U.S. Department
of Transportation
Federal Aviation Administration

Advisory Circular

Subject: AIRWORTHINESS APPROVAL OF ATTITUDE HEADING REFERENCE SYSTEM (AHRS) EQUIPMENT

Date: 4/7/14
Initiated By: AIR-130

AC No: 20-181

1. GENERAL INFORMATION.

1.1 Purpose. This advisory circular (AC) supplements existing airworthiness approval guidance for attitude heading reference system (AHRS) articles approved under technical standard order (TSO)-C201, *Attitude Heading Reference System*, or later revisions. TSO-C201 includes performance standards for non-gimbaled attitude, heading, and turn and slip systems. Appendix A contains a list of acronyms. Appendix B explains where to obtain reference documents. Refer to the latest revision of following list of ACs to complete the aircraft type specific primary or stand-by flight instrument airworthiness certification process:

a) AC 20-167, *Airworthiness Approval of Enhanced Vision Systems, Synthetic Vision Systems, Combined Vision Systems, and Enhanced Flight Vision Systems;*

b) AC 23-8, *Flight Test Guide for Certification of Part 23 Airplanes*;

c) AC 23-17, *Systems and Equipment Guide for Certification of Part 23 Airplane and Airships*;

d) AC 23.1309-1, *System Safety Analysis and Assessment for Part 23 Airplanes;*

e) AC 23.1311-1, *Installation of Electronic Displays in Part 23 Airplanes*;

f) AC 25-7, *Flight Test Guidance for Part 25 Airplanes*;

g) AC 25-11, *Electronic Flight Deck Displays;*

h) AC 25.1302-1, *Installed Systems and Equipment for Use by the Flightcrew*;

i) AC 25.1309-1, *System Design and Analysis*;

j) AC 25.1322-1, *Flightcrew Alerting*;

k) AC 25.1329-1, *Approval of Flight Guidance Systems*;

l) AC 27-1, *Certification of Normal Category Rotorcraft*; and

m) AC 29-2, *Certification of Transport Category Rotorcraft*.

1.2 Related CFR Regulations. Title 14 of the Code of Federal Regulations (14 CFR)

a) Part 23, §§ 23.1301, .1303, .1309, .1311, .1321, .1322, and .1327.

b) Part 25, §§ 25.1301, .1302, .1303, .1309, .1321, .1322, .1327, .1333, .1523 and Appendix D.

c) Part 27, §§ 27.1301, .1303, .1309, .1321, .1322, .1327, and Appendix B.

d) Part 29, §§ 29.1301, .1303, .1309, .1321, .1322, .1327, .1333, and Appendix B

1.3 Audience. This AC provides guidance for aircraft manufacturers, avionics manufacturers, installation shops, or other applicants seeking airworthiness approval under type certificate (TC), amended type certificate (ATC), supplemental type certificate (STC), or amended supplemental type certificate (ASTC) for TSO-C201 AHRS equipment.

1.4 Background. Manufacturers of attitude (pitch and roll), heading, turn and slip instruments have used TSO-C3, TSO-C4, TSO-C5, and TSO-C6 standards, dating back to 1958. More recently, AHRS based on micro-electro-mechanical systems (MEMS), ring-laser gyros (RLG), fiber optic gyros (FOG), and other technologies, are replacing conventional attitude and heading instruments to increase data performance reliability and accuracy. AHRS provides attitude and heading measurements with both static and dynamic accuracy comparable to traditional gimbaled systems. TSO-C201 does not cancel the older TSOs, but has been written for the non-gimbaled attitude and heading systems. When we published TSO-C201, many airworthiness approval policies existed for primary and stand-by flight instrumentation for each aircraft category type, as listed in Section 1.1. Although comprehensive, those policies do not address certain features included in TSO-C201 which require evaluation at installation. This AC's supplemental guidance addresses four specific areas:

a) Aiding Sources;

b) Degraded Mode;

c) TSO-C201 Categorizations and Applications; and,

d) Operational Considerations.

