



Department of Transportation
Federal Aviation Administration
Aircraft Certification Service
Washington, DC

TSO-C146a

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Technical Standard Order

Subject: STAND-ALONE AIRBORNE NAVIGATION EQUIPMENT USING THE GLOBAL POSITIONING SYSTEM (GPS) AUGMENTED BY THE WIDE AREA AUGMENTATION SYSTEM (WAAS)

1. **PURPOSE.** This Technical Standard Order (TSO) tells persons seeking a TSO authorization or letter of design approval what minimum performance standards (MPS) their stand-alone airborne navigation equipment, using the Global Positioning System (GPS) augmented by the Wide Area Augmentation System (WAAS), must first meet in order to obtain approval and be identified with the applicable TSO marking.

2. **APPLICABILITY.** This TSO is effective for new applications submitted after the effective date of this TSO. All prior revisions of this TSO are no longer effective and applications will not be accepted after the effective date of this TSO.

3. **REQUIREMENTS.** New models of airborne navigation equipment using GPS augmented by WAAS that are to be so identified and that are manufactured on or after the effective date of this TSO must meet the MPS for functional equipment class Gamma or class Delta equipment in Section 2 of RTCA/DO-229C, "Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment," dated November 28, 2001, as amended by Appendix 1 of this TSO. Class Gamma and class Delta equipment are defined in Section 1.4 of RTCA/DO-229C.

a. **Functionality.** The standards of this TSO apply to equipment intended to accept a desired flight path and provide deviation commands referenced to that path. These deviations will be used by the pilot or autopilot to guide the aircraft. These standards do not address integration issues with other avionics, such as the potential for the system inadvertently to command an autopilot hardover. These standards also do not address the use of position information for other applications, such as automatic dependent surveillance.

b. **Failure Condition Classification.** Failure of the function defined in paragraph 3 and 3a of this TSO has been determined to be: a major failure condition for loss of function and malfunction of en route, terminal, or nonprecision approach navigation data; a major failure condition for loss of function of precision approach navigation data; and a hazardous failure condition for the malfunction of precision approach navigation data. The applicant must develop the system to at least the design assurance level commensurate with this hazard classification.

c. **Functional Qualification.** The required performance shall be demonstrated under the test conditions and procedures specified in RTCA/DO-229C, Section 2.5. The use of test procedures other than those specified in Sections 2.5.2 through 2.5.11 of RTCA/DO-229C constitutes a deviation to this TSO.

d. **Environmental Qualifications.** The equipment shall be subject to the test conditions as specified in RTCA/DO-229C, Section 2.4 and RTCA/DO-160D, "Environmental Conditions and Test Procedures for Airborne Equipment," dated July 29, 1997.

e. **Software Qualifications.** If the article includes software, the software must be developed in accordance with Sections 3 through 11 and Annex A of RTCA/DO-178B, "Software Considerations in Airborne Systems and Equipment Certification," dated December 1, 1992.

f. **Barometric-Aided Fault Detection and Exclusion (FDE).** If the equipment uses barometric-aiding to enhance the availability of FDE, it must meet the requirements in Appendix G of RTCA/DO-229C.

g. **Deviations.** The FAA has provisions for using alternative or equivalent means of compliance to the criteria set forth in the MPS of this TSO. Applicants invoking these provisions shall demonstrate that an equivalent level of safety is maintained and shall apply for a deviation per 14 CFR § 21.609.

