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Minimum Operational Performance Standards (MOPS) for Strapdown Attitude and Heading Reference Systems (AHRS)

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Prepared by: SC-219
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FOREWORD

This report was prepared by Special Committee 219 (SC-219) and approved by the RTCA Program Management Committee (PMC) on March 21, 2012.

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- analyzing and recommending solutions to the system technical issues that aviation faces as it continues to pursue increased safety, system capacity and efficiency;
- developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of minimum operational performance standards for electronic systems and equipment that support aviation; and
- assisting in developing the appropriate technical material upon which positions for the International Civil Aviation Organization and the International Telecommunication Union and other appropriate international organizations can be based.

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1.0 PURPOSE AND SCOPE

1.1 Introduction

This document contains minimum operational performance standards for Strapdown Attitude and Heading Reference Systems (AHRS). This document is intended for equipment that does not use gimbaled sensors. This document is intended for equipment that outputs attitude (pitch and roll). It also addresses functions of heading, turn, slip, and the display of this information. This document does not specify the format of data outputs. These standards specify equipment characteristics that should be useful to designers, manufacturers, installers and users of the equipment.

Compliance with these standards is recommended as one means of assuring that the equipment will perform its intended function(s) satisfactorily under all conditions normally encountered in routine aeronautical operation. Any regulatory application of this document is the sole responsibility of appropriate governmental agencies.

Section 1.0 of this document provides information needed to understand the rationale for equipment characteristics and requirements stated in the remaining sections. It describes typical equipment applications and operation goals, as envisioned by the members of Special Committee 219, and establishes the basis for the standards stated in Sections 2.0 through 3.0. Definitions and assumptions essential to proper understanding of this document are also provided in this section.

Section 2.0 contains the minimum performance standards for the equipment. These standards specify the required performance under standard and environmental conditions. Also included are recommended laboratory and manufacturer flight evaluation procedures necessary to demonstrate equipment compliance with the stated minimum requirements.

Section 3.0 describes the performance required of the installed equipment. Tests for the installed equipment are included when performance cannot be adequately determined through laboratory testing.

Appendix A discusses demonstrating equipment performance using simulation in lieu of flight evaluation.

This document considers an equipment configuration consisting of an Attitude and Heading Reference Unit (AHRU) with complementary peripheral equipment specified by the AHRS manufacturer.

Operation performance standards for functions or components that refer to equipment capabilities that exceed the stated minimum requirements are identified as optional features.

The word “equipment” as used in this document includes all components and units necessary for the system to properly perform its intended function(s). For example, the “equipment” may include an AHRU, an associated mounting tray, and a magnetic sensing unit. In the case of this example, all of the foregoing components and units comprise the “equipment.” It should not be inferred from this example that each AHRS equipment design will necessarily include all of the foregoing components or units. This will depend on the specific design chosen by the manufacturer.

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1.2 System Overview

As shown in Figure 1-1, the AHRS system may consist of:

1.2.1 Attitude and Heading Reference Unit (AHRU)

The AHRU includes:

- Inertial sensing unit which includes a series of angular rate sensors, accelerometers and/or inclinometers.
- Electronics package that processes the sensor data into a usable output format.
- Integral power supply assembly.
- Mechanical housing, in which the above components are embedded, which is "strapped down" (not gimbaled) to an aircraft frame.

1.2.2 Magnetic Sensing Unit (MSU)

1.2.3 Option(s):

- Mounting tray to assist in precision alignment to aircraft axis
- Memory device(s) which preserve critical alignment data, as well as other information
- Installation hardware, connectors, fasteners, etc.

1.2.4 Complementary aiding devices:

- Air data
- GPS
- Etc.

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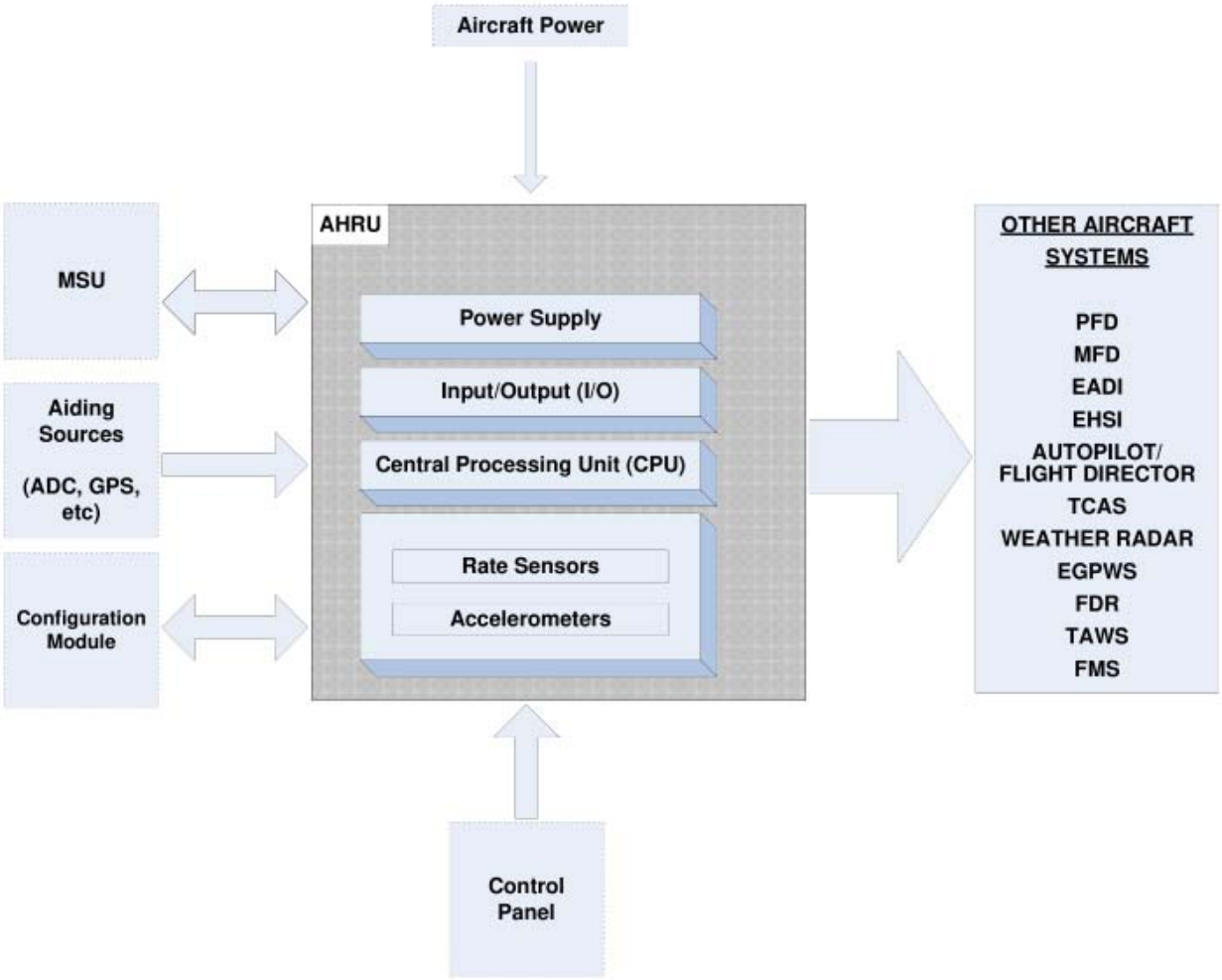

Figure 1-1 AHRS Diagram Example

1.3 Operational Applications(s)

One or more AHRS may be used on an aircraft to supply attitude and heading information to the pilots of the aircraft to aid them with the control and guidance of the aircraft.

The AHRS may be used to supply attitude and heading, and other information such as angular rates and accelerations to autopilots or stability augmentation equipment on the aircraft.

Information from the AHRS may be used by other equipment on the aircraft to control their functions. For example, attitude and heading information may be used in an antenna pointing system.

This document does not define the intended function for the AHRS, and instead requires that the AHRS manufacturer provide performance data to support installation. Thus, the

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onus is placed on the installer to define the intended use of AHRS, determine appropriate performance requirements, and establish that the AHRS complies with those requirements. For example, instead of defining attitude accuracy classes based on functions such as primary attitude indicator, secondary attitude indicator, or attitude stabilization device, the document defines five attitude accuracy categories with no definition of the intended use of each of these accuracy levels. As a result, the installation of AHRS will require installation-specific certification and review for each project.

1.4 Required Functions

1.4.1 Attitude

The attitude from the AHRS is the common aircraft pitch and roll information needed to control the aircraft. For a more thorough understanding of the required availability and integrity of this function, consult with the aircraft Functional Hazard Assessment (FHA) for the intended application.

The attitude requirements are found in Section 2.2.2.

1.5 Optional Functions

1.5.1 Heading

Heading from the AHRS, magnetic or non-magnetic, is the common information used by pilots to determine the direction the aircraft is pointing.

The heading requirements are found in Section 2.2.3.

1.5.2 Turn and Slip

The turn and slip functions provide the rate and the coordination (slip or skid) of the turn. The AHRS turn and slip performance requirements are provided in Section 2.2.5.

1.5.3 Other Functions

The AHRS may also provide angular rates and linear accelerations, but these functions are not addressed in this document.

1.6 Operational Goals

The goal of the AHRS is to provide attitude, and optionally heading, turn, standard turn bank angle, slip, angular rate, acceleration, and other information. This information is used to enable a pilot, autopilot or other equipment in the aircraft to control and guide the aircraft in a safe manner. The accuracy requirements of the outputs depend on the application. Different accuracy categories have been specified to help in distinguishing AHRS of different capabilities.

Some equipment may be capable of generating heading without a Magnetic Sensor Unit (MSU). Some equipment may only be capable of providing magnetic heading when operating with an MSU. Categories for these and other capabilities are specified.

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1.7 AHRS Categories

1.7.1 Modes of Operation

An AHRS system may have multiple modes of operation. The equipment will be categorized in accordance with the functions and accuracy that it provides in each of these modes. The manufacturer will declare the performance category for each operating mode (except degraded modes) using a six-character-alphanumeric string as denoted in Table 2-1, Table 2-2, and Table 2-3. Requirements for degraded modes are specified in Section 2.2.4.

1.7.2 Category Strings

The first two characters of a category string are reserved for the mode's attitude performance. The third and fourth characters of a category string are reserved for the mode's heading performance and availability. The fifth and sixth characters of a category string are reserved for the mode's turn and slip availability. An AHRS will have one or more category strings, each associated with an operating mode. An example of an AHRS with four available operating modes is shown in Table 1-1. Each operating mode has its own category string.

Table 1-1 AHRS Category String Examples

Category String			Mode Description
Attitude Category	Heading Category	Turn and Slip Category	
A3	H3	T3	Mode 1: Attitude static accuracy of 0.5° is provided. Magnetic slaving is used to provide 1.5° static heading accuracy. Both turn rate and slip outputs are provided.
A3	H8	T3	Mode 2: Attitude static accuracy of 0.5° is provided. DG mode is provided with 5° drift in one hour. Both turn rate and slip outputs are provided.
A4	H4	T3	Mode 3: Attitude static accuracy of 1.0° is provided. Magnetic slaving is used to provide 2.0° static heading accuracy. Both turn rate and slip outputs are provided.
A4	HX	TX	Mode 4: Attitude static accuracy of 1.0° is provided. Heading, turn rate, standard turn bank angle, and slip outputs are not provided.

