version *<insert version identification>* as the minimum version.

3. A valid and compatible database must be installed and contain current data.

*<Limitation for TSO-C129(AR) and TSO-C196 equipment:>*

4. The aircraft must have other operational, approved navigation equipment installed appropriate to the operation.

*<Limitation for all GNSS equipment:>*

5. The TSO-C*<insert number and revision>* equipment has an alternate airport flight planning limitation. Refer to section 1-1-19 in the Airman's Information Manual.

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

SECTION 3 - EMERGENCY/ABNORMAL PROCEDURESEMERGENCY 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.

SECTION 4 - NORMAL PROCEDURES

1. Normal operating procedures are outlined in the ABC Model XXX GPS Pilot's Guide.

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**Sample Airplane/Rotorcraft Flight Manual (Continued)**

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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>*
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>*

**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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## **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, 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. Definitions and Acronyms.

### A7-1. 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 the integrity of the GNSS position output. 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 United States 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/spgps2008.pdf>.

**l. GLONASS.** GLONASS is a Russian Federation satellite-based radio navigation system providing a global positioning service. GLONASS is not fully operational, and currently, no operational credit can be taken for its use in the United States 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. In the United States, this is referred to as local area augmentation system (LAAS). 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-United States) 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 United States.

**o. Local Area Augmentation System (LAAS).** LAAS is the United States 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 United States, 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 a GNSS position sensor and a navigation function, 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 United States implementation of GPS/SBAS.

## A7-2. Acronyms.

|               |   |
|---------------|---|
| <b>14 CFR</b> | Title 14 of the Code of Federal Regulations |
| <b>ABAS</b>   | Aircraft-Based Augmentation System          |
| <b>AC</b>     | Advisory Circular                           |
| <b>ACO</b>    | Aircraft Certification Office               |
| <b>ADAHRS</b> | Air Data Attitude Heading Reference System  |

|                        |   |
|------------------------|---|
| <b>ADS-B</b>           | Automatic Dependent Surveillance - Broadcast    |
| <b>AF/D</b>            | Airport/Facilities Directory                    |
| <b>AFM</b>             | Airplane Flight Manual                          |
| <b>AFMS</b>            | Airplane Flight Manual Supplement               |
| <b>AGL</b>             | Above Ground Level                              |
| <b>AHRS</b>            | Attitude Heading Reference System               |
| <b>AIRAC</b>           | Aeronautical Information Regulation and Control |
| <b>AML</b>             | Approved Model List                             |
| <b>APCH</b>            | Approach  |
| <b>(AR)</b>            | All Revisions                                   |
| <b>ARNS</b>            | Aeronautical Radio Navigation System            |
| <b>ASI</b>             | Aviation Safety Inspector                       |
| <b>ATIS</b>            | Automated Traffic Information System            |
| <b>atk</b>             | Along Track                                     |
| <b>baro-VNAV</b>       | Barometric Vertical Navigation                  |
| <b>CA</b>              | Course to Altitude termination per ARINC 424    |
| <b>CAT I</b>           | Category I precision approach                   |
| <b>CDI</b>             | Course Deviation Indicator                      |
| <b>CDU</b>             | Control Display Unit                            |
| <b>CF</b>              | Course to Fix per ARINC 424                     |
| <b>CFR</b>             | Code of Federal Regulations                     |
| <b>D<sub>MAX</sub></b> | Maximum Use Distance                            |
| <b>DA</b>              | Decision Altitude                               |
| <b>dB</b>              | Decibel   |
| <b>dBc</b>             | Decibels Relative to Carrier Power              |
| <b>dBm</b>             | Decibels Referenced to one Milliwatt            |
| <b>D/D/I</b>           | DME/DME/Inertial Reference Unit                 |
| <b>DER</b>             | Designated Engineering Representative           |
| <b>DER</b>             | Designated End of Runway (for RNP AR only)      |
| <b>DF</b>              | Direct to Fix per ARINC 424                     |
| <b>DME</b>             | Distance Measuring Equipment                    |
| <b>DOD</b>             | Department of Defense                           |
| <b>DOT</b>             | Department of Transportation                    |
| <b>DP</b>              | Departure Procedure                             |
| <b>EHSI</b>            | Electronic Horizontal Situation Indicator       |
| <b>ELT</b>             | Emergency Locator Transmitter                   |
| <b>EMC</b>             | Electromagnetic Compatibility                   |
| <b>EMI</b>             | Electromagnetic Interference                    |
| <b>ESV</b>             | Expanded Service Volume                         |
| <b>EVS</b>             | Enhanced Vision System                          |
| <b>FA</b>              | Fix to Altitude termination per ARINC 424       |
| <b>FAA</b>             | Federal Aviation Administration                 |
| <b>FAF</b>             | Final Approach Fix                              |
| <b>FAS</b>             | Final Approach Segment                          |
| <b>FD</b>              | Flight Director                                 |
| <b>FDE</b>             | Fault Detection and Exclusion                   |
| <b>FGS</b>             | Flight Guidance System                          |