4. **MARKING.** Under 14 CFR § 21.607(d), articles manufactured under this TSO must be marked as follows:

a. At least one major component must be permanently and legibly marked with all of the information listed in 14 CFR § 21.607(d), except for the following: the option in 14 CFR § 21.607(d)(2), where the name, type and part number must be used in lieu of the optional model number; and the option in 14 CFR § 21.607(d)(3), where the date of manufacture must be used in lieu of the optional serial number.

b. In addition to the requirements of 14 CFR § 21.607(d), each separate component that is easily removable (without hand tools), each interchangeable element, and each separate subassembly of the article that the manufacturer determines may be interchangeable must be permanently and legibly marked with at least the name of the manufacturer, manufacturer's subassembly part number, and the TSO number.

c. If the component includes software, the part number must include hardware and software identification, or a separate part number may be utilized for hardware and software. Either approach must include a means for showing the modification status. Note that similar software versions, which have been approved to different software levels, must be differentiated by part number.

d. At least one major component must be permanently and legibly marked with the operational equipment class as defined in Section 1.4.2 of RTCA/DO-229C (e.g., class 2). A marking of class 4 indicates compliance to Delta-4 requirements. The functional equipment class defined in Section 1.4.1 of RTCA/DO-229C (e.g. Gamma, Delta) is not required to be marked.

e. When applicable, identify the article as an incomplete system or that the article accomplishes additional functions beyond that described in paragraph 3 and 3a of this TSO.

5. DATA REQUIREMENTS.

a. **Application Data.** Under 14 CFR § 21.605(a)(2), the manufacturer must furnish the Manager, Aircraft Certification Office (ACO), Federal Aviation Administration (FAA), responsible for the manufacturer's facilities, one copy each of the following technical data to support the FAA design and production approval:

(1) Operating instructions and equipment limitations. The limitations shall be sufficient to describe the operational capability of the equipment. For class 1, 2, and 3 equipment, the operating instructions shall include:

(a) An operations manual that provides a reference on the use of the equipment.

(b) A training package to instruct the operator on the use of the equipment. This training package may use any medium (video, software, paper, etc.) and should familiarize the operator with all of the functions and operation of the equipment.

(c) A quick reference guide that contains instructions on how to accomplish at least the following operations: entering a flight plan; editing a flight plan; executing a Direct-TO; accomplishing a holding pattern; executing an approach procedure (class 2 and 3 equipment); and executing a missed approach (class 2 and 3 equipment).

(2) Installation procedures and limitations. The limitations shall be sufficient to ensure that the article, when installed in accordance with the installation procedures, continues to meet the requirements of this TSO. The limitations shall identify any unique aspects of the installation. The limitations shall include at least the following:

(a) A note with the following statement:

The conditions and tests required for TSO approval of this article are minimum performance standards. It is the responsibility of those installing this article either on or within a specific type or class of aircraft to determine that the aircraft installation conditions are within the TSO standards. TSO articles must have separate approval for installation in an aircraft. The article may be installed only if performed under 14 CFR part 43 or the applicable airworthiness requirements.

(b) Adequate specification of the interface between the GPS/WAAS equipment and other systems to ensure proper functioning of the integrated system. This must include maximum tolerable currents and voltages into the antenna port if the equipment is to be installed with a standard antenna (TSO-C144, "Airborne Global Positioning System Antenna").

(c) If the equipment has only been demonstrated to satisfy the requirements of RTCA/DO-229C when used with a particular antenna, the use of that antenna (by part number) should be made a requirement on the installation (i.e., a limitation).

(d) If the equipment is dependent on any inputs in order to satisfy the requirements of RTCA/DO-229C (e.g., baro-aided FDE), those inputs should be made a requirement on the installation (i.e., a limitation).

(e) If the software qualification limits the equipment to be eligible on certain aircraft types, identify the qualification level and that the equipment has not been determined to be eligible for all aircraft types (e.g., AC 23-1309-1C, "Equipment, Systems, and Installations in Part 23 Airplanes," states that the RTCA/DO-178B Level C software may be associated with a hazardous failure condition for certain aircraft types). Other limitations applicable to the failure condition classification should also be identified (e.g., two installed units are necessary).

(f) If the equipment has not been demonstrated to be compatible with SatCom, the limitations must include a note identifying that equipment should not be installed in an aircraft equipped with SatCom.