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1.8 Test Procedures

The test procedures specified in this document are intended to be used as one means of demonstrating compliance with the applicable performance requirements. Although specific test procedures are cited, it is recognized that other equivalent methods may be acceptable. Alternate procedures may be used if they provide at least equivalent information. In such cases, the procedures cited herein should be used as one criterion in evaluating the acceptability of the alternate procedures.

The order of tests specified suggests that the equipment be subjected to a succession of tests as it moves from design, and design qualification, into operational use. For example, compliance with the requirements of Section 2.0 will have been demonstrated as a precondition to satisfactory completion of the installed system tests of Section 3.0.

1. Environmental Tests

Environmental test requirements are specified in Section 2.3. The procedures and their associated requirements are intended to provide a laboratory means of determining the electrical and mechanical performance of the equipment under environmental conditions expected to be encountered in actual operations.

Unless otherwise specified, the environmental conditions and test procedures contained in RTCA/DO-160G (or other version acceptable to the certification authority), *Environmental Conditions and Test Procedures for Airborne Equipment*, will be used to demonstrate equipment compliance.

2. Laboratory Tests and Flight Evaluations

Laboratory test and flight evaluation procedures are specified in Section 2.4. These procedures provide a means of demonstrating compliance with the requirements of Section 2.2. Results may be used by equipment manufacturers as design guidance, for monitoring manufacturing compliance and, in certain cases, for obtaining formal approval of equipment design.

3. Installed Equipment Tests

The installed equipment test procedures and their associated limits are specified in Section 3.0. Installed tests are normally performed under two conditions:

a. With the aircraft on the ground and using simulated or operational system inputs.

b. With the aircraft in flight using operational system inputs appropriate to the equipment under test.

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1.9 Definitions of Terms and Acronyms

The following terms are used in this document:

Term	Definition
Accelerometer	A sensor used to measure acceleration. The inertial acceleration sensed includes both acceleration due to changes in velocity, as well as the acceleration induced by gravity.
AHRS	Attitude and Heading Reference System. Equipment on an aircraft that provides attitude and optionally heading information to other systems on the aircraft.
AHRU	Attitude and Heading Reference Unit. Portion of the AHRS containing the inertial sensors.
Air Data	Source of information derived from barometric source(s) such as air speed, altitude and vertical speed.
Angular Rates	Angular rotation rates. May be measured relative to the aircraft body axes (body rates) or a rate of change of Euler angles.
Annunciation	An output or indication of a specific event intended for, but not limited to, presentation to the pilot, provided for maintenance purposes, or flight control purposes.
Attitude	Orientation of the aircraft. Measured by Euler angles relative to local level. In this document attitude refers to pitch and roll angles only.
Body Accelerations	Linear accelerations expressed in the aircraft body axes.
Body Axes	Body axes are the mutually orthogonal aircraft longitudinal, lateral and vertical axes.
Body Rates	Angular rotation rates expressed in the body axes of the aircraft.
Category	Level of attitude, heading, turn and slip performance and characteristics that are denoted by alphanumeric characters.
DG Mode	Directional Gyro Mode. A mode where valid heading output is determined through the use of inertial sensors (i.e., angular rate sensors and accelerometers) without aiding from a magnetic sensing unit. The pilot is provided a means to activate the DG mode, and set or adjust the heading value. For DG mode considerations, see Section 2.2.3.4.
Dynamic Condition	This term is defined by the test conditions specified within this document.

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Term	Definition
Euler Angles	Euler angles are three angles introduced by Leonhard Euler to describe the orientation of a rigid body such as an aircraft. Euler angles define the attitude and heading of an aircraft in terms of a series of three rotations from a north-pointing local level coordinate system to the aircraft body coordinate system. The rotations consist of: heading rotation about the normal (down) axis; pitch rotation about the lateral axis; and roll rotation about the longitudinal axis.
Euler Rates	Rate of change of the pitch, roll, and heading Euler angles.
External Aiding	Any source of information provided from a system external to the AHRS inertial system or function. Potential external aiding sources include air data, MSU data and GPS data.
g	The local acceleration due to local gravity and Earth's centripetal acceleration, commonly used as a unit of acceleration measurement.
GPS	Global Positioning System. In this document, GPS is often utilized as an example of an external source of navigation information. In most cases, the examples would apply to any GNSS (Global Navigation Satellite System) or other satellite-based aid used to augment AHRS performance.
Grid	A method of navigation in polar regions frequently used by the military.
Gyrocompassing	The function of determining true heading based on measurements of the direction of the rotation rate of the Earth at the current position. At high latitudes gyrocompassing becomes less accurate as the horizontal component of Earth's rotation rate is reduced.
Gyro	Gyroscope. A device for maintaining or measuring changes to its orientation in inertial space. A strapdown AHRS includes strapdown gyros that measure angular rotation rates about three axes. Strapdown gyros are also called rotation rate sensors. In this document the term gyro refers to any sensor regardless of the sensing technology, not just spinning-mass instruments.
Heading	The relative angle between the projection of the longitudinal axis of the aircraft onto the local level frame and some definition of North, for example either True North or Magnetic North. Heading is positive for angles clockwise from (east of) North.
Heading Drift	A changing heading error, which typically occurs when an AHRS is in DG mode.
ILS	Instrument Landing System
IMC	Instrument meteorological conditions.

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Term	Definition
IFR	Instrument flight rules.
Inertial System	A system that produces inertial measurements such as acceleration or rotation rate.
Local Level	A reference plane that is level with respect to the gravity vector at the current fixed position. This is the same level reference produced by an inclinometer or bubble level if stationary at the current position.
Magnetic Flux Detector or Flux Valve	A device used to measure the magnetic field or flux. Flux detectors used with AHRS are often mechanically gimbaled devices which measure the local horizontal magnetic field.
Magnetic Heading	Aircraft heading defined relative to Magnetic North.
Magnetic North	The direction pointed to by an ideal, level magnetic compass in the current location. The direction is defined by the direction of the horizontal (level) component of the Earth's magnetic field at the current location. This can be significantly different than True North.
Magnetic Sensor Unit (MSU)	In this document "MSU" is any device used to sense the local magnetic field such as a magnetometer, a magnetic flux detector, or magnetic flux valve.
Magnetic Slaving	Correction of the AHRS heading estimate using measurements of the Earth's magnetic field.
Magnetic Variation	Also called "magnetic declination", is the angle between magnetic north and true north at the current location. Declination is considered positive when magnetic north is east of true north and negative when west.
Mode	A functional state of the AHRS. For example, a mode could be a state where the AHRS is fully aided and provides its highest categories of performance. Any condition which results in a change in performance category triggers a change of mode. A sustained loss of a type of aiding data will typically cause the AHRS to change modes.
Must	The term "must" in this document is used for items which are requirements, but are invoked by a "shall" statement either in this document or some other document (e.g. a regulation).
Pitch	The angle between local level and the longitudinal axis of the aircraft. It is defined as positive for the nose of the aircraft pointing above local level.
RMS	The square root of the mean of the squares of the original data.

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Term	Definition
Roll	The angle of rotation about the longitudinal axis of the aircraft. Roll is defined as 0° when the aircraft is upright and the lateral axis is in the level plane. It is defined as positive for the right wing of the aircraft below the left wing.
Shall	The term "shall" in this document is used to indicate requirements, for items which are requirements, as opposed to "should" items which are recommendations.
Should	The term "should" in this document is used to denote recommendations or guidelines that do not constitute a requirement.
Standard Turn Bank Angle	A bank angle calculated such that if the aircraft is flown in a constant altitude coordinated turn at the present true airspeed and the said calculated bank angle, a standard heading rate of change results. The standard heading rate of change is 180 deg/min by default, but may be selected to be 90 deg/min for higher classes of aircraft.
Static Condition	This term is defined by the test conditions specified within this document. Static condition is not necessarily equivalent to straight and level flight.
Strapdown	Refers to a system that uses direct mounting of sensors (without gimbals) to a vehicle.
Transport Rate	An apparent angular rate of the aircraft due to motion over the surface of the earth.
True Heading	Aircraft heading defined relative to True North.
True North	The direction along the earth's surface toward the geographic North Pole.
Truth Reference	An AHRS or navigation system of which heading and attitude outputs are assessed to be more accurate than the unit being tested by a least a factor of two.
Vertical Axis	Unless otherwise specified, refers to the local Earth vertical.
Vs	Stalling speed or minimum steady flight speed at which the airplane is controllable
Vso	Stalling speed or minimum steady flight speed in the landing configuration.

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2.0 EQUIPMENT PERFORMANCE REQUIREMENTS AND TEST PROCEDURES

2.1 General Requirements

Section 2.1 contains general requirements. There are no associated tests in Section 2.4. Verify these requirements by analysis, inspection, tests, or a combination thereof.

2.1.1 Airworthiness

In the design and manufacture of the equipment, the manufacturer **shall** provide for installation so as not to impair the airworthiness of the aircraft.

2.1.2 Intended Function

The equipment **shall** perform its intended function(s), as defined by the manufacturer, and its proper use **shall** not create a hazard to other users of the National Airspace System.

2.1.3 Fire Protection

All materials used **shall** be self-extinguishing except for small parts (such as knobs, fasteners, seals, grommets and small electrical parts) that would not contribute significantly to the propagation of a fire.

2.1.4 Operation of Controls

The equipment **shall** be designed so that controls intended for use during flight cannot be operated in any position, combination or sequence which would result in a condition detrimental to the reliability of the equipment or operation of the aircraft.

2.1.5 Accessibility of Controls

Controls which do not require adjustment during flight **shall** not be readily accessible to flight personnel.

2.1.6 Effects of Test

The equipment **shall** be designed so that the application of specified test procedures **shall** not be detrimental to equipment performance following the application of the tests, except as specifically allowed.

2.1.7 Design Assurance

The hardware and software **shall** be designed and developed such that the probability of providing hazardously misleading information and the probability of loss of function are acceptable based on the overall allocated attitude and heading reference system integrity and continuity requirements, respectively. These requirements apply when the equipment is in its installed configuration for the most stringent intended application. To demonstrate compliance, it will be necessary to conduct a safety assessment to evaluate the system's implementation against known failure conditions. Different design assurance levels for the various AHRS functions may apply.

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The manufacturer **shall** declare in the installation manual the hardware and software design assurance levels of the equipment.

To support installation approval, the manufacturer should supply information regarding failure modes and failure probabilities for loss of function, malfunction, annunciated misleading data, and un-annunciated misleading data.

The following two paragraphs define an acceptable means of compliance based on the hazard classification for complex electronic hardware and software.

2.1.7.1 Complex Electronic Hardware Compliance

An acceptable means of compliance is to show that the hardware design assurance level is commensurate with the hazard classification. For complex custom airborne electronic hardware, RTCA/DO-254 (or other version acceptable to the certification authority), Design Assurance Guidance for Airborne Electronic Hardware, provides an acceptable means of compliance.