|                         |   |
|-------------------------|---|
| <b>FHS</b>              | Functional Hazard Assessment                    |
| <b>FM</b>               | Fix to Manual termination per ARINC 424         |
| <b>FMS</b>              | Flight Management System                        |
| <b>FOM</b>              | Figure of Merit                                 |
| <b>FRP</b>              | Federal Radionavigation Plan                    |
| <b>FSTD</b>             | Flight Simulation Training Device               |
| <b>FTE</b>              | Flight Technical Error                          |
| <b>GBAS</b>             | Ground-Based Augmentation System                |
| <b>GEO</b>              | Geostationary Orbit Satellite                   |
| <b>GNSS</b>             | Global Navigation Satellite System              |
| <b>GLS</b>              | GBAS Landing System                             |
| <b>GNSS</b>             | Global Navigation Satellite System              |
| <b>GPA</b>              | Glide Path Angle                                |
| <b>GPS</b>              | Global Positioning System                       |
| <b>GPWS</b>             | Ground Proximity Warning System                 |
| <b>HAL</b>              | Horizontal Alert Limit                          |
| <b>HAT</b>              | Height Above Terrain                            |
| <b>HDOP</b>             | Horizontal Dilution of Precision                |
| <b>HFOM</b>             | Horizontal Figure of Merit                      |
| <b>HFOM<sub>v</sub></b> | Horizontal Figure of Merit (velocity)           |
| <b>HMI</b>              | Hazardously Misleading Information              |
| <b>HPL</b>              | Horizontal Protection Level                     |
| <b>HSI</b>              | Horizontal Situation Indicator                  |
| <b>HUL</b>              | Horizontal Uncertainty Level                    |
| <b>Hz</b>               | Hertz   |
| <b>ICAO</b>             | International Civil Aviation Organization       |
| <b>IF</b>               | Initial Fix per ARINC 424                       |
| <b>IFR</b>              | Instrument Flight Rules                         |
| <b>ILS</b>              | Instrument Landing System                       |
| <b>IMC</b>              | Instrument Meteorological Conditions            |
| <b>INS</b>              | Inertial Navigation System                      |
| <b>IRS</b>              | Inertial Reference System                       |
| <b>IRU</b>              | Inertial Reference Unit                         |
| <b>LAAS</b>             | Local Area Augmentation System                  |
| <b>LNAV</b>             | Lateral Navigation                              |
| <b>LNAV/VNAV</b>        | Lateral Navigation/Vertical Navigation          |
| <b>LOA</b>              | Letter of Acceptance                            |
| <b>LOC</b>              | Localizer                                       |
| <b>LODA</b>             | Letter of Design Approval                       |
| <b>LP</b>               | Localizer Performance without Vertical Guidance |
| <b>LPV</b>              | Localizer Performance with Vertical Guidance    |
| <b>LTP</b>              | Landing Threshold Point                         |
| <b>MAG</b>              | Magnetic  |
| <b>MEMS</b>             | Micro-Electro-Mechanical System                 |
| <b>MLS</b>              | Microwave Landing System                        |
| <b>MMR</b>              | Multi-Mode Receiver                             |
| <b>MNPS</b>             | Minimum Navigation Performance Standards        |

