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

TSO-C{XXX}

Effective
Date: {mm/dd/yy}

Technical Standard Order

PROPOSED

Subject: GNSS-Aided Inertial System

1.   PURPOSE. This technical standard order (TSO) is for manufacturers applying for a TSO authorization (TSOA) or letter of TSO design approval (LODA). In it, we (the Federal Aviation Administration, (FAA)) tell you what minimum performance standards (MPS) your Global Navigation Satellite System (GNSS)-aided inertial system must meet for approval and identification with the applicable TSO marking.

2.   APPLICABILITY. This TSO affects new applications submitted after its effective date. Applicants seeking approval for their GNSS-aided inertial system providing position outputs must meet the requirements of this TSO.

   a.   Some GNSS-aided inertial systems have approval using RTCA/DO-229() or RTCA/DO-316(), Appendix R for the requirements and test procedures for the tightly integrated GPS/Inertial system. However, the FAA will no longer accept any new applications using these criteria.
   Note: Minor updates to existing approved equipment (e.g., updates to magvar database, software modifications for anomaly resolution) can continue to use the means of compliance established at initial design approval.

   b.   Some GNSS-aided inertial systems have approval under TSO-C201, Attitude and Heading Reference Systems (AHRS), with the navigation capability of the product approved as a non-TSO function (e.g. the position outputs of the GNSS-aided inertial system making up the AHRS). TSO-C201 remains effective and is a prerequisite for GNSS-aided inertial systems incorporating Attitude and Heading functions. However, the FAA will no longer accept any new applications for TSO-C201 that seeks approval of the position outputs as a non-TSO function.

   c.   Manufacturers with a TSOA where the authorization recognizes the GNSS-aided inertial position outputs as a non-TSO function may still manufacture their product under the provisions of its original TSOA.

3. REQUIREMENTS. New models of GNSS-aided inertial systems identified and manufactured on or after the effective date of this TSO must meet the requirements in section 2.1 and 2.2 of RTCA, Inc. Document No. RTCA/DO-384, *Minimum Operational Performance Standards (MOPS) for GNSS Aided Inertial Systems*, dated December 17, 2020.

The GPS sensors for new GNSS-aided inertial systems must meet the requirements of either TSO-C196(), TSO-C145(), or TSO-C146().

The AHRS functions for new GNSS-aided inertial systems must meet the requirements of TSO-C201.

a. Functionality. This TSO's standard applies to GNSS-aided inertial systems. Due to the wide range of possible GNSS-aided inertial systems' capabilities, manufacturers must define the equipment's intended function and demonstrated performance. The word "system" includes all components or units necessary for the GNSS-aided inertial system to perform its intended function (excluding GNSS receiver function which meets requirements of TSO-C196(), TSO-C145() or TSO-C146() and AHRS functions which meet requirements of TSO-C201).

b. Failure Condition Classifications. There is no standard minimum failure condition classification of the function defined in paragraph **3.a** for this TSO. The failure condition classification appropriate for a GNSS-aided inertial system will depend on the intended use of the system in each specific aircraft. In support of the variety of aircraft the system may support, the manufacturer must document the impacts of loss of function and malfunctions on the system performance, along with the failure conditions and development assurance the system design embraces. Guidance for the development of systems, respectively loss of function and failure condition classification is in SAE ARP 4754A and ARP 4761.

c. Integrity Protection Limits. Both Advanced Receiver Autonomous Integrity Monitoring (ARAIM) and RTCA/DO-384 for GNSS-aided inertial systems define ways to compute protection limits with the same integrity and continuity objectives. However, hypotheses taken into account by ARAIM are much more stringent than the hypotheses taken into account by RTCA/DO-384.

(1) While RTCA/DO-384 integrity relies on the GPS prior satellite failure rate of 10^{-5}/hr, it does not take into account the temporal effects considered by ARAIM that lead to more pessimistic probabilities of missed detection to guarantee the integrity risk over the exposure period. However, RTCA/DO-384 requires validation activities that may account for the temporal behavior of various factors such as the troposphere, ionosphere, satellite clock, ephemeris, airborne multi-path, and receiver noise. For GNSS-aided inertial systems, manufacturers must evaluate whether RTCA/DO-384 temporal error characterization and sampling rate is adequate, particularly for lower grade inertial components.