(g) When applicable, identify the article as an incomplete system or a multi-use system and describe the functions that are intended to be provided by the article.

(3) Schematic drawings, as applicable to the installation procedures.

(4) Wiring drawings, as applicable to the installation procedures.

(5) List of the components, by part number, that make up the equipment complying with the standards prescribed in this TSO. Manufacturers should include vendor part number cross-references when applicable.

(6) Instructions, in the form of a Component Maintenance Manual (CMM) containing information on the periodic maintenance, calibration, and repair, for the continued airworthiness of installed GPS/WAAS airborne equipment, including recommended inspection intervals and service life.

(7) An environmental qualifications form as described in RTCA/DO-160D for each component of the system.

(8) Summary of the database updating process that complies with the requirements in Section 2.2.1.5.3 of RTCA/DO-229C. This summary must define the data quality requirements, identify the data source(s), and provide a brief description of the data distribution and update process.

(9) Materials and process specifications list.

(10) The quality control system description required by 14 CFR §§ 21.605(a)(3) and 21.143(a), including functional test specifications to be used to test each production article to ensure compliance with this TSO.

(11) Manufacturer's TSO qualification test report.

(12) Nameplate drawing providing the information required by paragraph 4 of this TSO.

(13) A list of all drawings and processes, including revision level, necessary to define the article's design. In the case of a minor change, any revisions to the drawing list need only be made available upon request.

(14) If the article includes software: Plan for Software Aspects of Certification (PSAC); Software Configuration Index; and Software Accomplishment Summary. The FAA recommends that the PSAC be submitted early in the software development process. Early submittal will allow timely resolution of issues such as partitioning and determining software levels.

b. Manufacturer Data. In addition to the data to be furnished directly to the FAA, each manufacturer must have available for review by the manager of the ACO responsible for the manufacturer's facilities the following technical data:

(1) The functional qualification specifications to be used to qualify each production article to ensure compliance with this TSO.

(2) Equipment calibration procedures.

(3) Corrective maintenance procedures within 12 months after TSO authorization.

(4) Schematic drawings.

(5) Wiring diagrams.

(6) Material and process specifications.

(7) The results of the environmental qualification tests conducted in accordance with RTCA/DO-160D.

(8) If the article includes software, the appropriate documentation as defined in RTCA/DO-178B, including all data supporting the applicable objectives found in Annex A of RTCA/DO-178B.

(9) Qualification test procedures used to determine compliance with this TSO.

(10) Documentation which describes the data distribution process in detail, compliant with RTCA/DO-200A, "Standards for Processing Aeronautical Data."

c. Furnished Data.

(1) One copy of the data and information specified in paragraphs 5(a)(1) through (8) of this TSO and any other data or information necessary for the proper installation, certification, use, and continued airworthiness of the GPS/WAAS airborne equipment must accompany each article manufactured under this TSO.

(2) If the appliance accomplishes any additional functions beyond that described in paragraphs 3 and 3a of this TSO or covered by another TSO authorization, then a copy of the data and information specified in paragraphs 5a(13) and (14) must also go to each person receiving for use one or more articles manufactured under this TSO.

6. AVAILABILITY OF REFERENCED DOCUMENTS.

a. You may buy copies of RTCA/DO-160D, DO-178B, DO-200A and DO-229C from RTCA Inc., 1828 L Street, NW, Suite 805, Washington, D.C. 20036 or from their website at www.rtca.org

b. You may buy copies of Federal Aviation Regulations 14 CFR part 21, Subpart O, from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402-9325. Copies also can be obtained from the Government Printing Office (GPO), electronic CFR Internet website at www.access.gpo.gov/ecfr/.

c. Advisory Circular (AC) 20-110, "Index of Aviation Technical Standard Orders," and AC 20-36, "Index of Articles Certified under the Technical Standard Order System," may be obtained from the U.S. Department of Transportation, Subsequent Distribution Office, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785, telephone (301) 322-4477 or FAX (301) 386-5394. Copies also may be obtained from the FAA Internet website at www.faa.gov/certification/aircraft/TSOA.htm.