2.1.7.2 Software Compliance

An acceptable means of compliance is to show that the software design assurance level is commensurate with the hazard classification. For software, RTCA/DO-178B (or other version acceptable to the certification authority), Software Considerations in Airborne Systems and Equipment Certification, provides an acceptable means for showing that software complies with applicable airworthiness requirements.

2.1.8 Multiple Operating Modes and Performance Categories

If the AHRS implements multiple operating modes (for example, operation with or without an aiding source) the manufacturer **shall** declare the performance category of all modes of operation except any degraded modes whose requirements are defined in Section 2.2.4.

Inclusion of degraded modes is not required. A manufacturer may invalidate the data in lieu of providing a degraded mode capability.

System transition from any mode to another **shall** be free from unacceptable transients, discontinuities, and adverse interactions with other aircraft systems.

The manufacturer **shall** conduct testing and/or analysis of each mode to ensure compliance with the performance category standards or degraded mode standard in Section 2.2.4. The installation manual **shall** clearly identify all operating modes and associated equipment performance.

The following paragraph describes an acceptable method for showing compliance with Section 2.3, Section 2.4.4 or 2.4.8 in place of repeating the test in each mode.

Verify performance to a specific environmental test or flight evaluation in the mode where the equipment is in the most stringent category being certified. While performing the test or evaluation, record all of the equipment's outputs and sensor data. Rerun the test or evaluation in the same mode using the equipment's software and the recorded sensor data. To validate replayed software, verify the results from the replayed data matches the recorded resulting data within the expected processing precision. Next, run

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the equipment's software in the other modes being certified and verify the outputs comply with its category requirements for the mode being tested or evaluated.

2.1.9 Range of Operation

The equipment **shall** be designed to operate and output pitch, roll and heading data through all attitudes and headings.

Operational limits on the angular rates, linear accelerations or other parameters of the equipment **shall** be specified by the manufacturer. The AHRS **shall** be designed to continuously output data without invalidating the outputs up to at least ± 70 deg/sec angular rates in each axis, at least ± 2 g body axis longitudinal and lateral acceleration, and at least ± 4 g body axis normal acceleration.

Note: The foregoing functional requirement does not impose a performance requirement over the operating range of the equipment. Performance requirements are specified in Section 2.2.

2.1.10 Magnetic Field Strength

Unless otherwise specified, the tests within this standard using MSU input should be made with a total magnetic field strength between 0.20 Gauss and 0.55 Gauss, and with a magnetic field inclination within either the range of +30° to +70° or the range of -30° to -70°. If testing is done at different magnetic field strengths or inclinations, the manufacturer **shall** test or perform analysis to show the equipment will meet the requirements for at least one magnetic field condition having characteristics as specified above.

If the test equipment causes magnetic field disturbances that would interfere with obtaining accurate test results, then the magnetic field measurements may be simulated and provided to the equipment under test via a digital communication protocol identical to that used in an actual installed instrument. Such simulated magnetic measurements must properly account for potential errors in the MSU, changes in the measurements due to any motion prescribed by the test, and the worst-case magnetic measurement errors anticipated in an actual vehicle installation of the equipment.

2.1.11 Geographical Restrictions

The manufacturer **shall** specify the geographical limits over which the equipment does not meet the performance requirements of this document. For example, outside of the manufacturer's specified range of latitudes, the heading accuracy of a magnetically slaved AHRS is unlikely to meet its specified performance.

2.2 Equipment Performance - Standard Conditions

2.2.1 General Requirements

2.2.1.1 Conditions

The test conditions are established in Section 2.4.1.1.

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2.2.1.2 Stationary Starting

The equipment **shall** start and provide valid attitude outputs within 3 minutes after normal rated power is applied.

If applicable, the equipment **shall** start and provide valid turn and slip outputs within 3 minutes after normal rated power is applied.

For heading category H1, the equipment **shall** start and provide valid heading output within 10 minutes after normal rated power is applied, when operating in latitudes less than ± 60°. The manufacturer **shall** specify the alignment time above ± 60°.

For heading categories H2 through H5, the equipment **shall** start and provide valid heading output within 3 minutes after normal rated power is applied.

For heading categories H6 through H11 the availability of DG mode heading **shall** be within 5 minutes of startup.

Note:

1. *Minor aircraft motion resulting from normal wind buffet and servicing of the aircraft, including loading fuel, cargo and passengers, should not significantly influence the ability of the equipment to align or the resulting system accuracy.*
2. *Any constraints or limitations associated with equipment alignment should be documented by the equipment manufacturer. Examples of such limitations include required availability of aiding inputs or other conditions under which alignment is not possible or requires additional time.*

2.2.1.3 In-Flight or In-Motion Alignment

In-flight or in-motion alignment should be supported. When supported, restrictions on the conditions where in-motion alignment is available and the subsequent performance that is provided **shall** be specified.

2.2.1.4 Annunciations

An appropriate annunciation per the definition in Section 1.9 **shall** be provided when the AHRS detects conditions where it does not meet the highest declared performance category.

In addition, each of the following conditions **shall** be adequately annunciated:

1. Loss of attitude, heading, or turn and slip
2. Operation in a DG mode if a non-DG mode is provided
3. Operation in degraded mode

Note: These annunciations may not be required to be displayed to the pilot depending on the intended function of the AHRS. However when data is provided to the pilot for control of the aircraft, the annunciation is required.

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2.2.1.5 Output Characteristics

The minimum characteristics may or may not be sufficient for all installations. For example, more stringent requirements may be needed when the AHRS is used to drive an autopilot.

2.2.1.5.1 Output Resolution

The resolution of the pitch, roll, and if provided, heading, turn, standard turn bank angle, and slip **shall** be defined by the manufacturer.

2.2.1.5.2 Update Rate

The update rate of the pitch, roll, and if provided, heading, turn, standard turn bank angle, and slip **shall** be a minimum of 10 hertz.

2.2.1.5.3 Latency

The latency of the pitch, roll, and if provided, heading, turn, standard turn bank angle, and slip, which is the interval between the motion and the time a measurement is output, **shall** be a maximum of 200 msec. This does not include filter phase delay.

2.2.1.5.4 Filtering

The filtering of the pitch, roll, heading, and other output parameters, **shall** be defined by the manufacturer. The noise content and resulting phase delay should be considered.

2.2.1.5.5 Range

The equipment **shall** be designed to operate through all attitudes and headings. During and subsequent to rotation of the equipment through pitch angles greater than 89° or less than -89° the equipment **shall** continue to function correctly in all regards without need for re-initialization, caging or resetting of the equipment.

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2.2.2 Attitude Performance Requirements

2.2.2.1 Equipment Categories

The equipment **shall** be categorized according to attitude accuracy performance as described in Table 2-1.

Table 2-1 Attitude Performance Requirements

Category	Attitude Accuracy	
	Static Conditions	**Dynamic and Flight Conditions**
A1	0.1°	0.2°
A2	0.2°	0.5°
A3	0.5°	1.0°
A4	1.0°	2.5°
A5	1.0°	2.5° (see note 2)

Note:

1. *All values are either evaluated as maximum (i.e., "not to exceed") or 2-RMS values as specified in Sections 2.3 and 2.4.*
2. *Category A5 equipment flight evaluation pass/fail verification is determined by visual comparison with a truth reference, rather than through data collection with a truth reference and statistical analysis of results (2.5° is a maximum allowable error during flight evaluations).*

2.2.2.2 Static Accuracy

The equipment **shall** meet the attitude static accuracy limits as defined in Table 2-1 and tested in accordance with Sections 2.3 and 2.4.

2.2.2.3 Dynamic Accuracy

The equipment **shall** meet the attitude dynamic and flight accuracy limits as defined in Table 2-1 and tested in accordance with Sections 2.3 and 2.4.

2.2.3 Heading Performance Requirements

2.2.3.1 Equipment Categories

The equipment **shall** be categorized according to the source of heading information as described in Table 2-2.

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Table 2-2 Heading Performance Requirements

Category	Source of Heading Information	Heading Accuracy	
		Static Conditions	**Dynamic and Flight Conditions**
H1	Non-Magnetic Heading Determination (i.e., Gyrocompassing system)	1.0°	2.0°
H2	Magnetic Slaving	1.0°	2.0°
H3	Magnetic Slaving	1.5°	4.0°
H4	Magnetic Slaving	2.0°	6.0°
H5	Magnetic Slaving	2.0°	6.0° (10° during maneuvers up to ±30° roll. No requirement outside ±30° roll.) (see Note 2)
		Heading Drift Accuracy, Under Static and Dynamic and Flight Conditions	
H6	DG Mode	2° in 6 hours	
H7	DG Mode	2° in 3 hours	
H8	DG Mode	5° in 1 hour	
H9	DG Mode	30° in 1 hour	
H10	DG Mode	5° in 10 minutes	
H11	DG Mode	10° in 10 minutes	
HX	No heading capability	n/a	

Note:

1. *Categories H1 through H4 are evaluated as maximum (i.e., "not to exceed") or 2-RMS values as specified in Sections 2.3 and 2.4.*
2. *This equipment flight evaluation pass/fail verification is determined by visual comparison with a truth reference, rather than through data collection with a truth reference and statistical analysis of results (6.0° is a max error 2 minutes after resuming steady flight after the maneuver).*

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3. *For category H1, if a magnetic variation model is used to convert from true heading to magnetic heading, the error inherent in the model is not included in the table values. This also applies to units that utilize GPS as an aiding sensor to correct heading error.*
4. *For category H1, the heading accuracy requirement is applicable at latitudes lower than ± 60°.*
5. *Categories H10 and H11 are generally intended for relatively short term use when the magnetic slaving source could be disturbed (e.g.: during take-off or landing on oil drilling platforms).*

2.2.3.2 Static Accuracy

The equipment **shall** meet the heading accuracy limits as defined in Table 2-2 and tested in accordance with Sections 2.3 and 2.4.

2.2.3.3 Dynamic Accuracy

The equipment **shall** meet the heading dynamic and flight accuracy limits as defined in Table 2-2 and tested in accordance with Sections 2.3 and 2.4.

2.2.3.4 DG Mode Considerations

A Directional Gyro (DG) mode **shall** include a means for the operator to activate the DG mode and manually adjust the heading. A valid heading output is determined through the use of inertial sensors (i.e., angular rate sensors and accelerometers) without aiding from a magnetic sensing unit. The AHRS may automatically activate the DG mode.

When operating in DG mode, the AHRS should not compensate for transport rate. For example, when crossing over or near the Earth's poles with a straight-line ground track, heading should not reverse direction.

Note:

1. *Short-term cutoff logic which ignores magnetic information during brief periods (e.g., during turns) does not constitute a DG mode. Likewise, automatic modes which ignore magnetic information for indefinite periods of time, and during which heading is appropriately invalidated, also does not constitute a DG mode.*
2. *Strapdown AHRS systems intended for use in a rotorcraft may be required to provide either (a) a DG mode as described above, or (b) provide an alternate means to address departure from landing platforms with significant magnetic disturbance. If an alternate means is provided, it may be desirable to include a means of setting a pilot-selectable initial heading, followed by a time-limited period of non-magnetic operation sufficient to complete take-off from the landing platform or another automatic means of re-selecting magnetically-slaved heading.*

2.2.4 Degraded Mode Performance Requirements

The intended function of a degraded mode (if provided) is to provide basic attitude performance, despite one or more AHRS failures. A degraded mode is intended to allow

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a pilot to maintain positive aircraft control while maneuvering under IMC, including IFR en route operations, climbs, descents, holds, fly an instrument approach to minimums, and return the aircraft back to level following an upset. Precision flying is secondary. A degraded mode may not be sufficient for all installations. Issues such as suitability and crew workload impacts are evaluated at time of installation. Specifically, degraded mode requirements do not consider autopilot input or ILS approach requirements. Degraded mode accuracies are stated as maximum, not-to-exceed errors.