2. AHRS AIDING SOURCES. An AHRS aiding source is an internal or external system which provides additional sensor information to the core strap down attitude heading reference function. Global Navigation Satellite System (GNSS) and air data computer (ADC) aiding sources are commonly used to identify aircraft accelerations to reduce errors in the attitude function. Flux valves and magnetometers provide magnetic reference for heading functions, and numerous sources can be used for performance monitoring. Some aiding designs only supplement the AHRS functionality, and loss of aiding may only have limited effect on AHRS performance. On other designs, aiding may provide integral information where loss of the aiding source could lead to loss of AHRS functionality.

2.1 Internal Aiding Source Installations. Evaluate internal aiding sources as part of the overall article’s intended function evaluation. The internal aiding source should be qualified as part of the TSO-C201 design approval process. Ensure the aiding source provides the needed inputs with the appropriate accuracy, integrity, availability, and software level and electronic hardware design assurance for its intended use. For example, if the system was developed for a general aviation aircraft, but will be installed on a commuter aircraft, then the internal aiding source may need to be re-evaluated to ensure the appropriate compatibility with the aircraft's design architecture and its usage.

2.2 External Aiding Source Installations. This paragraph applies to external aiding sources not qualified as part of the TSO-C201 article's design approval.

2.2.1 External Aiding Source Performance. When the AHRS requires an external aiding source, ensure the aiding source installed in the aircraft provides the appropriate accuracy, integrity, availability, software level and electronic hardware design assurance.

2.2.2 External Aiding Source Annunciations. The applicant should determine how an external aiding source failure and annunciation affects AHRS performance. Conduct ground and flight testing as necessary to ensure appropriateness of the annunciation and pilot action. Any annunciations should be operationally relevant to minimize flightcrew workload; should be clear, unambiguous and timely; should only be indicated while the condition exists; should be consistently located in a specific area of the electronic display; and be located in the flightcrew's primary field of view when immediate flightcrew awareness is required. If testing is not possible, provide an analysis to ensure the appropriate action occurs with degradation or failure of the external aiding source. For example, if the AHRS disables the attitude output or switches modes when the aiding source fails, as part of the §§23.1309, 25.1309, 27.1309, or 29.1309 safety analysis, ensure the AHRS acts per design when the aiding source is intentionally disabled.

2.3 GNSS Aiding. GNSS refers to all types of positioning satellites which provide autonomous geo-spatial positioning. Common GNSS systems include, but are not limited to, the navigation signal timing and ranging (NAVSTAR) global positioning system (GPS) (U.S.), globalnaya navigatsionnaya sputnikovaya sistema (GLONASS) (Russian) and Galileo (Europe). GNSS velocity data can be used to compute longitudinal accelerations to help eliminate errors.

2.3.1 GNSS Qualification: When interfacing the AHRS to an external GNSS, ensure the external GNSS provides the needed inputs with the appropriate accuracy, integrity, availability, and software and hardware design assurance.

2.3.1.1 When interfacing with an external GNSS, ensure the external GNSS is qualified to the standards of any revision of:

a) TSO-C145d, *Airborne Navigation Sensors Using the Global Positioning System Augmented by the Satellite Based Augmentation System*;

b) TSO-C146d, *Stand-Alone Airborne Navigation Equipment Using the Global Positioning System Augmented by the Satellite Based Augmentation System*; or

c) TSO-C196b, *Airborne Supplemental Navigation Sensors for Global Positioning System Equipment using Aircraft-Based Augmentation*.

2.3.1.2 This AC does not address AHRS interface to TSO-C129a, *Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS),* since this TSO design standard may not provide sufficient availability in high interference environments.

2.3.2 GNSS Velocity Accuracy. If you use velocity accuracy from a GNSS position source, you should ensure the GNSS source data meets the minimum velocity accuracy requirement prescribed by the AHRS installation. GNSS position sources are not required to pass velocity accuracy tests to receive TSO authorization. One means to verify this performance is to ensure the GNSS source passes the velocity accuracy tests prescribed in AC 20-138D, *Airworthiness Approval of Positioning and Navigation Systems* or subsequent revisions. Typically, the GNSS source equipment manufacturer will accomplish these GNSS tests.

2.3.3 GNSS Faults. It is possible for some GNSS articles to output erroneous position and velocity data after the data is flagged invalid. Review the GNSS specifications to determine if this condition can occur, and if the AHRS detects the annunciated GNSS fault, the AHRS should cease using erroneous GNSS data. Analysis may be used as a means of compliance.