(2) When assigning probability of misleading information equal to or less than 10^{-7}, manufacturers must consider additional fault modes or anomalies affecting multiple satellites. GPS Standard Positioning Service (SPS) Performance Standard specifies that the probability of a GPS major service failure on two or more satellites due to a common cause (Pconst) shall not

exceed 10^{-8} (consistent with the proposed amendment to International Civil Aviation Organization (ICAO) Annex 10 - Aeronautical Telecommunications, Volume I - Radio Navigation Aids). Manufacturers may use the tests described in RTCA/DO-384, Appendix Q: Alternate Trajectories, to demonstrate the performance of the GNSS-aided inertial system in detecting, mitigating and recovering from multiple satellite failures.

    c. **Functional Qualification.**   Demonstrate the required functional performance under the test methods and procedures specified in RTCA/DO-384, Section 2.5.

    d. **Environmental Qualification.** Demonstrate the required performance under the environmental conditions specified in RTCA/DO-384, Section 2.4, using the standard environmental conditions and test procedures appropriate for airborne equipment. You may use a different standard environmental condition and test procedure than RTCA/DO-160G, provided the standard is appropriate for GNSS-aided inertial systems.

> **Note:** The use of RTCA/DO-160D (with Changes 1 and 2 only, without Change 3 incorporated) or earlier versions is generally not considered appropriate and will require substantiation via the deviation process as discussed in paragraph **3.h** of this TSO.

    e. **Software Qualification.** If the article includes software, develop the software according to RTCA, Inc., document RTCA/DO-178C, *Software Considerations in Airborne Systems and Equipment Certification*, dated December 13, 2011, including referenced supplements as applicable, to at least the software level consistent with the failure condition classification and development assurance defined in paragraph **3.b** of this TSO. You may also develop the software according to RTCA, Inc., document RTCA/DO-178B, dated December 1, 1992, if you follow the guidance in AC 20-115D, *Airborne Software Development Assurance Using EUROCAE ED-12() and RCTA DO-178()*, dated July 21, 2017.

    f. Electronic Hardware Qualification. If the article includes complex custom airborne electronic hardware, then develop the component according to RTCA, Inc., Document RTCA/DO-254, *Design Assurance Guidance for Airborne Electronic Hardware*, dated April 19, 2000, to at least the design assurance level consistent with the failure condition classification defined in paragraph **3.b** of this TSO. For custom airborne electronic hardware determined to be simple, RTCA/DO-254, section 1.6 applies.

    g. **Alternate GNSS Trajectories.** If the equipment provides detection and mitigation against the effects of erroneous (or alternate) GNSS trajectories, then the applicant must test the equipment according to RTCA/DO-384, Appendix Q: Alternate Trajectories.

    h. **Deviations.** We have provisions for using alternate or equivalent means of compliance with the criteria in the MPS of this TSO. If you invoke these provisions, you must show that your equipment maintains an equivalent level of safety. Apply for a deviation in accordance with 14 CFR 21.618.

4. **MARKING.**

a. Mark at least one major component permanently and legibly with all of the information in 14 CFR 45.15(b).

b. If the article includes software and/or airborne electronic hardware, then the article part numbering scheme must identify the software and airborne electronic hardware configuration. The part-numbering scheme can use separate, unique part numbers for software, hardware and airborne electronic hardware.

c. You may use electronic part marking to identify software or airborne electronic hardware components by embedding the identification within the hardware component itself (using software) rather than marking it on the equipment nameplate. If electronic marking is used, it must be readily accessible without the use of special tools or equipment.

d. The FAA recommends you identify the product as a "RTCA/DO-384 approved GNSS-aided inertial system" to facilitate operational credit for use of the position output for navigation under instrument flight rules (IFR).

Note: Equipment receiving this TSOA for category A and B (as defined in RTCA/DO-384) will meet the eligibility requirements for carriage of an "approved inertial system", associated with performance based navigation (PBN) operations.

e. At least one major component must be permanently and legibly marked with the equipment category and sub-category (for example, Category A-2) as defined in RTCA/DO-384, Section 1.3.