2.2.4.1 Incorporation of Degraded Mode

The AHRS may provide a degraded mode of operation. A degraded mode **shall** only be permissible if the equipment provides at least one operational mode with a declared category of performance.

2.2.4.2 Degraded Mode Accuracy (Pitch/Roll)

While operating in a degraded mode, the AHRS **shall** be stable, free of oscillations, steps, or other objectionable transients under all conditions.

2.2.4.2.1 Degraded Mode Pitch Accuracy

During un-accelerated, straight and level flight, the degraded mode pitch accuracy **shall** be less than or equal to ± 3°. During accelerations or maneuvers, and within the first 60 seconds following accelerations or maneuvers, the pitch error **shall** be less than or equal to ± 6° in the range of ± 10° pitch. Outside of ± 10° pitch, the pitch **shall** be in the correct direction and not provide objectionable pitch information.

2.2.4.2.2 Degraded Mode Roll Accuracy

During un-accelerated, straight and level flight, the degraded mode roll accuracy **shall** be less than or equal to ± 4°. During accelerations or maneuvers, and within the first 60 seconds following accelerations or maneuvers, the roll error **shall** be less than or equal to ± 8° up to ± 25° roll. Outside of ± 25° roll, the roll **shall** be in the correct direction and not provide objectionable roll information.

Note: It is generally more acceptable to output a bank angle that is larger than the actual bank angle than to output a bank angle that is smaller than the actual bank angle.

2.2.4.3 Degraded Mode Accuracy (Heading)

While operating in a degraded mode, the AHRS heading **shall** be stable, free of oscillations, steps, or other objectionable transients under all conditions.

2.2.4.3.1 Slaved Heading

During un-accelerated, straight and level flight, the degraded mode heading accuracy **shall** be less than or equal to ± 12°. During accelerations or maneuvers, and within the first 60 seconds following accelerations or maneuvers, the heading error **shall** be less than or equal to ± 24°.

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2.2.4.3.2 Free Gyro Heading

If a degraded free gyro mode is offered, the AHRS heading drift **shall** not exceed 20° in 10 minutes.

2.2.5 Turn and Slip Performance Requirements

Table 2-3 defines the turn rate, standard turn bank angle and slip categories. Sections 2.2.5.1, 2.2.5.2 and 2.2.5.3 establish the performance accuracies and requirements for each category.

Table 2-3 Turn and Slip Categories

Category	Description
T1	Turn rate, standard turn bank angle and slip information provided
T2	Turn rate and standard turn bank angle information provided
T3	Turn rate and slip information provided
T4	Standard turn bank angle and slip information provided
T5	Turn rate information provided
T6	Standard turn bank angle information provided
T7	Slip information provided
TX	No turn or slip information provided

2.2.5.1 Rate of Turn Performance Requirements

With the equipment level and subjected to the turn rates specified about the vertical axis, the turn rate output **shall** be within the values prescribed in Table 2-4.

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Table 2-4 Turn Rate Accuracy

Turn Rate (deg/min)	Tolerance (deg/min)
0	± 8
36	± 9
90	± 18
180	± 36
240	± 48

The preferred method for computing turn rate is based on heading rate. If the turn rate is not based on heading rate, the manufacturer **shall** provide its definition of how turn rate is computed.

2.2.5.2 Standard Turn Bank Angle Performance Requirement

Standard turn bank angle is a calculated bank angle dependent upon the current aircraft true airspeed. If a constant altitude coordinated turn is flown at the standard turn bank angle, then a standard heading rate of 180 or 90 degrees per minute (deg/min) will result at the current airspeed. When the aircraft is flown in a constant altitude coordinated turn at the standard turn bank angle, the resultant turn rate **shall** be 180 ± 36, or 90 ± 18 deg/min. The 180 deg/min specification is the default value; a 90 deg/min specification may be selected or may be configurable for application to higher classes of aircraft.

2.2.5.3 Slip Skid Performance Requirements

The range of the slip indicator **shall** be at least ± 7°. Within that range, the output **shall** be accurate to within ± 2°.

2.2.6 Aiding

The AHRS may use aiding sources, such as GNSS, air data, magnetic sensors, etc., in deriving AHRS outputs. Aiding inputs may take different forms, and have different levels of influence on the AHRS outputs, depending on the specific aiding scheme implemented by the manufacturer. Aiding sensors may be integral to the AHRS equipment design, or they may be separate components.

If aiding is implemented the following requirements apply.

2.2.6.1 Aiding Source Performance

For external aiding sources, the AHRS manufacturer **shall** define the minimum aiding source performance and integrity requirements. This can be accomplished by identifying the specific aiding equipment or by specifying the performance requirements for aiding sources. Particular attention must be paid to ensuring that the integrity of the aiding inputs is suitable for the intended use of the AHRS equipment. For this reason, when defining the minimum aiding source performance it is recommended to start with

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established standards, such as TSO-C145, TSO-C146, and TSO-C196 for GNSS sources, or TSO-C106 for air data sources.

Note:

1. *AHRS utilizing GNSS aiding to augment the AHRS output should comply with the integrity monitoring requirements as specified for TSO-C145, TSO-C146, or TSO C196 compliant GNSS sources. Aiding sources meeting only the minimum requirements of TSO-C129 may not provide sufficient availability or performance to perform properly in high interference environments.*
2. *The GNSS TSOs effective as of this writing do not include performance requirements for velocity accuracy or integrity. RTCA SC-159 has determined that horizontal position accuracy (HFOM) and integrity (HPL) cannot be correlated to the velocity performance. RTCA SC-159 has published a velocity accuracy test in DO-310. This velocity accuracy test is also available in AC 20-138B. At this time, no vetted method for determining velocity integrity has been published.*
3. *The foregoing requirements presume that the AHRS aiding sources are used as an integral portion of the AHRS attitude computation, and therefore require stringent monitoring, performance, and integrity checking. Aiding sources that are used to simply cross check the AHRS output or detect faults in AHRS input sources may not require the same fidelity as an aiding source which is used as an integral component of the AHRS attitude computations.*

2.2.6.2 Loss of Aiding

Following the detected loss of aiding, if the AHRS cannot meet the requirements of its current operational mode, the AHRS **shall** revert to a different operational mode, a degraded mode, or invalidate its output. The AHRS **shall** annunciate the mode change, which may indicate a performance change or loss of function in accordance with Section 2.2.1.4. The manufacturer **shall** provide information on the impact of the loss of aiding.

2.2.6.3 Annunciated Faults from Aiding Source

If the AHRS receives a fault indication from an aiding source, where the fault can result in AHRS performance not meeting the requirements of its current operational mode, then the AHRS **shall** transition to another operational mode, a degraded mode, or invalidate its output.

2.2.6.4 Faulted and Non-Normal Performance

Depending on the intended use of the AHRS equipment, an aircraft level safety assessment may require that undetected or latent faults in the AHRS equipment, including undetected faults in the AHRS aiding inputs, be mitigated to an acceptable level. The manufacturer **shall** identify and document (via installation limitations) potential undetected aiding source faults and non-normal performance that are likely to occur (see Note below). The AHRS design **shall** ensure that "likely" aiding source faults and non-normal performance are mitigated as required for the intended use. This mitigation can be accomplished through fault detection and mitigation at the input, real time monitoring of the AHRS performance, controlling the design assurance of the aiding source, or other means. The extent of fault monitoring and mitigation needs to be commensurate with the intended application and criticality of the equipment.

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Note: The term "likely" is used to limit the possible number of undetected aiding source faults. The equipment should be analyzed in the context of 14 CFR part 23, 25, 27 or 29.1309 to identify how the aiding source is used and the resultant effects on performance.

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2.3 Equipment Performance - Environmental Conditions

The environmental tests and performance requirements described in this subsection are intended to provide a laboratory means of determining the overall performance characteristics of the equipment under conditions representative of those which may be encountered in actual aeronautical operations.

Unless otherwise specified, the test procedures applicable to a determination of equipment performance under environmental test conditions are contained in RTCA/ DO-160G, *Environmental Conditions and Test Procedures for Airborne Equipment.* General information on the use of RTCA/DO-160G is contained in Sections 1 through 3 of that document. Also, a method of identifying which environmental tests were conducted and other amplifying information on the conduct of the tests is contained in Appendix A of RTCA/DO-160G. For additional guidance on RTCA/DO-160G, refer to AC 21-16G.

Some of the performance requirements in Section 2.2 are not required to be tested to all of the conditions contained in RTCA/DO-160G. Table 2-5 shows the environmental tests which are required to meet this standard.

When the physical test environment prevents normal determination of operational performance, manufacturer **shall** specify an acceptable alternative technique to determine performance to the maximum extent practical. For example, such a condition may exist when a magnetic sensing unit is placed near a source of significant magnetic fields, such as is commonly found with vibration tables.

Requirements in this section are used to demonstrate that the performance requirements of Section 2.2 are met when subjected to environmental test conditions defined in RTCA/DO-160G. The AHRS performance requirements are defined for a system, equipment and associated functions. The manufacturer **shall** define the items of AHRS equipment and associated wiring that are required for the system that will undergo RTCA/DO-160G environmental tests.

The manufacturer need only test the functions that are supported by the system/ equipment. If a complete system is not tested, the untested subsystem errors **shall** be accounted for via analysis or other methods.

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Table 2-5 Required DO-160G Testing By Category

Environmental Test	DO-160G Ref. Section	Minimum Required Environmental Test	Performance Requirement
Temperature and Altitude	4	√	Static
Temperature Variation	5	√	Dynamic
Humidity	6	√	NA
Operational Shocks and Crash Safety	7	√	Dynamic
Vibration	8	√	Dynamic
Explosion proof	9	Optional	NA
Waterproof	10	Optional	NA
Fluids susceptibility	11	Optional	NA
Sand and dust	12	Optional	NA
Fungus resistance	13	Optional	NA
Salt spray	14	Optional	NA
Magnetic effect	15	√	NA
Power input	16	√	Static
Voltage spike	17	√	Static
Audio frequency conducted susceptibility	18	√	Static
Induced signal susceptibility	19	√	Static
RF susceptibility	20	√	Static / Dynamic
Emission of RF energy	21	√	NA
Lightning induced transient susceptibility	22	√	Static
Lightning Direct Effects	23	Optional	NA
Icing	24	Optional	NA
Electrostatic Discharge	25	√	NA
Fire, Flammability	26	Optional	NA

Note:

1. *Performance requirement applicable during the prescribed environmental test.*
2. *For the definition of "Static", "Dynamic" and "Static/Dynamic", see Section 2.3.1.*
3. *"Optional" indicates tests which are not required by this MOPS.*

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2.3.1 Performance Standard for Environmental Testing

The test procedures specified in this section apply during environmental testing.