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APPENDIX 1. MINIMUM PERFORMANCE STANDARD FOR AIRBORNE NAVIGATION SENSORS USING GPS/WAAS

This appendix prescribes the MPS for airborne navigation sensors using GPS/WAAS, modified by the FAA in this TSO. The applicable standard is RTCA/DO-229C, "Minimum Operational Performance Standards for GPS WAAS Airborne Equipment", November 18, 2001, with errata dated August 16, 2002, and is modified as follows:

1. Page 32, paragraph 2.1.1.5.5 (GPS UNHEALTHY Designation). Replace first sub-bullet with:

- 6 bit health word in subframe 1: all cases where MSB="1" ~~except when other bits are "11101", indicating that the satellite will be out of service but is not at this time~~ (ref. 20.3.3.3.1.4 and 20.3.3.5.1.3 of ICD-GPS-200C, "Navstar GPS Space Segment / Navigation User Interfaces," April 2000.);

2. Page 38, paragraph 2.1.1.13.1 (Protection Level). Change latency requirement to 2 seconds as follows:

Class Beta equipment shall output the Horizontal Protection Level (HPL_{WAAS} or HPL_{FD} as described in Sections 2.1.2.2.2, 2.1.3.2.2, 2.1.4.2.2, and 2.1.5.2.2). Class Gamma and Delta equipment intended to support an external ADS-B function shall output HPL. The latency of the WAAS-based protection levels shall not exceed 2 ~~4-8~~ seconds, from the arrival at the antenna port of the last bit of a message which affects the horizontal protection level. The GPS/WAAS equipment shall indicate if the HPL cannot be calculated (insufficient number of WAAS HEALTHY satellites and fault detection is not available).

3. Page 55, paragraph 2.1.4.12.1 (Protection Level). Change latency requirement to 1 second as follows:

Class Beta-2 equipment shall output WAAS-based protection levels (HPL_{WAAS} and VPL_{WAAS}) once per second. The latency of the output of the WAAS-based protection levels shall not exceed 1 ~~0-7~~ second, from the arrival at the antenna port of the last bit of a message, which affects the horizontal or vertical protection levels to output of the last bit of a message containing the protection levels. The GPS/WAAS equipment shall indicate if the HPL_{WAAS} and VPL_{WAAS} cannot be calculated (insufficient number of WAAS HEALTHY satellites). Note that when the HPL_{WAAS} and VPL_{WAAS} cannot be calculated, LNAV/VNAV is not available.

4. Page 56, paragraph 2.1.4.12.2 (Navigation Alert). Change latency requirement for insufficient WAAS HEALTHY satellites to 1 second as follows:

Class Beta-2 equipment shall provide an indication or output of the loss of navigation capability within one second of the onset of any of the following conditions:

- a) The absence of power (loss of function is an acceptable indicator);
- b) Probable equipment malfunction or failure (must consider all malfunctions and failures that could affect the navigation function and are more probable than 10^{-5});
- c) The presence of a condition where fault detection detects a position failure; or
- d) when no valid WAAS message has been received for 4 seconds or more (this indicates a probable communications link problem or WAAS signal blockage).

Class Beta-2 equipment shall also provide an indication or output of the loss of navigation capability within 1 ~~0-6~~ second of the onset of any of the following conditions:

- e) there are fewer than 4 WAAS HEALTHY satellites (e.g., onset of condition is: (1) when satellite is blocked; (2) when the last bit of a WAAS message indicating "Don't Use" arrives at the antenna port).

The alert shall be returned to its normal state immediately upon termination of the responsible condition.

5. Pages 111-112, paragraph 2.2.4.6.1 (Alert Limits). Define HAL and VAL for LNAV/VNAV as follows:

Prior to sequencing the FAWP, the HAL shall be 0.3 NM. There is no VAL.