5. **APPLICATION DATA REQUIREMENTS.** You must give the FAA Aircraft Certification Office (ACO) manager responsible for your facility a statement of conformance, as specified in 14 CFR 21.603(a)(1) and one copy each of the following technical data to support your design and production approval. LODA applicants must submit the same data (excluding paragraph **5.g** of this TSO) through their civil aviation authority.

b. Manuals containing the following:

    (1) Operating instructions and article limitations sufficient to describe the equipment's operational capability.

    (2) Detailed description of any deviations.

    (3) Installation procedures and limitations sufficient to ensure that the GNSS-aided inertial system, when installed according to the installation and operational procedures, still meets this TSO's requirements. Limitations must identify any unique requirements for the installation of the system.

        (a) If the system's intended function does not support Automatic Dependent Surveillance Broadcast (ADS-B) Out as specified in 14 CFR 91.227, then include this limitation in the installation manual.

(b) If the system's intended function does not support Required Navigation Performance Authorization Required (RNP AR) operations as specified in AC 20-138D, then include this limitation in the installation manual.

(c) The installation manual must contain the characteristics and demonstrated performance of the GNSS-aided inertial system. Use the guidance in RTCA/DO-384 Appendix P: Claim Tables.

(d) Consistent with Executive Order 13905, "Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing Services", the applicant should provide protection from erroneous trajectories. If the equipment claims to provide detection and mitigation against the effects of erroneous (or alternate) GNSS trajectories, you must document the characteristics and performance of the GNSS-aided inertial system in a separate Alternate Trajectory Claims Table document. For generating the claims table, you should use the recommendations in RTCA/DO-384 Appendix Q.5: Alternate Trajectory Claims Table.

(e) The limitations must also include a note with the following statement:

"This article meets the minimum requirements of {insert the TSO number and revision letter}. Installation of this article requires separate approval."

(f) If the system interfaces with an external GNSS receiver and requires specific receiver performance characteristics for proper function (e.g., receiver clock performance), these requirements must be included in the installation manual or other equipment documentation. If such requirements are not included in the installation manual, then the installation manual must include a statement directing the installer to where the requirements are documented.

(4) For each unique configuration of software and airborne electronic hardware, reference the following:

(a) Software part number, including revision and design assurance level,

(b) Airborne electronic hardware part number including revision and design assurance level, and

(c) Functional description.

(5) A summary of the test conditions used for environmental qualifications for each component of the article. For example, a form as described in RTCA/DO-160G, *Environmental Conditions and Test Procedures for Airborne Equipment,* Appendix A.

(6) Schematic drawings, wiring diagrams, and any other documentation necessary for installation of the GNSS-aided inertial system.

(7) By-part-number list of replaceable components that makes up the GNSS-aided inertial system. Include vendor part number cross-references, when applicable.

c. Instructions covering periodic maintenance, calibration, and repair, to ensure that the GNSS-aided inertial system continues to meet the TSO approved design. Include recommended inspection intervals and service life, as appropriate.

d. If the article includes software: a plan for software aspects of certification (PSAC), software configuration index, and a software accomplishment summary.

e. If the article includes simple or complex custom airborne electronic hardware: a plan for hardware aspects of certification (PHAC), a hardware verification plan, top-level drawing, and hardware accomplishment summary (or similar document, as applicable).

f. A drawing depicting how the article will be marked with the information required by paragraph **4** of this TSO.

g. Identify functionality or performance contained in the article not evaluated under paragraph **3** of this TSO (defined as non-TSO functions). Non-TSO functions can be accepted in parallel with the TSOA. For those non-TSO functions to be accepted, you must declare these functions and include the following information with your TSO application:

(1) Description of the non-TSO function(s), such as performance specifications, failure condition classifications, software, hardware and environmental qualification levels. Include a statement confirming the non-TSO function(s) do not interfere with the article's compliance with the requirements of paragraph **3** of this TSO.

(2) Installation procedures and limitations sufficient to ensure that the non-TSO function(s) meets the declared function(s) and performance specification(s) described in paragraph **5.f.(1)** of this TSO.

(3) Instructions for continued performance applicable to the non-TSO function(s) described in paragraph **5.f.(1)** of this TSO.

(4) Interface requirements and applicable installation test procedures to ensure compliance with the non-TSO function(s) performance data defined in paragraph **5.f.(1)** of this TSO.