Mount the AHRS in a fixed position and subject it to the test environment when DO-160 requires validation of performance during exposure. Monitor the attitude, heading, turn, and slip (as applicable) and status indications. The attitude and heading **shall** not deviate from the initial reading by more than the amount specified in the Attitude Accuracy columns of Table 2-1 and the Heading Accuracy columns of Table 2-2 respectively. Depending on which DO-160 test is being performed use either the Static Conditions column or Dynamic and Flight Conditions column as directed in the Performance Requirement column of Table 2-5.

When DO-160 requires validation of performance following exposure to the environment, the following tests **shall** be accomplished.

1. 2.4.2.1 Attitude Static Accuracy
2. 2.4.2.2 Attitude Scale Factor Static Accuracy
3. 2.4.3.1 Heading Static Accuracy
4. 2.4.3.3 Static Accuracy, DG Mode, Category H6 through H11
5. 2.4.5.1 Turn Rate Test Procedures
6. 2.4.5.2 Standard Turn Bank Angle Test Procedures
7. 2.4.5.3 Slip Skid Test Procedures

Note: An Acceptance Test Procedure that validates hardware functionality following exposure may be adequate, as long as it tests any item that could be affected by the environmental test.

The static and dynamic tolerances are defined in Table 2-1, and Table 2-2 for each category of equipment. The turn and slip **shall** not deviate by more than 150% of the limits specified in Section 2.2.5 for all environments. The status shall remain valid during all tests that require validation of performance during the exposure to the environment.

Where "Static / Dynamic" (DO-160G Section 20) is specified in Table 2-5, if the attitude or heading deviates by more than the static requirement, the frequency at which the susceptibility occurred **shall** be dwelled for a minimum of 5 seconds and the attitude and heading output **shall** not deviate by more than the dynamic limit. For AHRS intended for helicopter applications it is recommended that the dwell be extended to 15 seconds and documented in the environmental qualification document.

It is understood that the mounting of the AHRS in a fixed position does not test all of the functionality that affects the accuracy of the AHRS system. For example, rate sensor scale factor performance could vary over temperature to an extent that the unit would no longer meet the performance requirements. AHRS performance characteristics that are not tested by being mounted in a fixed position **shall** be validated by the manufacturer through other means such as analysis, design, calibration, or informal testing.

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For units with a DG mode, the unit **shall** meet the DG requirements over the environments. The manufacturer may verify the unit meets these requirements by analysis, test or a combination of both.

2.4 Equipment Test Procedures

2.4.1 General Tests

2.4.1.1 Conditions

2.4.1.1.1 Definitions of Terms and Conditions of Test

The following are definitions of terms and the conditions under which the tests described in this subsection should be conducted.

1. Power Input Voltage - Unless otherwise specified, all tests **shall** be conducted with the power input voltage adjusted to a selected design voltage within the range for which the equipment is designed plus or minus 2%. The input voltage **shall** be measured at the input terminals of the equipment under test.
2. Power Input Frequency
    a. In the case of equipment designed for operation from an AC source of essentially constant frequency (e.g., 400 Hz), the input frequency **shall** be adjusted to design frequency plus or minus 2%.
    b. In the case of equipment designed for operation from an AC source of variable frequency (e.g., 300 to 1,000 Hz), unless otherwise specified, tests **shall** be conducted with the input frequency adjusted to within 5% of a selected frequency and within the range for which the equipment is designed.
3. Test Equipment - All equipment used in the performance of the tests should be identified by make, model and serial number where appropriate, and its latest calibration date. When appropriate, all test equipment calibration standards should be traceable to national and/or international standards.
4. Ambient Conditions - Unless otherwise specified, all tests **shall** be made within the following ambient conditions:
    a. Temperature: +15° to +35° Celsius (+59° to +95° Fahrenheit)
    b. Relative Humidity: Not greater than 85%
    c. Ambient Pressure: equivalent to -1,500 to +8,000 feet of altitude

    When tests are conducted at ambient conditions which differ from the above values, allowances **shall** be made and the differences recorded.

5. Connected Loads - Unless otherwise specified, all tests **shall** be performed with the equipment connected to loads having the impedance values for which it is designed.
6. If appropriate for the test being conducted, equipment installation procedures **shall** be performed before testing.
7. Whenever a rotation rate is specified, a short period of time to change to and from that rotation rate is allowed.

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2.4.1.1.2 Required Test Equipment

For the verification of the performance required in Section 2.2 the following test equipment is suggested as one possible means of taking required measurements:

1. Equipment for providing mechanical interface of the AHRS (Laboratory Test and Flight Evaluation)
    a. Tray or mounting plate if applicable
2. Equipment for providing the electrical interface of the AHRS (Laboratory Test and Flight Evaluation)
    a. Power Supply
    b. Digital Interface (if applicable)
    c. Analog Interface (if applicable)
3. Rate table (Laboratory Test)
4. Scorsby table or equivalent (Laboratory Test)
5. Flight evaluation aircraft (Flight Evaluation)
6. Data logger (Laboratory Test and Flight Evaluation)
7. Reference measurement system (truth reference) adequate to the performance categories (Flight Evaluation)

2.4.1.2 On Ground (Stationary) Starting

With the equipment on a stable level support, apply nominally rated power. Valid attitude, heading, turn and slip (as provided) output errors **shall** not exceed the static accuracy specified in Table 2-1, Table 2-2 and Section 2.2.5 within the time specified in Section 2.2.1.2.

2.4.1.3 In-Flight or In-Motion Alignment

If in-flight alignment is provided, the manufacturer **shall** verify the performance by test or analysis.

2.4.1.4 Annunciations

Start the AHRS in a normal operating mode. In each operating mode specified in Section 2.2.1.4 the appropriate annunciation **shall** be observed.

2.4.1.5 Output Characteristics Tests

2.4.1.5.1 Output Resolution Test

The AHRS **shall** meet the manufacturer defined output resolution requirements.
This can be demonstrated through test or analysis.

2.4.1.5.2 Update Rate Test

The AHRS **shall** meet the manufacturer defined update rate requirements. This can be demonstrated through test or analysis.

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2.4.1.5.3 Latency Test

The AHRS **shall** meet the manufacturer defined latency requirements. This can be demonstrated through test or analysis.

2.4.1.5.4 Filtering Test

The AHRS **shall** meet the manufacturer defined filtering requirements. This can be demonstrated through test or analysis.

2.4.1.5.5 Range Test

Rotate the equipment a minimum of 360° around the lateral axis. Pitch, roll, and if provided, heading, turn, standard turn bank angle, and slip outputs **shall** be continuously provided. Within 10 seconds of the completion of the maneuver, the pitch, roll, and heading errors in all axes **shall** not exceed the dynamic accuracy requirement for its category.

Rotate the equipment a minimum of 360° around the longitudinal axis. Pitch, roll, and if provided, heading, turn, standard turn bank angle, and slip outputs **shall** be continuously provided. Within 10 seconds of the completion of the maneuver, the pitch, roll, and heading errors in all axes **shall** not exceed the dynamic accuracy requirement for its category.

Rotate the equipment a minimum of 360° around the vertical axis. Pitch, roll, and if provided, heading, turn, standard turn bank angle, and slip outputs **shall** be continuously provided. Within 10 seconds of the completion of the maneuver, the pitch, roll, and heading errors in all axes **shall** not exceed the dynamic accuracy requirement for its category.

2.4.2 Attitude Performance Test Procedures

2.4.2.1 Attitude Static Accuracy and Alignment

Place the AHRS in each of the attitudes listed in Table 2-6 within ± 1.0°. At each attitude, power the AHRS and allow it to stabilize. For each position in Table 2-6, the absolute attitude error (the attitude error relative to the true position of the AHRS) **shall** not exceed the static value for the declared performance category found in Table 2-1.

Table 2-6 Attitude Static Accuracy Test Positions

Roll Position (deg)	Pitch Position (deg)
0.0	0.0
0.0	+15.0
0.0	-15.0
+15.0	0.0
-15.0	0.0

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2.4.2.2 Attitude Scale Factor Static Accuracy

With the equipment level and stabilized, rotate the equipment in one axis within 5 seconds to achieve a test position specified in Table 2-7 ± 1.0°. Within 1 second after the equipment is at the test position specified, the error in the attitude outputs **shall** not exceed the static accuracy called out in Table 2-1 for the declared performance category. After the measurement at each position in Table 2-7, return the equipment to level position and allow it to stabilize before moving to the next test position.

Table 2-7 Attitude Static Accuracy Scale Factor Test Positions

Roll Position (deg)	Pitch Position (deg)
+60.0	0.0
-60.0	0.0
+30.0	0.0
-30.0	0.0
0.0	+60.0
0.0	-60.0
0.0	+30.0
0.0	-30.0

2.4.2.3 Multi-Axis Dynamic Accuracy Flight Evaluation

2.4.2.3.1 Categories A1, A2, A3 and A4

The dynamic accuracy of the attitude outputs is tested using a flight evaluation that conforms to the requirements specified in Section 2.4.8. The flight evaluation is conducted using a truth reference device. Record the output of the AHRS and the output of the truth reference simultaneously during the flight to allow for analysis of the difference between the two outputs. Compare the output of the equipment with the output of the truth reference and calculate the RMS error as described in Section 2.4.8. This calculated RMS output error multiplied by two **shall** not exceed the flight condition accuracy specification defined in Table 2-1 for the performance category.

*Note: The accuracy requirements for flight are defined as 2*RMS limits. For example, if the flight evaluation analysis gives an RMS error of 1.1°, then the 2*RMS error for the flight is 2.2°. This value of 2.2° must be less than or equal to the flight evaluation accuracy specification defined in Table 2-1.*

2.4.2.3.2 Category A5

The dynamic accuracy of the attitude outputs is tested using a flight evaluation that conforms to the requirements specified in Section 2.4.8. Compare the output of the equipment with the output of the truth reference. The truth reference device and the AHRS attitude indication should be visible to the test pilot or test engineer during the flight. Compare the output of the equipment with the output of the truth reference during and after each maneuver defined in the flight evaluation. The observed difference in roll and pitch angles between the equipment and the truth reference **shall** not exceed the flight condition accuracy specification defined in Table 2-1 for performance category A5.

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2.4.3 Heading Performance Test Procedures

2.4.3.1 Heading Static Accuracy

The equipment **shall** meet the heading accuracy under static conditions as described in Table 2-2 according to the applicable equipment category. These limits represent maximum allowable deviation values.

2.4.3.1.1 Heading Error for Categories H1 through H5

With the equipment placed on a level surface, power it on and allow it to initialize. Position the equipment at a heading of 0°. Rotate the equipment through a full 360° about the vertical axis, stopping at 30° increments to record measurements, waiting one minute or until heading is stabilized, whichever is greater before recording data. The magnitude of the error at each point **shall** not exceed the static accuracy limit defined in Table 2-2.