|                        |   |
|------------------------|---|
| <b>MOPS</b>            | Minimum Operational Performance Standards           |
| <b>MSL</b>             | Mean Sea Level                                      |
| <b>NAC<sub>v</sub></b> | Navigation Accuracy Category (velocity)             |
| <b>NAS</b>             | National Airspace System                            |
| <b>NAVAID</b>          | Navigation Aid                                      |
| <b>NDB</b>             | Non-Directional Beacon                              |
| <b>NM</b>              | Nautical Mile                                       |
| <b>NOTAM</b>           | Notice to Airmen                                    |
| <b>NSE</b>             | Navigation System Error                             |
| <b>NTAP</b>            | Notices to Airman Publication                       |
| <b>OBS</b>             | Omni Bearing Selector                               |
| <b>ODP</b>             | Obstacle Departure Procedure                        |
| <b>OEM</b>             | Original Equipment Manufacturer                     |
| <b>PAN</b>             | Precision and Navigation                            |
| <b>PAPI</b>            | Precision Approach Path Indicator                   |
| <b>PHAC</b>            | Plan for Hardware Aspects of Certification          |
| <b>POH</b>             | Pilot Operating Handbook                            |
| <b>PSAC</b>            | Plan for Software Aspects of Certification          |
| <b>PVT</b>             | Position, Velocity, Time                            |
| <b>RAIM</b>            | Receiver Autonomous Integrity Monitoring            |
| <b>RF</b>              | Radius to Fix per ARINC 424                         |
| <b>RFM</b>             | Rotorcraft Flight Manual                            |
| <b>RFMS</b>            | Rotorcraft Flight Manual Supplement                 |
| <b>RNAV</b>            | Area Navigation                                     |
| <b>RNP</b>             | Required Navigation Performance                     |
| <b>RNP APCH</b>        | RNP Approach  |
| <b>RNP AR .</b>        | RNP Authorization Required                          |
| <b>RTA</b>             | Required Time of Arrival                            |
| <b>SAAAR</b>           | Special Aircraft and Aircrew Authorization Required |
| <b>SATCOM</b>          | Satellite Communications                            |
| <b>SBAS</b>            | Satellite-Based Augmentation System                 |
| <b>SFAR</b>            | Special Federal Aviation Regulation                 |
| <b>SID</b>             | Standard Instrument Departure                       |
| <b>STAR</b>            | Standard Terminal Arrival Route                     |
| <b>STC</b>             | Supplemental Type Certificate                       |
| <b>STC-AML</b>         | Supplemental Type Certificate Approved Model List   |
| <b>SVS</b>             | Synthetic Vision System                             |
| <b>TAWS</b>            | Terrain Awareness and Warning System                |
| <b>TC</b>              | Type Certificate                                    |
| <b>TF</b>              | Track to Fix per ARINC 424                          |
| <b>TOAC</b>            | Time of Arrival Control                             |
| <b>TOGA</b>            | Take-Off Go Around                                  |
| <b>TSE</b>             | Total System Error                                  |
| <b>TSO</b>             | Technical Standard Order                            |
| <b>TSOA</b>            | Technical Standard Order Authorization              |
| <b>VA</b>              | Heading to Altitude termination per ARINC 424       |
| <b>VAL</b>             | Vertical Alert Limit                                |

|                         |   |
|-------------------------|---|
| <b>VASI</b>             | Visual Approach Slope Indicator             |
| <b>VDB</b>              | Very High Frequency Data Broadcast          |
| <b>VDOP</b>             | Vertical Dilution of Precision              |
| <b>VFOM</b>             | Vertical Figure of Merit                    |
| <b>VFOM<sub>v</sub></b> | Vertical Figure of Merit (velocity)         |
| <b>VFR</b>              | Visual Flight Rules                         |
| <b>VHF</b>              | Very High Frequency                         |
| <b>VI</b>               | Heading to Intercept per ARINC 424          |
| <b>VM</b>               | Heading to Manual termination per ARINC 424 |
| <b>VNAV</b>             | Vertical Navigation                         |
| <b>VOR</b>              | Very High Frequency Omni-Directional Range  |
| <b>VPL</b>              | Vertical Protection Level                   |
| <b>VSWR</b>             | Voltage Standing Wave Ratio                 |
| <b>URA</b>              | User Range Accuracy                         |
| <b>WAAS</b>             | Wide Area Augmentation System               |
| <b>x tk</b>             | Cross Track                                 |