(5) Test plans, and analysis, as appropriate, to verify that the performance of the hosting TSO article is not affected by the non-TSO function(s).

(6) Test plans and analysis as appropriate, to verify that the function and performance of the non-TSO function(s) as described in paragraph **5.f.(1)** of this TSO.

h. The quality manual required by 14 CFR 21.608, including functional test specifications. The quality system must ensure that you will detect any change to the approved design that could adversely affect compliance with the TSO MPS and reject the article accordingly. Applicants

who currently hold TSOAs must submit revisions to the existing quality manual as necessary (not required for LODA applicants).

> **i.** A description of your organization as required by 14 CFR 21.605.

> **j.** Material and process specifications list.

> **k.** A list of all drawings and processes (including revision level) that define the article's design.

> **l.** Manufacturer's TSO qualification report showing results of testing accomplished according to paragraph **3.c** of this TSO.

6. **MANUFACTURER DATA REQUIREMENTS.** Besides the data given directly to the responsible ACO, have the following technical data available for review by the responsible ACO:

> **Note:** The following data for a LODA applicant may be made available for review through its CAA. Refer to the applicable bilateral agreement for specific details regarding access to this data.

> **a.** Functional qualification specifications for qualifying each production article to ensure compliance with this TSO.

> **b.** Article calibration procedures.

> **c.** Schematic drawings.

> **d.** Wiring diagrams.

> **e.** Material and process specifications.

> **f.** The results of the environmental qualification tests conducted according to paragraph **3.d** of this TSO.

> **g.** If the article includes software, the appropriate documentation defined in RTCA/DO-178B or RTCA/DO-178C specified in paragraph **3.e** of this TSO, including all data supporting the applicable objectives in RTCA/DO-178B, Annex A, *Process Objectives and Outputs by Software Level.*

> **h.** If the article includes complex custom airborne electronic hardware, the appropriate hardware life-cycle data in combination with design assurance level, as defined in RTCA/DO-254, Appendix A, Table A-1. For simple custom airborne electronic hardware, the following data are required: test cases or procedures, test results, test coverage analysis, tool assessment and qualification data, and configuration management records, including problem reports.

i. If the article contains non-TSO function(s), you must also make items **6.a** through **6.h** of this TSO available as they pertain to the non-TSO function(s).

7. **FURNISHED DATA REQUIREMENTS.**

   a. When furnishing one or more articles manufactured under this TSO to one entity (such as an operator or repair station), provide one copy or online access to the data in paragraphs **5.a** (except the data in **5.a.(3)(d)**) and **5.b** of this TSO. Add any other data needed for the proper installation, certification, use, or continued compliance with the TSO, of the GNSS-aided inertial system.

   b. If the article declares and contains non-TSO function(s), include one copy of the data in paragraphs **5.f.(1)** through **5.f.(4)** of this TSO.

   c. If the article contains software and/or complex custom airborne electronic hardware, include one copy of the Open Problem Report (OPR) summary to type certification, supplemental type certification, or amended type certification design approval holders.

8. **HOW TO GET REFERENCED DOCUMENTS.**

   a. Order RTCA documents from RTCA, Inc., 1150 18th Street NW, Suite 910, Washington, DC 20036. Telephone: (202) 833-9339; fax: (202) 833-9434. You can also order copies online at www.rtca.org.

   b. Order copies of 14 CFR parts from the Superintendent of Documents, Government Publishing Office, P.O. Box 979050, St. Louis, MO 63197-9000. Telephone (202) 512-1800, fax (202) 512-2104. You can also order copies online at https://bookstore.gpo.gov , or find them online at any of the following Internet websites:

   (1) The FAA Dynamic Regulatory System (DRS) website at https://drs.faa.gov .

   (2) The U.S. Government's online Electronic Code of Federal Regulations website, https://www.ecfr.gov (select Title 14 - Aeronautics and Space).

   c. You can find a current list of TSOs and advisory circulars on the FAA RGL at https://rgl.faa.gov/ or the FAA DRS at https://drs.faa.gov/. You will also find the TSO Index of Articles at the same websites.

Patrick R. Mullen
Manager, Technical Innovation Policy Branch
Policy and Innovation Division
Aircraft Certification Service