2.4.3.1.2 Heeling Test for Categories H2 through H5

This test is only applicable for categories H2 through H5. Place the equipment on a level surface and operate in slaved mode. Position the equipment at a heading of 360°. Tilt the equipment and MSU (or simulated MSU) about the roll axis by 10°. Allow the equipment to stabilize. Record the heading. Rotate the equipment through a full 360° about the vertical axis, stopping at 30° increments for measurements. Note the heading at each 30° increment after waiting one minute or until heading is stabilized, whichever is greater. The magnitude of the difference between the measurement while tilted and the measurement while level at each point **shall** not exceed twice the performance category static limit.

Repeat the test with the equipment tilted about the pitch axis instead of the roll axis.

2.4.3.1.3 Field Strength Variation for Categories H2 through H5

This test is only applicable for categories H2 through H5. Place the equipment on a level surface at a heading of 45°. The applied magnetic field should be set to total field strength of 0.57 ± 0.02 Gauss at a dip angle of 72° ± 1°. Power the equipment and allow it to initialize. Record the heading output. Change the dip angle of the applied magnetic field to 80° ± 1° while maintaining the same total field strength. Record the heading after waiting one minute or until heading is stabilized, whichever is greater. The difference between the heading output at the initial dip angle and the heading output at the second dip angle **shall** not exceed the static accuracy limit defined in Table 2-2.

2.4.3.2 Heading Dynamic Accuracy, Category H1 through H5

2.4.3.2.1 Categories H1 through H4

The equipment **shall** meet the heading accuracy under flight conditions as described in Table 2-2, according to the applicable equipment category. These limits represent 2*RMS values measured against a truth reference. Perform the test using a flight evaluation with a truth reference device. Section 2.4.8 contains a description of the flight evaluation profile.

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Note: The AHRS under test may output magnetic and/or true heading. If available, both should be tested. The truth reference data should be converted to either magnetic or true, whichever is being evaluated.

2.4.3.2.2 Category H5

Test the dynamic accuracy of the heading output using a flight evaluation that conforms to the requirements specified in Section 2.4.8. Conduct the flight evaluation using a truth reference device. The truth reference device and the AHRS heading indication should be visible to the test pilot or test engineer during the flight. Compare the output of the equipment to the output of the truth reference during and after each maneuver defined in the flight evaluation. Record the comparison after each maneuver. The observed difference in heading angle between the equipment and the truth reference **shall** not exceed the flight condition accuracy specification defined in Table 2-2 for performance category H5.

2.4.3.3 Static Accuracy, DG Mode, Category H6 through H11

These tests only apply to equipment that implements a DG mode.

2.4.3.3.1 DG Mode Heading Drift Test

Start the equipment and allow it to initialize per normal operating procedures.

Switch the equipment into DG mode and record the heading for the duration defined in the time component of the accuracy specification in Table 2-2. The deviation from the initial reading **shall** not exceed the Heading Drift Accuracy angle defined in Table 2-2 at any time during the test duration. If earth rate is not compensated in the AHRS, then the amount of earth rate applicable to the test location **shall** be corrected in the AHRS data prior to computing the error. For example, for category H8, the error must not exceed 5.0° at any point during the 1 hour test.

2.4.3.3.2 DG Mode Scale error

Start the equipment and allow it to initialize per normal operating procedures.

Switch the equipment into DG mode and record the initial reading as the zero point of the following calculations. Rotate the equipment 30° around the vertical axis within 5 seconds. Within one second of stopping at the test position record the heading. Repeat the 30° rotations, taking data at each test position until a full 360° has been completed. The error in heading reported at each position **shall** not exceed 2°.

2.4.3.3.3 DG Mode Heading Stability

Start the equipment and allow it to initialize per normal operating procedures, including aiding if used. Activate the DG mode.

Tilt the equipment to 54° ± 2° about either pitch or roll. Record the heading output within 1 second of achieving this position. Rotate the equipment 360° about the vertical at a rate between 30 and 50 deg/sec and record the output within 1 sec of completing the rotation. The second reading **shall** not differ from the initial reading by more than 2°**.** Repeat this test rotating in the opposite direction.

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2.4.3.4 Dynamic Accuracy, DG Mode

Flight evaluation is used to validate the DG Mode performance for AHRS that include a DG Mode Category (Category H6 through H11).

For category H6 through H9 use the flight test maneuvers described in Section 2.4.8, optionally excluding maneuvers with bank angles exceeding 40°. If the time for the defined flight evaluation is less than the time specified within the category, the maximum drift when compared to the truth reference **shall** not exceed the specified drift multiplied by the flight time divided by the category specified time. If the time for the defined flight evaluation is greater than the time specified within the category, the flight evaluation can be limited to the category time**.**

For DG Mode Category H10 and H11, the drift **shall** be validated during two 10 minute segments of the flight. The first segment starts when the aircraft is stationary on the ground and ends when the aircraft is in flight. The second segment starts when the aircraft is in flight and ends when the aircraft is stationary on the ground. The maximum drift when compared to the truth reference **shall** not exceed the specified drift for either of the two segments.

Prior to each drift test allow the AHRS to stabilize per the manufacturer operation instructions.

2.4.3.5 DG Mode Indication

This test only applies to AHRS that support a DG mode. Operate the AHRS in its normal condition, with aiding as applicable. Switch DG mode on and off. Proper annunciation of the mode **shall** be observed.

2.4.3.6 DG Mode Pilot Adjustment of Heading

Operate the AHRS in DG mode and manually adjust the heading by the manufacturer specified means. Proper heading adjustment **shall** be observed.

2.4.4 Degraded Mode Flight Evaluation

Begin with the AHRS operating in a normal mode. Simulate applicable failures or remove requisite aiding as appropriate to drive the AHRS into degraded mode(s). These tests are only applicable to equipment with at least one optional degraded mode. Each degraded mode supported **shall** be tested.

Accomplish the designated flight maneuvers for degraded mode from Table 2-9. During all maneuvers the AHRS **shall** be free of oscillations, steps, or other objectionable transients and meet the requirements of Section 2.2.4.2 and Section 2.2.4.3.

2.4.5 Turn and Slip Test Procedures

This section establishes the test procedures for equipment with turn rate, standard turn bank angle and/or slip indicator outputs as prescribed in Section 2.2.5.

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2.4.5.1 Turn Rate Test Procedures

The equipment is mounted level. Apply the turn rates specified in Table 2-4 about the vertical axis. The turn rate output **shall** equal the actual within the tolerance prescribed in Table 2-4.

If the turn rate is not based on heading rate the manufacturer **shall** provide the definition of turn rate for the equipment.

2.4.5.2 Standard Turn Bank Angle Test Procedures

For any airspeed within the design range of the equipment, the standard turn rate bank angle output **shall** indicate a bank angle that would result in a turn rate of 180 ± 36 or 90 ± 18 deg/min when the turn is coordinated. Compliance with this requirement may be demonstrated by analysis.

2.4.5.3 Slip Skid Test Procedures

Roll the equipment to at least the angular range specified in Section 2.2.5.3. The output of the slip data at 0° (level) and the endpoints of the roll range tested **shall** be within the tolerances specified in Section 2.2.5.3.

2.4.6 Aiding Tests

2.4.6.1 Loss of Aiding Source Data

For each AHRS mode that uses an external aiding source data, start with the AHRS in a steady state operating condition with all aiding sources enabled and valid. Remove an aiding source. The AHRS **shall** respond in accordance with Section 2.4.6.4. If the given AHRS mode uses more than one aiding source, repeat the test by removing all possible combinations of the aiding sources until the system responses to all possible losses are verified.

2.4.6.2 Annunciated Aiding Source Data Faults

For each AHRS mode that uses an external aiding source data, start with the AHRS in a steady state operating condition, with all aiding sources enabled and valid. Change the status of the aiding source data. The AHRS **shall** respond in accordance with Section 2.4.6.4. If the given AHRS mode uses more than one aiding source or if there is more than one way for the aiding to report its status, repeat the test invalidating each, one at a time.

2.4.6.3 Un-annunciated Aiding Source Data Faults

For those un-annunciated faults identified by the manufacturer as required in Section 2.2.6.4, induce each fault in the aiding source data and verify that the AHRS responds in accordance with Section 2.4.6.4. This test may also be satisfied by analysis.

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2.4.6.4 Test for Aiding Source Issues

2.4.6.4.1 Pitch/Roll Test

Following the change in condition of an aiding source, the AHRS **shall** make the proper annunciation in accordance with Section 2.2.1.4 and **shall** do at least one of the following:

1. Meet the requirements of Section 2.2.2 for the current mode.
2. Switch to a different mode (A1-A5) and meet the requirements for that mode.
3. Switch to a degraded mode and meet the requirements in Section 2.2.4.
4. Remove and/or invalidate the output.

2.4.6.4.2 Heading Test

Following the change in condition of an aiding source, the AHRS **shall** make the proper annunciation in accordance with 2.2.1.4 and **shall** do at least one of the following:

1. Meet the requirements of Section 2.2.3 for the current mode.
2. Switch to a different mode (H1-H11) and meet the requirements for that mode. Pilot activation of DG mode is an acceptable means of meeting this requirement.
3. Switch to a degraded mode and meet the requirements in Section 2.2.4.
4. Remove and/or invalidate the output.

2.4.6.4.3 Turn and Slip Test

Following the change in condition of an aiding source, the AHRS **shall** make the proper annunciation in accordance with 2.2.1.4 and **shall** do at least one of the following:

1. Meet the requirements of Section 2.2.5 for the current mode.
2. Remove and/or invalidate the output.

2.4.7 Multi-Axis Dynamic Accuracy Laboratory Test

2.4.7.1 Heading Modes, Category H1 through H5

For equipment that offers magnetic slaving or gyro compassing heading modes of operation (heading performance categories H1 through H5), mount the equipment on a Scorsby table or equivalent. After application of normal rated power and following the alignment period, record the heading and attitude output values. Oscillate the equipment in roll, pitch and yaw at an angle of at least ± 7.5° at a frequency of 5 to 7 cycles per minute for 30 minutes and return the equipment to a level position. It is permissible to conduct this test in three 30 minute portions of dual-axis simultaneous motion: 1) roll-pitch, 2) roll-yaw and 3) pitch-yaw with 90° of phase between the two axes for each portion of the test. Within 10 seconds after returning to the level position, record the heading and attitude outputs. The ending heading and attitude values **shall** not differ from the initial readings by more than the dynamic limits in Table 2-1 and Table 2-2 (for heading performance categories H1 through H5).

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2.4.7.2 DG Heading Modes, Category H6 through H11

For AHRS that offer DG heading modes of operation (heading performance categories H6 through H11) mount the equipment on a Scorsby table or equivalent. After application of normal rated power and following the alignment period, switch the equipment into DG heading mode and record the heading and attitude output values. Oscillate the equipment in roll, pitch and yaw at an angle of at least ± 7.5° at a frequency of 5 to 7 cycles per minute for the duration specified in Table 2-8. Return the equipment to a level position. It is permissible to conduct this test in three portions of dual-axis simultaneous motion: 1) roll-pitch, 2) roll-yaw and 3) pitch-yaw with 90° of phase between the two axes for each portion of the test. Within 10 seconds after returning to the level position, record the heading and attitude outputs. The ending attitude values **shall** not differ from the initial readings by more than the dynamic limits in Table 2-1, and the ending heading value **shall** not differ from the initial reading by more than the maximum allowable heading drift value specified in Table 2-8.