**Appendix 8. Related Documents.****A8-1. FAA Advisory Circulars.**

- a. AC 20-107B, *Composite Aircraft Structure*.
- b. AC 20-115B, *Radio Technical Commission for Aeronautics, Inc. Document RTCA/DO-178B*.
- c. AC 20-152, *RTCA, Inc., Document RTCA/DO-254, Design Assurance Guidance for Airborne Electronic Hardware*.
- d. AC 20-153, *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 20-165, *Airworthiness Approval of Automatic Dependent Surveillance - Broadcast (ADS-B) Out Equipment for Operation in the National Airspace System (NAS)*.
- h. AC 21-16F, *RTCA Document DO-160 versions D, E, and F, Environmental Conditions and Test Procedures for Airborne Equipment*.
- i. AC 21-40A, *Application Guide for Obtaining a Supplemental Type Certificate*.
- j. AC 23-8B, *Flight Test Guide for Certification of Part 23 Airplanes*.
- k. AC 23-13A, *Fatigue, Fail-Safe, and Damage Tolerance Evaluation of Metallic Structure for Normal, Utility, Acrobatic, and Commuter Category Airplanes*.
- l. AC 23-17, *Systems and Equipment Guide for Certification of Part 23 Airplanes*.
- m. AC 23-18, *Installation of Terrain Awareness and Warning System (TAWS) Approved for Part 23 Airplanes*.
- n. AC 23-21 with Change 1, *Airworthiness Compliance Checklists Used to Substantiate Major Alterations for Small Airplanes*.
- o. AC 23-22, *Guidance for Approved Model List (AML) Supplemental Type Certificate (STC) Approval for Part 23 Airplane Avionics Installations*.
- p. AC 23.1309-1D, *Equipment, Systems, and Installations in Part 23 Airplanes*.
- q. AC 23.1311-1B, *Installation of Electronic Displays in Part 23 Airplanes*.

- r.** AC 23.1419-2D, *Certification of Part 23 Aircraft for Flight in Icing Conditions.*
- s.** AC 25-7A, *Flight Test Guide for Certification of Transport Category Airplanes.*
- t.** AC 25-10, *Guidance for Installation of Miscellaneous, Non-Required Electrical Equipment.*
- u.** AC 25-11A, *Transport Category Airplane Electronic Display Systems.*
- v.** AC 25-15, *Approval of Flight Management Systems in Transport Category Airplanes.*
- w.** AC 25-23, *Airworthiness Criteria for the Installation Approval of a Terrain Awareness and Warning System (TAWS) for Part 25 Airplanes.*
- x.** AC 25-1309-1A, *System Design and Analysis.*
- y.** AC 25.1329-1, *Approval of Flight Guidance Systems.*
- z.** AC 25.1419-1A, *Certification of Part 25 Aircraft for Flight in Icing Conditions.*
- aa.** AC 25.1529-1A, *Instructions for Continued Airworthiness of Structural Repairs on Transport Airplanes.*
- bb.** AC 27-1, *Certification of Normal Category Rotorcraft.*
- cc.** AC 29-2C, *Certification of Transport Category Rotorcraft.*
- dd.** AC 43.9-1F, *Instructions for Completion of FAA Form 337.*
- ee.** AC 43.13-1B, *Acceptable Methods, Techniques and Practices – Aircraft Inspection and Repair.*
- ff.** AC 43.13-2B, *Acceptable Methods, Techniques and Practices – Aircraft Alterations.*
- gg.** 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).*
- hh.** AC 90-100, *U.S. Terminal and Enroute Area Navigation (RNAV) Operations.*
- ii.** AC 90-101A, *Approval Guidance for RNP Procedures with SAAAR.*
- jj.** AC 90-105, *Approval Guidance for RNP Operations and Barometric Vertical Navigation in the U.S. National Airspace System.*



**kk.** AC 91-49 with Change 1, *General Aviation Procedures for Flight in North Atlantic Minimum Navigation Performance Specification Airspace.*