2.4 ADC Aiding. ADC information helps correct attitude pitch and bank angle errors. Ensure AHRS interfaces to an external ADC are qualified, such as any revision of TSO-C106, *Air Data Computer,* and provides the needed inputs with the appropriate accuracy, integrity, availability, and software and hardware design assurance.

2.5 Pitot Tube Airspeed Sensor Aiding. Pitot data information helps correct attitude pitch and bank angle error introduced by aircraft acceleration. It may directly interface with the AHRS. It is typically used for low velocity and non-complex velocity aircraft profiles. When interfacing the AHRS, ensure information is from a certified aircraft source (for example, TSO-C16, *Electrically Heated Pitot and Pitot Static Tubes)*, and provides the needed inputs with the appropriate accuracy, integrity, availability, and software and hardware design assurance. For more complex velocities, the interface with an ADC may be necessary. Also see Rotorcraft Considerations in Section 5.5

2.6 Magnetic Aiding. When interfacing a magnetic sensor, ensure the sensor's location is selected to avoid interference from the aircraft structure and systems. For interference associated with known aircraft magnetic anomalies, a compensator may be required to ensure accurate magnetic heading information. Ensure continuous operation of all heading instruments in all foreseeable operating conditions.

3. DEGRADED MODE. TSO-C201 provides allowances for an optional degraded mode to provide basic attitude performance when the AHRS has a partial failure or loses an aiding source. This mode is intended to allow an operator, even under instrument meteorological conditions (IMC), to maintain positive control of the aircraft. RTCA DO-334, *Minimum Operational Performance Standards (MOPS) for Solid-State Strapdown Attitude and Heading Reference Systems (AHRS)*, indicates the degraded mode can support cruise flight, climbs, descents, holding, and instrument approaches. However, the degraded mode may not be acceptable for autopilot operation or certain flight procedures. Evaluate the degraded mode during the airworthiness certification to ensure suitability of the design and operation. Refer to the AHRS manufacturer's installation manual for specific information regarding AHRS operating modes and equipment performance.

3.1 Degraded Mode Suitability. Determine if the degraded mode performance is acceptable for the intended aircraft and mode of operation in accordance with §§ 23.1301, 25.1301, 27.1301, or 29.1301. Degraded mode may be used on any aircraft type, for primary and secondary attitude sources; however, the TSO-C201 degraded mode is intended for smaller lower performance aircraft, such as part 23 and "non-appendix B" part 27 aircraft, which are typically certificated for one pilot and thus do not have two primary attitude systems installed. The degraded mode provides an alternative to a total loss of primary attitude in an aircraft with a single primary attitude system. In aircraft certificated for two pilot operations, use of the second primary attitude system is the preferred operating method when the first primary attitude system fails or degrades. Do not use degraded mode as a basis to reduce the required number of attitude instruments in an aircraft. If the AHRS installation manual requires flight envelope or time limitations for the degraded mode, insure those limitations are incorporated in the flight manual. The degraded mode is for abnormal conditions and should not be enabled while on the ground, either during initial system start-up or after engine start.

3.2 Degraded Mode Testing. There are two types of degraded mode triggers in AHRS equipment. One can be evaluated in-flight and the other cannot.

3.2.1 For initial AHRS installations, where the degraded mode can be disabled in-flight, such as circuit breaker pull, then the degraded mode should be evaluated through flight testing.

3.2.2 For initial AHRS installations, where the degraded mode cannot be evaluated in-flight, such as accelerometer degradation, then the applicant may use analysis or simulation. Testing should include pilot workload, acceptability of degraded mode through normal instrument flight rules (IFR) maneuvers, including climbs, descents, standard rate turns, and instrument approaches. Testing should also evaluate any effects on the flightcrew's ability to control the aircraft in flight.