Table 2-8 DG Mode Scorsby Table Test Parameters

DG Mode Heading Performance Category	Duration of Applied Scorsby Table Test Motion	Maximum Allowable Heading Drift During Scorsby Table Test (degrees)
H6	6 hours	2.0
H7	3 hours	2.0
H8	1 hour	5.0
H9	1 hour	30.0
H10	10 minutes	5.0
H11	10 minutes	10.0

2.4.7.3 Equipment with No Heading Output, Category HX

For equipment that does not offer heading output (heading performance categories HX), mount the equipment on a Scorsby table or equivalent. After application of normal rated power and following the alignment period, record the attitude output values. Oscillate the equipment in roll, pitch and yaw at an angle of at least ± 7.5° at a frequency of 5 to 7 cycles per minute for 30 minutes. Return the equipment to a level position. It is permissible to conduct this test in three portions of dual-axis simultaneous motion: 1) roll-pitch, 2) roll-yaw and 3) pitch-yaw with 90° of phase between the two axes for each portion of the test. Within 10 seconds after returning to the level position, record the attitude outputs. The ending attitude values **shall** not differ from the initial readings by more than the dynamic limits in Table 2-1.

2.4.8 Flight Evaluation for Declared Performance Categories

Perform a flight evaluation to ensure compliance with the dynamic performance requirements which are shown in the Dynamic and Flight Conditions columns of Table 2-1 and Table 2-2. Although testing in a single aircraft type cannot guarantee performance in all aircraft types, the flight evaluation is intended to exercise the

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equipment under dynamic conditions that cannot be mechanically simulated with static ground testing. The flight evaluation **shall** include shallow, standard and steep turns in both the left and right directions, extended periods of acceleration and deceleration, significant changes in altitude, straight and level flight, and uncoordinated maneuvers with lateral acceleration in both right and left directions (such as side slips). Table 2-9 shows a recommended flight profile which exercises the AHRS with all the dynamic conditions described above. During the actual flight evaluation, the profile may be modified as needed to accommodate air traffic, logistics and local conditions provided equivalent maneuvers are performed. It is intended that this evaluation be accomplished in a single flight. For DG mode, categories H6 through H9 (if included), the flight evaluation **shall** be a minimum of one hour.

Throughout the flight evaluation collect data (e.g., computer acquisition, video, or manual) from the AHRS and the reference system. For Categories A1 through A4 and H1 through H4, the flight evaluation results **shall** be determined by measuring twice the RMS difference of the AHRS and the truth reference system. The data used to calculate the RMS should include all maneuvers and a portion of each straight and level flight immediately following the maneuver. The total time of straight and level flight following the maneuvers, included in the RMS calculation, **shall** not exceed the total time of the maneuvers. Maneuver number 2, in particular, should be counted as maneuver time and not part of the straight and level time.

The manufacturer shall provide the actual flight test profile used to meet the requirements of this section. This profile will include the speed range through which the flight test was conducted.

For categories A1 through A4, at any time during the flight evaluation, the one second averages of the differences between the truth system and the AHRS pitch and roll **shall** not exceed two times the value specified in the Dynamic and Flight Conditions column of Table 2-1.

For categories H1 through H4, at any time during the flight evaluation, the one second averages of the differences between the truth system and the AHRS heading **shall** not exceed two times the value specified in the Dynamic and Flight Conditions column of Table 2-2.

Note:

1. *Before the data between the truth system and AHRS are compared, minor adjustments may be made to the data to account for the mounting alignment, timing and filtering differences between the truth system and the AHRS being tested.*
2. *Note: The following flight evaluation maneuvers may not be adequate to ensure proper operation in an aircraft other than the one in which testing was performed. For example, helicopters may operate at low speeds and in an uncoordinated manner (See Table 3-1).*

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Table 2-9 Sample Flight Evaluation Profile

Flight Evaluation Profile: Standard Maneuvers			
No.	**Maneuver**	**Condition**	**Evaluate in Degraded Mode**
1	Taxi, Take Off, Climb Out		No
2	Straight and level	10 minutes	Yes
3	Standard rate left turn	360° of heading change	Yes
4	Standard rate right turn	360° of heading change	Yes
5	Standard rate left or right turn	180° of heading change at 1.3 Vs	Yes
6	Standard rate left or right turn	180° of heading change at high-speed cruise	Yes
7	Half Standard rate left turn	180° of heading change	Yes
8	Half Standard rate right turn	180° of heading change	Yes
9	Shallow bank left turn, 6° bank	90° of heading change	Yes
10	Shallow bank right turn, 6° bank	90° of heading change	Yes
11	Steep turn left, 45° bank	360° of heading change	Yes
12	Steep turn right, 45° bank	360° of heading change	Yes
13	Steep turn left, 60° bank	540° of heading change	No
14	Steep turn right, 60° bank	540° of heading change	No
15	Lazy eight		No
16	Maintain minimum speed Straight and level	1.15 Vso, 90 seconds	Yes
17	Accelerate (Note 2)	Min 1 knots/s for 40 seconds	Yes
18	Decelerate (Note 2)	Min 1 knots/s for 40 seconds	Yes
19	Pitch Up	From max level speed, pitch up and maintain delta 7.5° nose up until 1.3 Vs or 90 seconds, whichever comes first	Yes
20	Pitch Down	From 1.3 Vs, pitch down and maintain delta 7.5° nose down until near maximum speed or 90 seconds, whichever comes first	Yes
21	Steady heading side slip – right	Min sustained lateral acceleration of 0.1g, 30 seconds	Yes
22	Steady heading side slip - left	Min sustained lateral acceleration of 0.1g, 30 seconds	Yes
23	Approach and Landing	Descent from en route environment, followed by full procedure non precision (dive and drive) approach, with missed to the hold, 2 turns in the hold, and another approach to a full stop landing.	Yes

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Note:

1. *All maneuvers, except number 1, 2, 14 and 21 should be followed by at least 60 seconds of straight and level operation to assess equipment response and stability. If the equipment has settled sooner than 60 seconds, a shorter straight and level operation is permissible.*
2. *Pitch changes may be used to achieve the desired acceleration/deceleration profile.*

2.5 Requirements for Display of Pitch, Roll, Heading and Turn and Slip Information

The requirements of this section apply to AHRS that include an optional display or to a stand-alone display system that will present information generated by an AHRS. This section contains design requirements. The associated tests are in Section 2.6.

These requirements are derived from the historically accepted marking requirements of the applicable TSOs for pitch, roll, direction, turn and slip. Compatibility with emerging cockpit display technology may require characteristics differing from those specified herein. In these cases an alternate means of compliance will be acceptable upon the approval of the certification authority.

In addition to meeting the requirements of this section, requirements such as those found in SAE ARP 4102/7 and/or minimum operational performance specifications associated with TSO C113 are acceptable.

Performance requirements, such as accuracy or latency, for the display portion of the system are not defined in this document. Performance of complete systems will have to be evaluated during installation approval.

2.5.1 General Display Requirements

The display hardware should conform to an accepted standard for display quality requirements, such as visibility, parallax, reflectance, viewing angles, jitter, and flicker. One example of an accepted standard is TSO-C113.

2.5.2 Annunciation

The display **shall** indicate when a condition is required to be annunciated as identified in Section 2.2.1.4.

2.5.3 Pitch and Roll

Present pitch and roll angles such that over the range of indication the earth horizon presentation shall appear as viewed by the pilot when looking forward out of the aircraft.

The pitch display **shall** provide minor graduation lines every 5° and major graduation lines every 10° between -30° and +50°. This entire range need not be visible at one time. The major graduations **shall** be marked with their numerical value. The design **shall** provide suitable contrast between sky and ground segments such that pitch up/down are

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immediately recognizable. Some indication of both sky and ground **shall** always be visible even at extreme attitudes.

A 0° pitch reference **shall** be provided. The 0° pitch reference may be adjustable to accommodate a range of pitch attitude trim.

The display **shall** provide a roll attitude index that indicates through 360 ° of bank with markings at least for 0° and 30° right and left roll angles.

Note: Some regulations require that adjustments of attitude reference not be accessible to the flight crew.

2.5.4 Direction Indicator

Direction, if provided, **shall** be indicated using either of the two following methods:

1. A rotating dial or dial segment with a fixed datum or lubber line; dial rotation **shall** be counterclockwise for right turns.
2. A horizontal scale display with fixed datum or lubber line; scale graduations **shall** move to the left for right turns.

The indicator **shall** provide minor graduation lines at 5° or smaller intervals with major graduation lines every 10°. In addition, direction numerals **shall** be provided at 30°, 60°, 120°, 150°, 210°, 240°, 300°, and 330°. The markings at 0° (360°), 90°, 180°, and 270° **shall** be either numerals or the letters "N", "E", "S", and "W" respectively.

Direction of flight indications may be shown using aircraft heading or ground track. If more than one operating mode is provided, the direction reference **shall** be clearly indicated to the pilot. In addition, the direction of flight reference may be displayed in various units, such as magnetic north, true north, or grid north reference. The direction reference **shall** be indicated if more than one method is available.

In addition, a digital display of aircraft direction may be provided to supplement the compass card or heading scale indications.

2.5.5 Turn Rate, Standard Turn Bank Angle and Slip/Skid

Turn rate, standard turn bank angle and slip are optional functions.

2.5.5.1 Turn Rate

The turn rate **shall** be indicated by a pointer deflecting in the direction of the turn, or by other means equally suitable. If the aircraft is not turning, the pointer **shall** align with the center tick mark or be removed from view.

When displaying rate of turn by means of a pointer on a fixed scale, indices for standard rate (180 deg/min) **shall** be provided. Indices for half standard rate (90 deg/min) may be provided.

The range of the rate of turn indicator **shall** be a minimum of ± 240 deg/min.

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2.5.5.2 Standard Turn Bank Angle

The standard rate bank angle **shall** be indicated on the roll scale in both directions when it is displayed.

2.5.5.3 Slip/Skid

Slip/skid **shall** be indicated by a figure or object moving with respect to a reference or by other means equally suitable. One example is a ball moving in a tube with reference marks centered in the tube, one ball width apart. Another example is a rhombus moving with respect to a roll marker triangle.

When the AHRU is static on the bench and is rolled in a direction, the slip indicator (e.g. ball or rhombus) **shall** deflect in that same direction.

It is recognized that different scaling may be required for different applications. The manufacturer **shall** specify the scaling.

The slip indicator width (e.g. ball or rhombus width) **shall** be 3° to 8°. The range each side of level **shall** be the greater of one and a half indicator widths or 7°.

2.6 Display Tests.

2.6.1 General Display Tests.

Conforming to an acceptable standard may be accomplished by analysis or test.

2.6.2 Display Annunciation Test.

For each condition in Section 2.2.1.3 that requires a display annunciation, verify that the display annunciates the condition.

2.6.3 Pitch and Roll Display Test

The pitch and roll display **shall** ensure the following:

1. Pitch displays minor graduation lines at 5° between -30° and +50°.
2. Pitch displays major graduation lines every 10° between -30° and +50°.
3. Pitch displays major graduations are marked with their numerical value.
4. Pitch display provides suitable contrast between sky and ground.
5. Roll indicates through 360° of bank.
6. The roll attitude index has markings for 0° and 30° right and left roll angles.
7. A 0° pitch reference is provided.