**ll.** AC 120-28D, *Criteria for Approval of Category III Weather Minima for Takeoff, Landing, and Rollout.*

**mm.** AC 120-29A, *Criteria for Approval of Category I and Category II Weather Minima for Approach.*

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

**A8-2. FAA Technical Standard Orders.**

**a.** TSO-C66, *Airborne Distance Measuring Equipment (For Air Carrier Aircraft).*

**b.** TSO-C115, *Airborne Area Navigation Equipment Using Multi-Sensor Inputs.*

**c.** TSO-C129, *Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS).*

**d.** TSO-C144a, *Passive Airborne Global Navigation Satellite System (GNSS) Antenna.*

**e.** TSO-C145c, *Airborne Navigation Sensors Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS).*

**f.** TSO-C146c, *Stand-Alone Airborne Navigation Equipment Using the Global Positioning System (GPS) Augmented by the Satellite Based Augmentation System (SBAS).*

**g.** TSO-C151b, *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-C165, *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-C196, *Airborne Supplemental Navigation Sensors for Global Positioning System Equipment Using Aircraft-Based Augmentation.*

**A8-3. RTCA, Inc. Documents (RTCA DO) documents.**

**a.** RTCA DO-160F, *Environmental Conditions and Test Procedures for Airborne Equipment.*

**b.** RTCA DO-178B, *Software Considerations in Airborne Systems and Equipment Certification.*

**c.** RTCA DO-187, *Minimum Operational Performance Standards For Airborne Area Navigation Equipment Using Multi-Sensor Inputs.*

**d.** RTCA DO-189, *Minimum Performance Standard for Airborne Distance Measuring Equipment (DME) Operating Within the Radio Frequency Range of 960-1215 Megahertz.*

**e.** RTCA DO-200A, *Standards for Processing Aeronautical Data.*

**f.** RTCA/DO-201A, *Standards for Aeronautical Information.*

**g.** RTCA DO-208 with Change 1, *Minimum Operational Performance Standards For Airborne Supplemental Equipment Using Global Positioning System (GPS).*

**h.** RTCA DO-228 with Change 1, *Minimum Operational Performance Standards For Global Navigation Satellite System (GNSS) Airborne Antenna Equipment.*

**i.** RTCA DO-229D, *Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System(GPS/WAAS) Airborne Equipment.*

**j.** RTCA DO-235B, *Assessment of Radio Frequency Interference Relevant to the GNSS L1 Frequency Band.*

**k.** RTCA DO-236B, *Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation.*

**l.** RTCA DO-246D, *GNSS Based Precision Approach Local Area Augmentation System (LAAS) Signal-in-Space Interface Control Document (ICD).*

**m.** RTCA/DO-253C, *Minimum Operational Performance Standards for GPS Local Area Augmentation System Airborne Equipment.*

**n.** RTCA/DO-254, *Design Assurance Guidance for Airborne Electronic Hardware.*

- o.** 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)*.
- p.** RTCA/DO-257A, *Minimum Operational Performance Standards for the Depiction of Navigation Information on Electronic Maps*.
- q.** RTCA/DO-282B, *Minimum Operational Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance-Broadcast (ADS-B)*.
- r.** RTCA/DO-283A, *Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation*.
- s.** RTCA/DO-301, *Active Airborne Global Navigation Satellite System (GNSS) Antenna*.
- t.** RTCA DO-316, *Minimum Operational Performance Standards for Global Positioning System/Aircraft-Based Augmentation System Airborne Equipment*.

#### **A8-4. 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](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/spsp2008.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/](http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/library/documents/).
- f.** DOD/DOT 2008 Federal Radionavigation Plan (FRP). The FRP is published every two years. Copies may be ordered through the National Technical Information Service, Springfield, VA 22161 (DOT-VNTSC-RITA-08-02/DOD-4650.5); internet: [https://www.navcen.uscg.gov/pubs/frp2008/2008\\_federal\\_radionavigation\\_plan.pdf](https://www.navcen.uscg.gov/pubs/frp2008/2008_federal_radionavigation_plan.pdf).

**A8-5. 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/](http://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](http://www.rtca.org).

**c.** Order copies of ACs from the United States Department of Transportation, Subsequent Distribution Office, M-30, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785. You can also get copies from our website at [http://www.faa.gov/regulations\\_policies/advisory\\_circulars/](http://www.faa.gov/regulations_policies/advisory_circulars/) or [www.airweb.faa.gov/rgl](http://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](http://www.airweb.faa.gov/rgl). You will also find the TSO Index of Articles on the same site.