After sequencing the FAWP, the alert limits shall be as follows:

- a) LNAV/VNAV: HAL = 556 m, VAL = 50 m. ~~HAL and VAL as stored in the database for each LNAV/VNAV per Section 2.2.4.5.1.~~

The equipment shall not provide the flight crew a means of changing the alert limit.

As described in Section 2.2.4.7.4, the equipment must provide an advisory of the level of service available. Once that advisory is provided, the level of service shall not change unless the missed approach is initiated or the pilot changes the desired level of service.

The equipment shall use the alert limits for the monitoring described in Sections 2.2.4.6.2 and 2.2.4.6.3.

6. Page 119, paragraph 2.2.5.5.1 (Content). Insert a reference to the data defined in Appendix D (which includes the HAL and VAL as described in item 7 below), and delete redundant requirement for VAL to be stored in the database as follows:

In addition to the requirements of paragraph 2.2.1.5.2, the equipment shall store the GLS and APV-II procedures in the area(s) in which IFR operation is intended, including the data defined in Appendix D (Table D-1). For each procedure, the equipment shall also identify the types of approach with vertical guidance that are published (i.e., GLS, APV-II, and/or LNAV/VNAV), and the naming convention associated with the types of approach (e.g., "GLS", "LNAV/VNAV").

The complete sequence of waypoints, in the correct order for each approach, must be retrievable as a procedure (so that selecting the procedure by name results in loading the appropriate waypoints and legs into the flight plan).

Waypoints utilized as a final approach waypoint (FAWP) and LTP/FTP in a GLS and APV-II procedure shall be uniquely identified as such to provide proper approach mode operation.

~~In addition to the above requirements, the equipment shall store the VAL for each GLS and APV-II approach.~~

7. Page D-5, Appendix D, section D.3.2, Table D-1. Insert the HAL and VAL into the table before the CRC, as follows:

Table D-1 Final Approach Segment (FAS)

<i>Data content</i>	<i>Bits used</i>	<i>Range of values</i>	<i>Resolution</i>
Operation type	4	0 to 15	1
SBAS provider ID	4	0 to 15	1
Airport ID	32	-	-
Runway number (Note 1)	6	0 to 36	1
Runway letter	2	-	-
Approach performance designator	3	0 to 7	1
Route indicator	5	-	-
Reference path data selector	8	0 to 48	1
Reference path identifier	32	-	-
LTP/FTP latitude	32	$\pm 90.0^\circ$	0.0005 arcsec
LTP/FTP longitude	32	$\pm 180.0^\circ$	0.0005 arcsec
LTP/FTP height	16	-512.0 to 6041.5 m	0.1 m
Δ FPAP latitude	24	$\pm 1.0^\circ$	0.0005 arcsec
Δ FPAP longitude	24	$\pm 1.0^\circ$	0.0005 arcsec
Approach threshold crossing height (TCH) (note 1)	15	0 to 1638.4 m (0 to 3276.8 ft)	0.05 m (0.1 ft)
Approach TCH units selector	1	-	-
Glidepath angle (GPA)	16	0 to 90.0 $^\circ$	0.01 $^\circ$
Course width at threshold (Note 1)	8	80.0 to 143.75 m	0.25 m
Δ Length offset	8	0 to 2032 m	8 m
<u>Horizontal Alert Limit (HAL)</u>	<u>8</u>	<u>0 to 50.8 m</u>	<u>0.2 m</u>
<u>Vertical Alert Limit (VAL)</u> <u>(Note 2)</u>	<u>8</u>	<u>0 to 50.8 m</u>	<u>0.2 m</u>
Final approach segment CRC	32	-	-

Note 1: When the runway number is set to 00, then the course width field is ignored and the course width is 38 meters.

Note 2: A VAL of 0 indicates that the vertical deviations should not be used (i.e., a lateral-only approach).