3.2.3 Follow-on installations should demonstrate degraded mode performance for unique aircraft flight envelopes or operating conditions. Applicants using analysis to comply with §§23.1309, 25.1309, 27.1309, 29.1309 and 25.1523 and appendix D to part25 should ensure the degraded mode will safely perform its intended function and will not significantly affect pilot workload or aircraft operation. This analysis should also take into account any effects on the flightcrew's ability to control the aircraft in flight. In either case, the airplane/rotorcraft flight manual supplement (A/RFMS) should include the degraded mode performance characteristics and limitations.

3.3 Other System Interfaces. The degraded mode performance was defined to support primary attitude, heading, turn rate, and slip-skid indications. Evaluate the suitability of the degraded mode performance for other applications, as it may not be sufficient for higher performance applications, such as an autopilot, head-up display (HUD), or a synthetic vision system (SVS) display. If the analysis shows the degraded mode is not sufficient for other aircraft applications, ensure the degraded mode does not drive those particular aircraft applications.

3.4 Operating Instructions. Ensure the appropriate A/RFMS or applicable operating instructions are updated with a description of the degraded mode, the annunciations provided in degraded mode, and instructions for operating the aircraft. The operating instructions should also indicate which system applications will be lost (e.g., autopilot) and the limitations on types of maneuvers or operations which can be accomplished in degraded mode.

4. TSO-C201 CATEGORIZATIONS AND APPLICATIONS. AHRS, as a minimum, provides attitude information to pilots and/or aircraft. It may also provide heading, turn and slip and other information including acceleration, vertical speed, angular rates, lateral velocity, track data and position. TSO-C201 AHRS articles will typically be identified with a six digit category string. The first two letters define the attitude accuracy, the third and fourth letters define the heading accuracy and availability, and the fifth and sixth letters define the turn and slip capability. For example, the category string A4H4T3 denotes a dynamic attitude accuracy of 2.5º, dynamic heading accuracy of 6º with magnetic slaving, and turn rate and slip information is provided. It is possible the AHRS will have different category strings for different modes of operation. Refer to RTCA DO-334, section 2.2 for descriptions of the attitude, heading and turn and slip categories.

4.1 Attitude Category and Application. The attitude categories, A1 through A5, primarily pertain to the accuracy of the AHRS attitude output. All five categories are suitable to drive basic attitude indicators. Some applications, such as HUD and integration of autopilot, may require the higher accuracy categories. Refer to the interfacing systems attitude performance and airworthiness requirements and ensure your AHRS installation meets those requirements.

4.2 Heading Category and Application. There are eleven (11) potential heading categories for TSO-C201 articles, all of which articulate the accuracy of the heading information and its source. The H1 system uses a non-magnetic heading determination (e.g., a gyrocompassing system), the H2 through H5 systems are magnetically slaved (e.g., to a flux valve or magnetometer), and the H6 through H11 categories operate in directional gyro (DG) mode. All heading categories are suitable to drive basic heading indicators; however, categories H10 and H11 are for short-term use when magnetic anomalies exist. Some applications, such as enhanced flight vision systems (EFVS) and integration of the flight management system (FMS) may require higher accuracy categories. Refer to the interfacing systems heading performance and airworthiness requirements and ensure your AHRS installation meets those requirements.

4.3 Turn and Slip Category Application. The seven (7) turn and slip categories, T1 through T7 relate to the availability of turn, bank angle, slip and skid information. Refer to the interfacing systems of turn, bank angle, slip and skid performance and airworthiness requirements and ensure your installation meets those requirements.

4.4 Other AHRS Information for Other Applications. AHRS articles can also provide other features such as acceleration, vertical velocity, angular rates, magnetic wind direction, ground speed, magnetic track angle, and velocity. TSO-C201 does not provide performance requirements for this data, so ensure the AHRS data is appropriate for the intended applications.

5. OPERATIONAL CONSIDERATIONS.

5.1 Polar Operations. The polar region environment is defined as the area beginning at 5º to 30º latitude from the pole, depending on location, and extending to either the north or south pole. Anomalies with the earth’s magnetic field in the polar region can provide erroneous magnetic heading indications. Aircraft will typically use true heading information when flying in Polar Regions.

5.1.1 If the AHRS article is installed on aircraft intended to operate in the Polar Regions, the applicant should conduct a flight test demonstration to show proper operation for new AHRS articles or show previous successful flight test demonstration in an aircraft of like or similar installation. If the AHRS article was flight tested under the combined TSO-STC process, then the applicant should ensure the aircraft complies with the TSO article installation limitations and STC. Simulation testing and/or analysis are acceptable methods of compliance for follow-on installations.