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2.6.4 Direction Indicator Display Test

The direction indicator **shall** perform as follows:

1. The AHRS displays direction by one of the two methods described in Section 2.5.4.
2. The AHRS displays minor graduation lines at 5° or smaller intervals.
3. The AHRS displays major graduation lines every 10°.
4. The AHRS display has makings at 30°, 60°, 120°, 150°, 210°, 240°, 300°, and 330°. The markings at 0° (360°), 90°, 180°, and 270° may be either numerals or the letters "N", "E", "S", and "W" respectively.

If the direction indicator can display both heading and ground track, ensure the display provides a clear indication to the pilot whether heading or ground track is being displayed.

2.6.5 Turn and Slip Indicator Tests

2.6.5.1 Rate of Turn Display Test

The rate of turn **shall** be displayed in accordance with Section 2.5.5.1.

2.6.5.2 Standard Turn Bank Angle Display Test

The standard rate bank angle **shall** be displayed in accordance with Section 2.5.5.2.

2.6.5.3 Slip/Skid Display Test

The slip/skid **shall** be displayed in accordance with Section 2.2.5.3.

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3.0 INSTALLED EQUIPMENT PERFORMANCE AND TEST REQUIREMENTS

This section states considerations for achieving an acceptable level of performance for AHRS equipment when installed in an aircraft. Installed performance requirements are consistent with those specified in Section 2.0 as verified by the equipment manufacturer through flight evaluation, laboratory testing, and environmental testing. Acceptable installed performance is dependent on adherence to the AHRS equipment manufacturer's installation instructions and limitations. Parties performing a first of type integration of an AHRS into a make/model or class of aircraft will need to verify that the installed performance of the AHRS is appropriate for its intended function.

3.1 Equipment Installation

3.1.1 Accessibility

As installed, controls and monitors provided for in-flight operation **shall** be readily accessible from the pilot's normal seated position. The appropriate operator/crew member(s) **shall** have an unobstructed view of any displayed data when in the normally seated position.

3.1.2 Aircraft Environment

Equipment environmental qualification levels **shall** be compatible with the actual environmental condition expected in the specific location on the aircraft where the equipment will be installed.

3.1.3 Display Visibility

Display data **shall** be easily readable by the flight crew under all cockpit ambient light conditions ranging from dark night to direct sunlight environments.

Note: Visors, glare-shields or filters may be an acceptable means of obtaining daylight visibility.

3.1.4 Dynamic Response

Installed equipment performance **shall** be verified during normal aircraft maneuvers and flight operations to validate there are no adverse effects on the AHRS operation due to the installation.

3.1.5 Interference Effects

The equipment **shall** not be the source of harmful conducted or radiated interference nor be adversely affected by conducted or radiated interference from other equipment or systems installed in the aircraft.

Note: Electromagnetic compatibility problems noted after installation of this equipment may result from such factors as the design characteristics of previously installed systems or equipment and the physical installation itself. It is not intended that the equipment manufacturer design for all installation environments. The installing facility will be responsible for resolving any incompatibility between this equipment and previously installed equipment in the aircraft.

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3.1.6 Inadvertent Turnoff

Appropriate protection **shall** be provided to avert the inadvertent turnoff of the equipment.

3.1.7 Aircraft Power Source

Systems that perform critical functions or whose continued operation is required for safe flight and landing **shall** be powered from suitably rated power sources, including any requirements for redundant or separate power inputs. Power sources should be appropriately qualified.

3.2 Conditions of Test

The following subparagraphs define conditions under which tests specified in Section 3.3 **shall** be conducted.

3.2.1 Conformity

As installed, the equipment **shall** conform to the detailed design developed for the integration of the AHRS equipment into the target platform. All AHRS equipment manufacturer's limitations and requirements **shall** be considered in developing the installation design. Deviation from the requirements of the AHRS manufacturer must be evaluated for their potential effects on AHRS installed performance.

As installed, visually inspect the installed equipment to determine the use of acceptable workmanship and adherence to the installation design.

3.2.2 Power Input

Unless otherwise specified, all aircraft electrically operated equipment and systems **shall** be turned on before conducting interference test.

3.3 Test Procedures for Installed Equipment Performance

The following test procedures provide one means of determining installed equipment performance. Although specific test procedures are cited, it is recognized that other methods may be preferred by the installing activity. These alternate procedures may be used if they provide at least equivalent information. In such cases, the procedures cited herein should be used as one criterion in evaluating the acceptability of the alternate procedures.

3.3.1 Ground Tests

3.3.1.1 Equipment Function

Vary all controls of the equipment through their full range to determine that the equipment is operating according to the manufacturer's instruction and that each control performs its intended function.

3.3.1.2 Interference Effects

With the equipment energized, operate the other electrically operated aircraft equipment and systems to determine that significant conducted or radiated interference does not

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exist. Evaluate all reasonable combinations of control settings and operating modes. Operate communication and navigation equipment on the low, high and at least one but preferably four mid-band frequencies. Make note of system or modes of operation that should also be evaluated during flight. If appropriate, repeat tests using emergency power with the aircraft's batteries alone and the inverters operating.

3.3.2 Flight Evaluation Procedures

3.3.2.1 Evaluation Procedure

The installed performance of the highest claimed normal operating mode of the equipment **shall** be evaluated in accordance with the requirements of Section 2.4.8. All operating limitations and procedures associated with the installation **shall** be adhered to during these tests.

The installed performance of a degraded operating mode **shall** be evaluated in accordance with the requirements of Section 2.2.4.

3.3.2.2 Rotorcraft-Specific Flight Evaluation Procedures

Although there are no specific rotorcraft design or flight test requirements for the AHRS, these flight test procedures are provided to aid in installation approval for rotorcraft.

For equipment intended for use in rotorcraft, the maneuvers of Table 3-1 should be conducted and the performance of the equipment should be evaluated and documented. All operating limitations and procedures associated with the installed equipment should be adhered to during these tests.

Some maneuvers listed address problematic flight conditions previously noted, while others are intended to aggressively exercise the AHRS design and to validate computational integrity. Airspeed, altitude and target g-levels are as required or as desired to complete each maneuver.

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Table 3-1 Rotorcraft Flight Maneuvers

Flight Evaluation Profile: Recommended Maneuvers for Equipment Intended for Rotorcraft		
No.	**Test**	**Condition**
1	Extended duration coordinated turn (1 each direction)	10 minutes duration at cruise airspeed
2	Low speed coordinated turn	360° each direction at 20 to 30 knots airspeed
3	Symmetric Pull Up	Target airspeed: as required to avoid exceeding load factor limit
4	Symmetric Push Over	Target airspeed: as required to avoid exceeding load factor limit
5	Roll Reversal	Cruise airspeed
6	Left Rolling Pull Up	Cruise airspeed
7	Right Rolling Pull Up	Cruise airspeed
8	Left Steady Heading Side Slip	At approach airspeed
9	Right Steady Heading Side Slip	At approach airspeed
10	Hover Reposition Aft	30 seconds duration
11	Hover Reposition Forward	30 seconds duration
12	Pedal Turn	Maneuver initiated from hover regime
13	Left Sideward Flight	Maneuver initiated from hover regime
14	Right Sideward Flight	Maneuver initiated from hover regime
15	Long duration deceleration to hover	Maneuver initiated at approach airspeeds (typical profile flown from MAP to ground)
16	Max power takeoff	Maneuver initiated from hover regime
17	Quick stop	Maneuver initiated from approach airspeed

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APPENDIX A: VALIDATION OF EQUIPMENT PERFORMANCE USING SIMULATION

A.1 Simulation Fidelity

In lieu of flight evaluation, the AHRS dynamic heading and attitude performance may be verified through the use of a high fidelity simulation. A very high level of confidence in the simulation results should be attained to bypass the flight evaluation activity. The importance of achieving accurate results with the simulation cannot be overstated. The simulation should account for all significant sources of error including:

1. Sensor misalignment (gyro, accelerometer)
2. Sensor scale factor (gyro, accelerometer, MSU, barometric altitude)
3. Sensor bias (gyro, accelerometer, MSU, barometric altitude, TAS)
4. Sensor noise (gyro, accelerometer, MSU)
5. Sensor range limit (gyro, accelerometer)
6. Speed-dependent noise (barometric altitude, TAS)
7. Other known sensitivity factors to sensor error if any (e.g. g-sensitivity of gyro)
8. AHRU installation alignment
9. Algorithm estimations
10. Environmental variables including
    a. Temperature ramps
    b. Vibration (including acoustically induced vibration)
    c. Weather induced actions such as horizontal and vertical wind gusts
    d. Air Data
    e. GPS Errors

A.2 Simulation Validation

The simulation should be validated to ensure it accurately predicts real-world measurement error characteristics produced by the in-service equipment under a flight profile with the characteristics similar to the one described in Section 2.4. This validation process should demonstrate the following:

1. Validate that the simulated input signals are represented appropriately. A successful validation should demonstrate that:
    a. The simulated trajectory of the vehicle is as expected. This should include all relevant trajectory parameters not only including body rates and body accelerations (or increments), but also attitudes, velocities, accelerations, position, and altitude. The simulated trajectory can be verified by comparing the desired trajectory to the attitudes, position, altitude, and velocities that are physically expected, and, as a crosscheck, those that are generated from the simulated sensor data (body rates and body accelerations or increments). A canonical way of checking the

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physical consistency of the simulated trajectory is to compare simulated data to real flight data of an identical aircraft in identical flight conditions. When applicable, a complimentary way to insure physical consistency of the simulated trajectory is to check physical consistency of the aircraft dynamics model.

b. The simulated signal errors are accurately modeled. The simulated signal errors can be validated by comparing the statistics of real sensor errors to the statistics of the simulated sensor errors. This comparison has to be done either in the dynamic conditions of the test trajectory, or in any condition ensuring that the modeled sensor errors accurately predict the error characteristics when used in the context of the test trajectory.

c. The environment is simulated with appropriate degree of fidelity, meaning that all significant environment effects (static and dynamical, uniform and gradients) are duly modeled and other environment effects are proved insignificant. The analysis should include;

   i. Vibration

   ii. Acoustic noise

   iii. Wind

   iv. Magnetic field, with magnetic anomalies

   v. Temperature

2. Validate that the algorithm performs the same in the simulation as it does when it is on hardware target. This can be achieved by passing the same input data into both the algorithm in simulation and the algorithm on target, and then comparing the output. Any source of simulated/real input can be the basis of the proof, and likewise any platform (target or other) can be used to execute the algorithm, as long as the tested algorithm is byte-per-byte identical to the one on target and the test trajectory is sufficiently complex to exercise all aspects of the algorithm.

3. Validate that the analysis based on the simulation provides accurate results. It should be demonstrated that:

   a. The inputs into the analysis are correct, including the sensor error budget. The error budget should be described in the system specification, against which it can be verified.

   b. The mathematical models and algorithms (e.g. computation of RMS or other statistics) used in the analysis should be validated for correctness and accuracy.

The simulation results should be validated with actual AHRS flight test performance. The acceptable deviation of the simulation from the actual flight test should be within the limits expected from an analysis.

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