5.1.2 Ensure a means is provided to identify when true heading is selected, such as information on the display or marking on a control panel.

5.1.3 Evaluate any automatic switching from magnetic to true heading or vice versa while entering and exiting Polar Regions. If the automatic switching between magnetic/true heading is not sufficiently self-evident, a suitable alerting or other annunciation should accompany the automatic switching.

5.1.4 Ensure the flight manual is updated with any unique procedures for landing, departing and flying the aircraft in Polar Regions.

5.1.5 If AHRS performance degrades in the polar region a visual indication should be provided to the flightcrew. An aural annunciation may be provided as well, depending on the specific system design and overall flight deck philosophy. Any annunciation should be clear, unambiguous, timely and attention getting; should only be indicated while the condition exists; should be consistently located in a specific area of the electronic display; and be located in the flight crew's primary field of view when immediate flightcrew awareness is required.

5.1.6 If the AHRS is not qualified to fly in the polar region, ensure the A/RFMS includes the appropriate limitations.

5.2 Areas of High Magnetic Disturbances. High magnetic disturbance areas can be caused by aircraft carriers, power lines, elevated helicopter-landing platforms, buried concrete steel reinforcing bars, ground equipment in close proximity to the aircraft, or a myriad of other conditions.

5.2.1 When an AHRS installation includes a flux valve or magnetometer, evaluate the functionalities below used to compensate for magnetic disturbance if they are included with the AHRS installation.

a) A DG mode which temporarily deactivates the flux valve or magnetometer;

b) A manual alignment mode allowing the pilot to manually align the affected system in an area away from the magnetic interference;

c) Rapid alignment capability once the magnetic interference is gone; or,

d) Automatic reversion. Automatic reversion may be required for those installations where Magnetic Resonance Imaging (MRI) systems and oil drilling platforms are normal landing areas to meet the applicable safety requirements. A timed, free gyro mode (DG or similar) may be acceptable. Ensure the system is available at landing and initial alignment or allows an alternate short-term un-slaved mode with a set-heading alignment capability. A ground or flight test will need to be conducted to evaluate the operational and performance capability.

5.2.2 Evaluate the installation of the flux valve or magnetometer in a representative environment to ensure magnetic disturbances are minimized.

5.2.3 Evaluate the effects of power-up, initial alignment, take offs, and landings from areas of high magnetic disturbance, when applicable.

5.2.4 Ensure instructions for the rapid alignment, manual and automatic reversion modes are added to the flight manual or pilot's operating handbook (POH).

5.2.5 Ensure instructions are added to the flight manual or POH identifying the potential for magnetic disturbances, when applicable.

5.3 Low Power Setting. Evaluate low power engine settings and possible associated low voltage conditions to determine if they affect AHRS performance. This evaluation is necessary because the FAA has identified concerns with low power settings causing fluctuations and erroneous orientations of heading and attitude displays. Ensure any resulting limitations are addressed in the A/RFMS or POH.

5.4 Wind Speeds. Some AHRS use wind calculations to correct the heading information. Depending on the magnetic variation and algorithms, some are more sensitive to changes in wind speed and direction than others. For aircraft using these corrections and flying in or around tropical areas or polar jet streams between 18,000 ft - 40,000 ft Mean Sea Level (MSL), ensure AHRS operability for these regimes. Also, evaluate these systems at lower aircraft speeds near stall with high headwind components. If testing with the unique wind dynamics is not possible, then the installer should provide some means of analysis to ensure the system is capable of operating with no adverse safety issues and provide any limitations in the A/RFMS. If the AHRS integrates with a windshear system, verify operational capability and limitations.

5.5 Rotorcraft Considerations. Some AHRS have a difficult time distinguishing between rotorcraft movement and the normal vibration spectrum of the platform to which it is mounted. Manufacturers of this technology have different approaches on how to “filter” these inputs so an accurate attitude solution can be derived. Other solutions are possible, but listed are a few accepted approaches.

a) One approach relies on surveying the vibration spectrum of the applicable installation area by conducting a series of flight test evaluations. Based on data obtained during these flight tests, adjustments are made to the software logic to allow the system to adequately distinguish valid from invalid inputs (i.e., those resulting from the rotorcraft’s normal vibration). This approach results in the need to create a specific part number for each installation.

b) Another approach relies on the use of GNSS and vector data to “stabilize and correct” the attitude solution.

d) A third approach relies on the use of pitot static information to help correct and stabilize the accelerometer derived attitude solution. AHRS designed with MEMS technology using TSO-C16 pitot/static corrections, may not be sufficient for rotorcraft AHRS applications. Operational rotorcraft maneuvers differ in performance from fixed wing aircraft, because they involve roll, pitch, and yaw rates coupled with translations in all directions to a stationary hover. For rotorcraft applications, ensure the pitot system, if used, provides the needed inputs with the appropriate accuracy, integrity, and availability. If necessary, demonstrate or evaluate the performance of the pitot system especially in low speeds, where pitot/static data may affect the reliability and integrity of the attitude solution. If it does affect the attitude solution, a limitation on the operation may apply.

James D. Seipel
Acting Manager, Design, Manufacturing, &
Airworthiness Division
Aircraft Certification Service

APPENDIX A. ACRONYMS.

AC	Advisory Circular
ADC	Air Data Computer
A/RFMS	Airplane/Rotorcraft Flight Manual Supplement
AHRS	Attitude Heading Reference System
ASTC	Amended Supplemental Type Certificate
ATC	Amended Type Certificate
CFR	Code of Federal Regulations
DG	Directional Gyroscope
EFVS	Enhanced Flight Vision System
FMS	Flight Management System
GLONASS	globalnaya navigatsionnaya sputnikovaya sistema - Global Navigation Satellite System operated by the Russian Aerospace Defence Forces
GNSS	Global Navigation Satellite System
GPS	Global Positioning System operated by the United States Air Force
HUD	Head-Up Display
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
MOPS	Minimum Operational Performance Standards
MRI	Magnetic Resonance Imaging
MSL	Mean Sea Level
NAVSTAR	Navigation Signal Timing and Ranging
POH	Pilot Operating Handbook
STC	Supplemental Type Certificate
SVS	Synthetic Vision System
TC	Type Certificate
TSO	Technical Standard Order

APPENDIX B. WHERE TO GET REFRENCED DOCUMENTS.

1. Order RTCA documents from RTCA Inc., 1150 18th Street NW, Suite 910, Washington, D.C. 20036. Telephone (202) 833 9339, fax (202) 833-9434. Order copies online at **www.rtca.org**.

2. Order copies of 14 CFR parts 23, 25, 27, 29, 91, 135, 121 and 45 from the Superintendent of Documents, Government Printing Office, P.O. Box 979050, St. Louis, MO 63197. Telephone (202) 512-1800, fax (202) 512-2250. Order copies online at **www.access.gpo.gov**. Select “Access,” then “Online Bookstore.” Select “Aviation,” then “Code of Federal Regulations.”

3. A current list of TSOs and ACs can be found on the FAA Internet website Regulatory and Guidance Library at **http://rgl.faa.gov/**. TSO Index of Articles can be found at the same site.

APPENDIX C. ADVISORY CIRCULAR FEEDBACK INFORMATION

If you have comments or recommendations for improving this advisory circular (AC), or suggestions for new items or subjects to be added, or if you find an error, you may let us know about by using this page as a template and 1) emailing to 9-AWA-AVS-AIR500-Coord@faa.gov or 2) faxing it to the attention of the AIR Directives Management Officer at 202-267-3983.

Subject: (insert AC number and title) Date: (insert date)

Comment/Recommendation/Error: (Please fill out all that apply)

An error has been noted:

Paragraph ____________________

Page ______

Type of error (check all that apply): Editorial:----- Procedural-----

Conceptual____

Description/Comments: ____
____
____

Recommend paragraph ______ on page ______ be changed as follows:
(attach separate sheets if necessary)

____

In a future change to this advisory circular, please include coverage on the following subject: (briefly describe what you want added attaching separate sheets if necessary)

____

Name: __________________________